Green Alliance policy insight
October 2016

Smart investment

valuing flexibility in the UK electricity market

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Summary

"The government risks making consumers pay for a bigger, but less nimble, power system."

The electricity system is kept going and our lights are kept on by a continuous balancing act. Second by second, electron by electron, the system is sustained by the exact correspondence of electricity demand with electricity supply.

Maintaining the security of this system depends on two conditions: resource adequacy, ie enough power generating capacity to meet demand; and flexibility adequacy, ie the system's responsiveness to changing conditions. In the past, resource adequacy has been the dominant security concern. But the structural shift to variable renewables is making flexibility adequacy a more pressing question.

A system wide transformation is needed to increase the number of resources that improve system flexibility. New technologies that can do just that are already beginning to revolutionise the power system. Demand side response (DSR), batteries and interconnection are the ideal complements to variable renewable generation, and studies have shown that technologies like these will make the energy system cheaper and lower carbon. They are what the National Infrastructure Commission refers to as 'no regrets' options, with the potential to save consumers up to £8 billion a year by 2030.

The government's current strategy is hindering investment in flexibility. There are two main issues. The first is that government auctions don't value flexibility, which means consumers' money is being wasted on supporting old, inflexible power plants. The second is that reforms which have a narrow focus on procuring new combined cycle gas turbine power plants (CCGTs) are distorting the capacity market and putting an unnecessarily high cost burden on consumers: we estimate that these will cost consumers an additional £1.35 billion in 2016's auction, which is two and half times more than 2015. In effect, the government risks making consumers pay for a bigger, but less nimble, power system.

"This smart approach would be nearly 20 per cent cheaper than the current strategy and would produce up to two thirds less carbon in 2030."

A smarter strategy, which we outline here, would prioritise the flexibility needed to balance the power system in the future. It would use auctions to procure demand reduction and flexible power from new gas plants and zero carbon sources.

To do this, the existing capacity market should evolve into a stratified market, which can place a higher value on more flexible resources. The different types of resources would be specified by a system architect, who would also determine the necessary quantities of each resource type. This would be based on ongoing forward assessments of future system needs, which is common practice in the US.

This new market structure would avoid excessive subsidies for old and inflexible plant. It would avoid building CCGTs that could become stranded assets as carbon constraints tighten. And it would improve competition within the energy system, by enabling new demand response and demand reduction companies to compete with electricity generation.

This smart approach would be nearly 20 per cent cheaper than the current strategy and would produce up to two thirds less carbon in 2030, keeping the UK on the least cost pathway to meet its carbon budgets.

Greater flexibility: cheaper and lower carbon

"As the UK power system undergoes a structural shift towards significant renewable generation, mostly from solar and wind plants, flexibility adequacy is becoming a more pressing question."

Our power system is a finely tuned machine. This machine is enormous, spanning the length and breadth of Great Britain, encompassing large coal-fired power plants as well as rooftop solar panels, large urban centres of demand as well as remote rural dwellings. Yet it is also very sensitive. Electricity demand must always equal electricity supply, second by second, otherwise the machine breaks. The greater the system's ability to balance demand and supply, the greater its security.

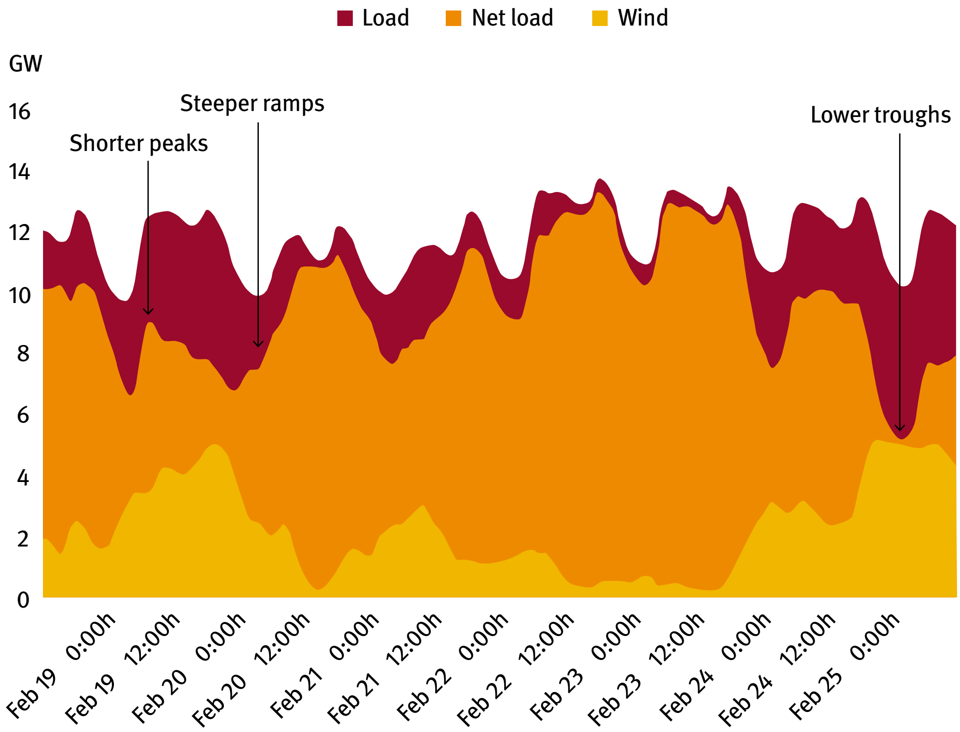
Two major components of electricity system security are resource adequacy and balancing, or flexibility adequacy. Resource adequacy is a measure of whether there is enough generation capacity to meet the peak level of demand with a comfortable margin. Flexibility adequacy is a measure of the system's responsiveness to relatively sudden changes; for example, an unexpected plant shutdown, a lull in wind speed or an up-tick in demand in the minutes after the FA Cup final.

In the past, resource adequacy, ie making sure enough power generating capacity is available to meet peak demand, has been the main preoccupation of those concerned about system security. But, as the UK power system undergoes a structural shift towards significant renewable generation, mostly from solar and wind plants, flexibility adequacy is becoming a more pressing question.

Renewables are worth having. They are low carbon, cheap and getting cheaper, and they are popular with the public.[1,2] But the variability of the power they generate means the system as a whole must become better able to increase or reduce supply and demand more quickly. This is not a qualitatively new challenge, because the current system already copes with large changes in demand at short notice. But it is quantitatively different.

The following graph illustrates how variable resources, in this case wind, cause more frequent and intense fluctuations in 'net load' or 'net demand' (gross demand minus variable renewable generation).[3] For example, the 'ramps' become steeper. A ramp is the rate of increase in demand, with steeper ramps requiring resources that can ease the ramp rate either by generating electricity very quickly, releasing stored electricity or shifting demand. Renewables create a requirement for more flexible resources, which can complement variable renewables by easily ramping up and down, or stopping and starting multiple times within a short window of time.

Variable renewables like wind create a greater need for flexibility in the power system



To integrate large amounts of renewables cost effectively, a system wide transformation is needed, to decrease the amount of inflexible baseload plants and increase both the supply side and demand side resources that improve system flexibility.[4] This will make the system cheaper and lower carbon. Imperial and NERA have found that increasing flexibility reduces the overall cost of the energy system and maintains security as power system decarbonisation takes place.[5] Interconnection, for example, could save £1 billion a year by 2020, because it enables the UK to take advantage of cheaper electricity from abroad during times of high demand, which lowers wholesale prices.[6] This is the case even for slower rates of decarbonisation, when carbon emissions by 2030 would be higher than those consistent with carbon budgets (eg 200g per kWh).[7] The National Infrastructure Commission (NIC) has, therefore, concluded that flexible resources are 'no regrets' options from a 2030 perspective, and could save consumers up to £8 billion a year by 2030.[8]

No silver bullet, just better and worse options

But what are flexible resources? A range of technologies fall into this category, each bringing different energy system benefits (see the glossary on page 16). They vary in their usefulness over time as the nature of the security challenge evolves. To illustrate this, the following table shows how the system security challenge is likely to change over the next 15 years and indicates the usefulness of different technologies over three different time periods.

Forthcoming energy challenges: comparing the usefulness of flexible technologies

	Period to 2020	Early 2020s	Late 2020s
Nature of the system security challenge	Increasing resource adequacy challenge as old plants retire	Resource adequacy challenge	Flexibility adequacy challenge
Conventional fossil fuel technologies			
CCGT	Useful	Useful	Uneconomic at low load factor
CHP	No policy driver; upfront cost	Useful	Very useful to help cut heat emissions
Highly flexible fossil fuel technologies			
Diesels	Too polluting	Too polluting	Too polluting
OCGT	Useful	Too polluting	Useful
Gas reciprocating engines	Useful	Too polluting	Useful
Zero carbon flexibility			
Demand response	Useful; scaling up needs new policy	Useful, but not enough	Ideal
Batteries	Useful; scaling up needs new policy	Useful, but not enough	Ideal, if cheap
Compressed air	Useful; scaling up needs new policy	Useful, but not enough	Ideal, if cheap
Pumped hydro	Useful; scaling up needs new policy	Useful, but not enough	Ideal, if cheap
Zero carbon capacity			
Interconnection	Very useful; around 7GW is possible	Very useful; around 12GW is possible	Very useful; up to 18GW is possible
Demand reduction	Useful; scaling up needs new policy	Very useful	Very useful

> "The most flexible fossil generation technologies have a pollution problem if they are relied upon too heavily in the early 2020s."

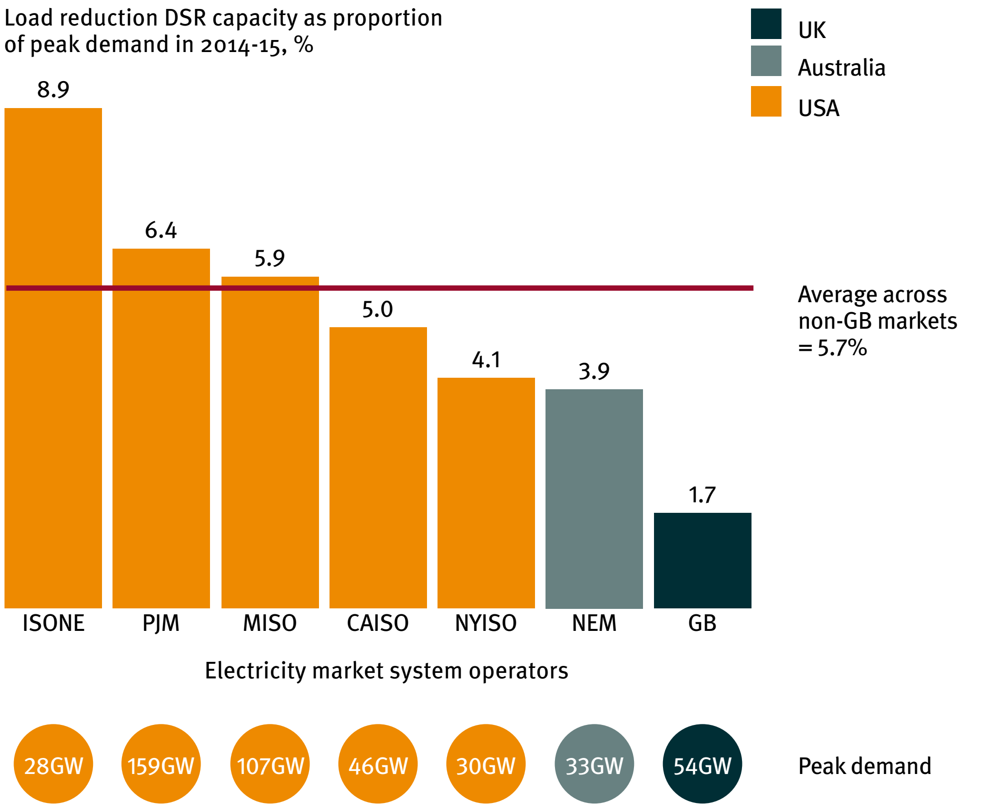
The table shows that the main risk for investors in CCGT is that new plants will become uneconomic halfway through their life, due to a combination of climate policy and technology change. This will make them stranded assets unless they are very flexible and receive sufficient capacity payments to compensate for extremely low load factors. A better use of gas would be in flexible combined heat and power plants (CHP). These have much lower emissions intensity, so they are unlikely to be stranded, making CHP useful into the 2030s.

The clear winners are zero carbon flexibility resources, but they require policy ambition or a continued trend of technical improvements to realise that potential. Some are already proven: in some US markets, DSR can offset nine per cent of peak demand, far greater than the current UK level which is estimated at less than two per cent of peak demand (see graph opposite). Asset management company Lazard expects that battery technologies will be competitive with new gas plants within five years, as an option for complementing variable renewables, and the latest assessment by National Grid indicates that costs will continue to fall (see opposite).[9] The NIC found that, if storage costs continue to fall, up to 15GW of a range of storage technologies could be economically deployed by 2030, from a current baseline of 3GW of pumped storage.[10]

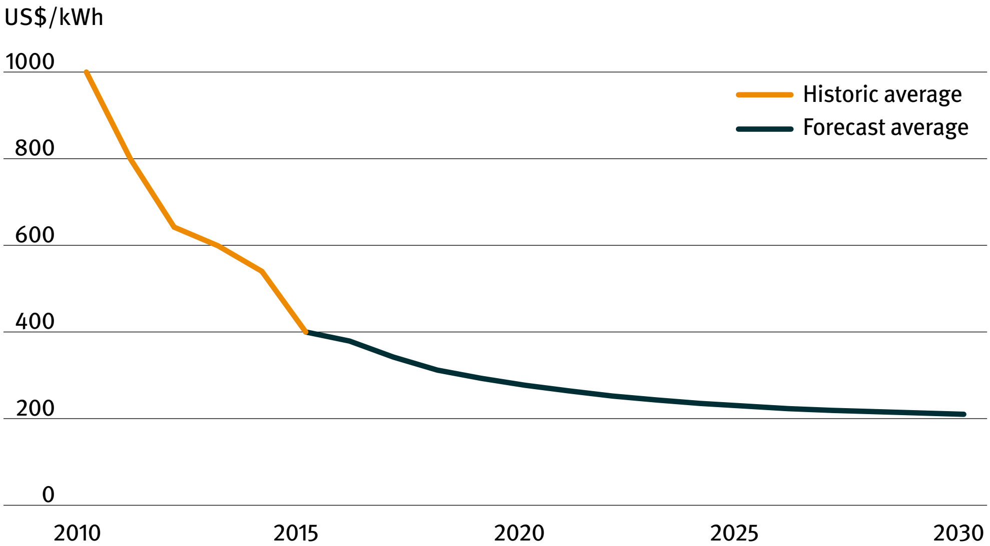
Over the next 15 years, however, these zero carbon technologies will not be enough on their own. The NIC notes that storage and DSR are unlikely to obviate entirely the need for additional flexible generation on this timescale, because it cannot solve the problem posed by a lull in renewable output for a period of two or three weeks.[11] There is a need for some flexible gas capacity. But the most flexible fossil generation technologies have a pollution problem if they are relied upon too heavily in the early 2020s. There is a trade-off between flexibility and efficiency, which means that more flexible plants are less efficient at converting fuel into power and are, therefore, more polluting.

"In some US markets, demand side response can offset nine per cent of peak demand, far greater than the current UK level which is estimated at less than two per cent of peak demand"

Comparing demand side response capacity across US, Australian and UK electricity markets[12]



Lithium-ion battery prices are falling fast[13]



Two problems with the current approach

"The capacity market is harmful to both system efficiency and economic efficiency, because it throws a lifeline to old, inflexible power plants."

The government has recognised the need for greater energy system flexibility, noting the multiple benefits of a whole system approach.[14] These are: deferring or avoiding investment in network reinforcement; reducing the need for a significant increase in reserve generation capacity; meeting binding climate change targets with less low carbon generation; making the best use of domestic low carbon generation; and optimising balancing of the energy system on a minute-by-minute basis.

This leads the government to conclude, rightly, that "solutions will be needed sooner rather than later so we can meet these challenges and respond cost effectively. Decisions taken in this parliament will influence the extent to which smart, flexible solutions become widespread in the 2020s."[15] Initial activities are focusing on reducing regulatory barriers to flexible resources and improving price signals to consumers, both of which are areas ripe for improvement. But there has been little or no attention given so far to improving the price signals to resource owners and investors.

There are two related problems with the government's current strategy, which are hindering investment in flexible resources. The first is that flexibility is undervalued in the energy market and the second is that a narrow focus on procuring CCGTs is distorting the market and putting an unnecessarily high cost burden on consumers.

1.
The energy market is undervaluing flexibility and wasting money on inflexible plant

Energy prices do not currently reflect the high value of flexibility in such a way as to drive investment in the flexible resources that the system needs. The only marketplace in which flexibility is valued is the balancing market, but this is a short term market that does not operate on investment timescales. Also, participation in the balancing market is restricted, in practice, to large providers connected to the transmission system: the hurdles are too great for smaller, distribution connected providers.

There is a market mechanism for system security: the capacity market. But this was set up to respond only to the resource adequacy challenge, not the flexibility adequacy challenge, so it is blind to the value of flexibility. The capacity market is harmful to both system efficiency and economic efficiency, because it throws a lifeline to old, inflexible power plants and is failing to procure a mix of resources appropriate to system requirements.

"The government's misguided strategy could increase costs to consumers threefold."

2.
There is a too narrow focus on CCGTs

The second problem is that the government is narrowly focused on procuring CCGTs as a solution to all the UK's system security needs. As the capacity auctions have failed to yield the anticipated number of new gas plants, the government's response has been to raise the volume of capacity targeted in the next capacity market auction by 6GW, in the hope that two or three new-build CCGTs will clear the auction.[16]

This is likely to prove a costly decision. Our analysis suggests the rule changes alone could cost consumers an additional £1.35 billion. Investment risks created by the vote to leave the EU, and additional uncertainty surrounding reform to the transmission network charging regime, will push up the clearing price still further. These combined factors could result in a clearing price of around £50 per kW, meaning the government's misguided strategy could increase costs to consumers threefold compared with the previous auction: to £2.6 billion in 2016, from only £833 million in 2015.[17]

Due to the auction design, which means that every successful bidder is paid the clearing price, rather than the price at which they bid, this would dramatically inflate the payments to existing plants that bid in as low as £5 per kW. It would mean paying more for something that power stations were going to do anyway, and it is difficult to see why this is a good use of money.[18]

While new CCGTs are part of the answer to the flexibility problem, they also create new pollution problems. Decarbonisation commitments mean CCGTs cannot play a major role in the power system beyond 2030, unless fitted with carbon capture and storage.[19] A CCGT-only strategy creates significant risks of either stranding assets or locking in pollution. Going all out for CCGTs is likely to result in a difficult choice in the late 2020s: whether to keep relatively new plant running at high load factors so that investors can recoup their costs or to constrain generation to meet carbon budgets.

A smarter strategy

"Overall, CCGTs in our scenario three are as cheap as the 'cheap and dirty' scenario one, but their pollution levels are two thirds lower."

A smarter approach would avoid this conundrum, with a strategy that is lower carbon, more cost effective and more attractive to investors. This would involve building fewer CCGTs, bringing them online sooner, and running them at higher load factors, before constraining them. It would make use of the low carbon, flexible technologies listed in the table on page seven.

To illustrate different strategies and their outcomes, we have developed three scenarios:

Scenario one

This is the base case. It would see some 15GW of new CCGT capacity built in the early to mid-2020s and then constrained from 2030 to meet carbon targets. We believe this approximates to the government's current approach.

Scenario two

This would happen if the same amount of new capacity were built as the base case but strict carbon constraints were not imposed from 2030. It would mean building 15GW of new CCGT capacity and leaving it to run at high load factors until 2040, thereby exceeding carbon constraints.

Scenario three

In this scenario only 3GW of new CCGT is built, compatible with other published scenarios (see the annex on page 17), but all of it is built by 2020. This relatively small amount of capacity allows returns to investors without surpassing carbon budgets. Because there is so little new capacity in this approach, it limits the carbon emissions enabling it to run at a higher load factor for longer, before tailing off after 2035. Remaining capacity and flexibility requirements would be met by increased levels of renewables, storage, interconnection and DSR.

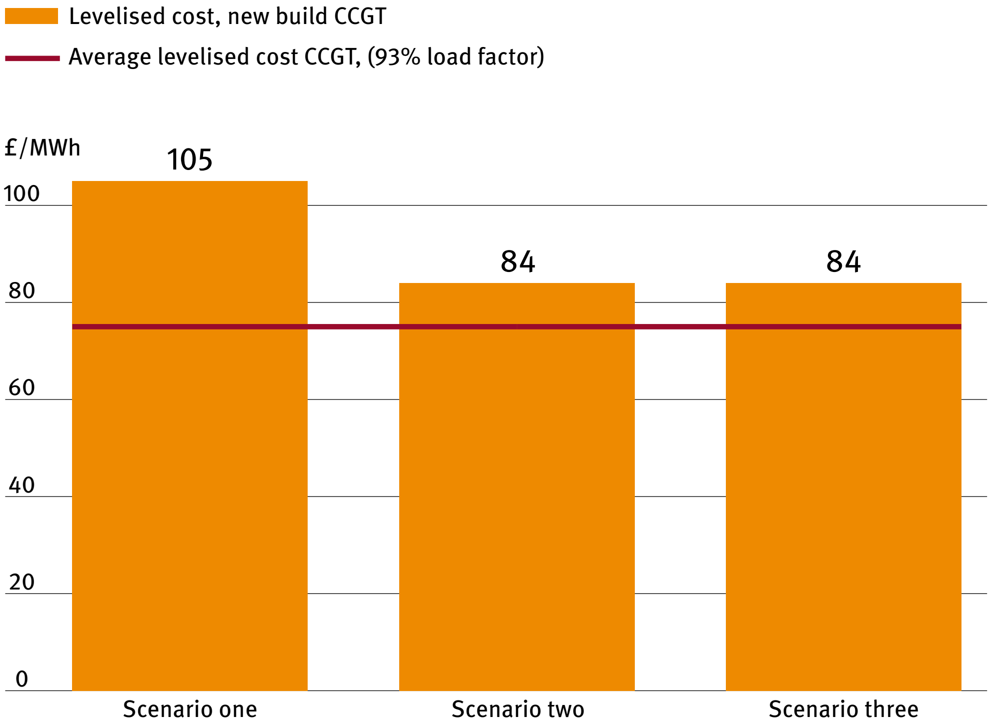
In all scenarios, we assume 15GW of existing CCGT capacity stays online until 2030, running at moderate load factors. All scenarios also allow room in carbon budgets for CHP and small amounts of more flexible gas generation, compatible with other published scenarios (see annex on page 17).

Our analysis suggests the levelised cost of the new build CCGT would be around 20 per cent lower in scenario three compared with scenario one. It is possible to constrain costs by allowing CCGTs to run at higher load factors, because this makes CCGTs more economic. But doing this only brings the costs level with our scenario three (see chart opposite).

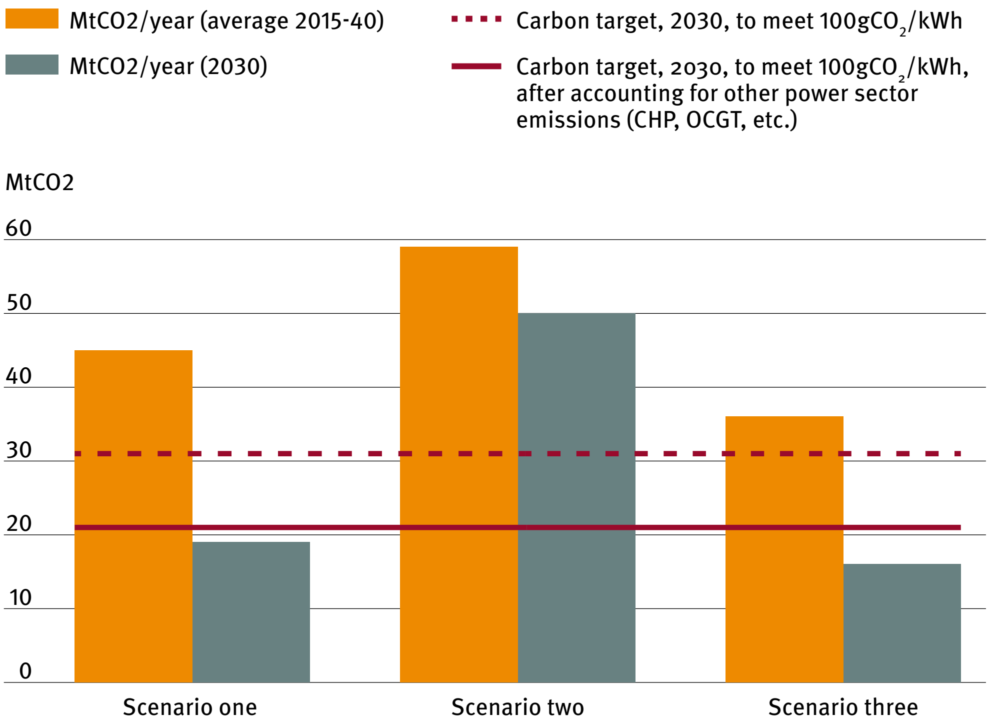
However, running CCGTs more often without carbon constraints, as in scenario two, would far exceed carbon budgets: it would be three times as carbon intensive as scenario three in 2030 (see opposite). Overall, CCGTs in our scenario three are as cheap as the 'cheap and dirty' scenario one, but their pollution levels are two thirds lower.

Our scenarios are illustrations rather than predictions of the future energy system, the nature of which will depend significantly on levels of total demand, change in technology costs and customer choice. But they do show the major opportunity created by moving to a more flexible energy system and optimising the number of new CCGT plants built.

The levelised cost of a new build CCGT plant for each scenario[20]



Carbon emissions from all CCGT plants (new and existing) for each scenario[21]



Recommendations: how to build a market for flexibility

"As well as procuring a certain quantity of resources, the capacity market should differentiate based on the quality of resources."

Flexible energy resources need to be valued properly, so that investment can be focused on the technologies that best fulfil system needs. The UK already has a market for system security: the capacity market, but its remit needs to expand to include flexibility adequacy. As well as procuring a certain quantity of resources, the capacity market should differentiate based on the quality of resources. This would unlock investment in small scale gas and a relatively low number of new CCGTs, while providing a market for the newer, cheaper and lower carbon flexibility technologies the UK needs.

Evolve the market

The capacity market should evolve into a stratified market, which can place a higher value on more flexible resources. The different types of resources would be specified by a system architect, determining the necessary quantities of each resource type to be procured, based on ongoing forward assessments of future system needs, as shown below.

Proposed process

System architect ↓	Assesses what type of resources, in what quantities, will be needed in one and four years' time Advises the system operator
System operator ↓	Sets the size of capacity auction pots based on anticipated system need Manages the capacity auction
Resource owners ↓	Bid into the capacity auction Successful bidders sign capacity contracts and deliver the contracted resource in one or four years' time

The reformed market would yield different clearing prices for each resource type. Because flexibility is system specific, the relative size of the different auction tranches could change over time to reflect changing system requirements, as determined by the system architect.[22] This would ensure the institutional framework is robust to any change in technology and prices.

The new market structure would avoid the inefficiency of paying excessive subsidies to inflexible plant, which retrenches the system into reliance on old infrastructure. It would also avoid building too many new CCGTs that could become stranded assets as carbon constraints tighten. And it would improve competition within the energy system, particularly if it is open to demand side response and energy demand reduction on an equal basis with electricity generation.

"The EPS needs to decline over time, to ensure that emissions are constrained in line with carbon budgets."

Example of a stratified market with four auction pots[23]

First auction ↓	A 'flex' option: the ability to shut down and restart or cycle a resource multiple times within a reasonably short window of time and up to hundreds of times over the course of the year
Second auction ↓	A 'dispatch' option: the ability to reduce a resource to a low level of stable operation and ramp it back up at a specified rate, not in a traditional operating reserve role but as a ramping capability in normal operating conditions
Third auction ↓	Secondary reserves to address issues arising in tens of minutes (eg due to forecasting error)
Fourth auction ↓	The remaining tranche of capacity would be open to all firm resources, including energy demand reduction

Reform the emissions performance standard

To ensure system security without compromising the UK's carbon reduction goals, the emissions performance standard (EPS) also requires reform. There are two issues with the current EPS. First, it only applies to all new fossil fuel electricity generation plants above 50MWe.[24] As an increasing proportion of fossil fuel electricity generation is distribution connected, in the form of smaller gas engines and diesels, the 50MWe floor could permit harmful levels of emissions, putting carbon budgets in jeopardy. Therefore, we recommend that the EPS is extended to plants below 50MWe.

The second issue is that the current level of the EPS, 450g CO_2 per kWh, does not limit the construction of new gas plants, whose emission intensity is below that level. The EPS needs to decline over time, to ensure that emissions are constrained in line with carbon budgets. This trajectory should be set out soon, to give investors clear visibility and to ensure accurate capacity market pricing. Current EPS regulations stipulate that the standard is fixed, applying to all plants built from 2014 until the end of 2044. While plants built between 2014 and today must benefit from this fixed level, because they were built on that assumption, those built from now on must be subject to a declining EPS level.

The combination of a stratified capacity market with a declining, universal EPS would ensure that prices reflect the value to the energy system of flexible resources. It would clarify the investment landscape, giving developers the confidence to build a limited number of new CCGT plants, while avoiding the risk of stranded assets. And it would channel investment towards the 'no regrets' technologies that will underpin a flexible energy system fit for the 21st century.

Glossary of flexibility options

Batteries A range of electrochemical storage technologies, including solid state batteries such as lithium-ion batteries, as well as flow batteries, where the energy is stored in an electrolyte solution.

Combined cycle gas turbines (CCGTs) CCGTs are more efficient and less polluting than open cycle gas turbines (OCGTs - see below) as the heat from the exhaust is used to drive a steam turbine that generates additional electric power. CCGTs have higher capex costs than OCGTs, but provide a range of services to the electricity system, including baseload power, fast ramping, peaking and inertia.

Combined heat and power plants (CHPs) Also known as cogeneration, CHP generates heat and power simultaneously, by utilising the heat normally wasted from electricity generation. This greatly increases efficiency and can reduce carbon emissions by up to 30 per cent compared to generating the same amount of heat and power separately. CHP can be fuelled by gas or renewable sources such as biomass.

Compressed air storage Using electricity to compress air into confined spaces and then releasing it when required to drive the compressor of a natural gas turbine.

Demand side response (DSR) Shifting or lowering electricity demand at times of system need, for example, by delaying energy intensive industrial processes.

Diesel generators Very flexible small scale generation used as back up, typically running at very low load factors. As well as being highly carbon intensive, above that of a coal plant, diesel generators have a range of negative environmental impacts such as releasing toxic air contaminants and the ozone depleting gas nitrogen oxide.

Electricity demand reduction (EDR) Permanent electricity demand reduction measures, for example replacing inefficient household appliances with more efficient ones.

Gas reciprocating engines Also known as piston engines, these are heat engines that convert pressure into a rotating motion. They are also a very flexible form of generation, used at low load factors. They are higher carbon than CCGTs and also produce nitrogen oxides.

Interconnection Cables that physically link electricity markets across borders to allow international trading of electricity.

Open cycle gas turbines (OCGTs) Gas powered generators consisting of a single compressor or gas turbine. OCGTs have lower efficiency than CCGTs, so are more expensive and carbon intensive to run, but have lower capex costs. They can ramp up and down quickly and are used to meet peak demand.

Pumped hydro storage Using low cost electricity to pump water from a lower to a higher water reservoir and then running as a conventional hydro power plant during high electricity cost periods.

Annex
Future energy scenarios

A number of studies have illustrated how the power system could make better use of smarter, lower carbon technologies to meet capacity and flexibility requirements. All these models are economically optimised and meet carbon targets.

In **National Grid's Gone Green** scenario, interconnection plays a key role, with 23GW in place by 2030. This means only 24GW (of which 2GW is from OCGT and has gas reciprocating engines) of unabated gas plants need to be online in 2030, plus 3GW of CHP.[25]

Aurora's Low Stress scenario suggests 35GW of gas (10GW coming from OCGT and small scale reciprocating gas engines) will be needed in 2030. This is higher than the Gone Green scenario, but it relies less on expensive new build CCGT, making much heavier use of existing CCGT and small scale technologies, such as gas reciprocators that don't rely on high load factors to be economic. This scenario also makes moderate use of interconnection, storage and DSR.[26]

Greenpeace's two 2030 Energy Scenarios both require only 20GW of gas capacity in 2030, a substantial proportion of which could be met from existing plant, and which, in their ambitious scenario, would run only two per cent of the time. This is possible by ramping up energy efficiency and relying on DSR and batteries.[27]

UKERC's Maintain (Tech Fail) scenario models as little as 16GW of gas on the system in 2030, relying on energy efficiency, increased interconnection and biomass CHP, as well as moderate amounts of storage. This small amount of gas can run at higher load factors, without emitting too much carbon.[28]

Most of these scenarios rely on small amounts of other fossil capacity, such as CHP, OCGTs and gas reciprocating engines. The Gone Green scenario is the only one that gives numbers: 17TWh of these non-CCGT gas sources (15.5TWh of CHP, 1.5TWh small scale gas) are used in 2030, which, by our calculations, would produce approximately 10MtCO_2.[29,30] Our modelling, therefore, reserves 10MtCO_2 from the 31Mt CO_2 carbon budget for non-CCGT gas sources.

These scenarios are confident, but not unrealistically optimistic, about the role of low carbon flexible technologies. Other studies have suggested greater ambition is warranted, with the potential for much higher levels of DSR, storage and interconnection to be integrated into the system.[31]

Endnotes

1 D Benton, A Francis and A Mount, 2016, *Beyond subsidy: how the next levy control framework can cut carbon at least cost* , Green Alliance

2 DECC, April 2016, *Public Attitudes Tracking Survey: Wave 17*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/519438/DECC_Public_Attitudes_Tracker_-_Wave_17_Summary_Tables.xlsx

3 J Cochran et al, 2014, *Flexibility in 21st century power systems*, National Renewable Energy Laboratory, p2

4 IEA, 2014, *The power of transformation – wind, sun and the economics of flexible power systems*

5 G Strbac et al, 2015, *Value of flexibility in a decarbonised grid and system externalities of low carbon generation technologies*, Imperial College and NERA Economic Consulting

6 G Strbac et al, 2012, *Understanding the balancing challenge*, Imperial College and NERA Economic Consulting

7 G Strbac et al, 2015, ibid

8 National Infrastructure Commission, 2016, *Smart Power*

9 Cited in L van der Burg and S Whitley, 2016, *Rethinking power markets: capacity mechanisms and decarbonisation*, ODI

10 National Infrastructure Commission, 2016, ibid

11 National Infrastructure Commission, 2016, ibid

12 Source: Adapted from Aurora Energy Research graphic, tweeted on 15 June 2016, https://twitter.com/AuroraER_Oxford/status/743126219328237569

13 National Grid, 2016, *Future energy scenarios*

14 DECC, 2015, *Towards a smart energy system*, p 8

15 DECC, 2015, *Towards a smart energy system*, p 5

16 Capacity Market parameters for T4 auction for 2020-21, and early auction and transitional arrangements auction for 2017-2018, available at: www.gov.uk/government/collections/capacity-market-parameters-for-t4-auction-for-202021-and-early-auction-and-transitional-arrangements-auction-for-20172018

17 Green Alliance analysis, based on data from Cornwall Energy cited in *Utility Week*, 13 July 2016, 'Capacity market costs to climb by £364m due to Brexit', available at: http://utilityweek.co.uk/news/capacity-market-costs-to-climb-by-364m-due-to-brexit/1261022#.V5cisesrLct

18 Cornwall Energy, 'The capacity market and the false economy', available at: www.cornwallenergy.com/Opinion/The-capacity-market-and-the-false-economy

19 Green Alliance analysis using data from National Grid, 2016, *Future energy scenarios*

20 We take the expected levelised cost of a CCGT, running at 93 per cent load factor, to be £75 per MWh. The different costs we calculate come from assuming different load factors in each scenario. All costs except for fuel costs are taken from: DECC, 2013, *Electricity generation costs* (build year 2019). Fuel costs, which have fallen far below DECC's 2013 estimates, are taken from a more recent source: VGB Powertech, 2015, *Levelised cost of electricity*, p 12

21 The dotted line, at 31Mt, shows the maximum emissions for the power sector, consistent with carbon targets. As the majority of electricity generation in 2030 will be zero carbon, emissions will come primarily from CCGTs, CHP and small scale gas (OCGTs and gas reciprocating engines). All three of our scenarios assume 10Mt comes from sources other than CCGT (see the annex for examples of the breakdown of these emissions), leaving 21Mt, the solid line, as the maximum emission level for CCGTs. The bars show the emissions of CCGTs in different scenarios.

22 J Cochran et al, 2014, ibid

23 Adapted from M Hogan, 2012, *What lies "beyond capacity markets"? Delivering least-cost reliability under the new resource paradigm*, RAP, p 15

24 'Draft explanatory memorandum to the emissions performance standard regulations', 2015 No. 933, p 4, available at: www.legislation.gov.uk/uksi/2015/933/pdfs/uksiem_20150933_en.pdf

25 National Grid, 2016, *Future energy scenarios*

26 B Caldecott, 2015, *Keeping the lights on: security of supply after coal*

27 D Quiggin and M Wakefield, 2015, *Greenpeace 2030 Energy Scenarios*, available at:

www.demandenergyequality.org/2030-energy-scenario.html

[28] C McGlade et al, 2016, *The future role of natural gas in the UK*, UKERC

[29] The emissions from other gas sources range from 518 to 777gCO2 per kWh. Sources: CCC, 2015, *Power sector scenarios for 2030 – data for exhibits*, Figure 1.3; VGB Powertech, 2015, *Levelised cost of electricity*; CCC, 2016, *Meeting carbon budgets – progress report to Parliament*; and D Hart et al, 2016, *Hydrogen and fuel cells: opportunities for economic growth*, E4tech and Element Energy.

[30] CHP emissions estimates vary, depending on whether they are accounted for by the heat or power sector. We use a central estimate of 560gCO2 per kWh based on sources: VGB Powertech, 2015, *Levelised cost of electricity*, available at www.vgb.org/en/lcoe2015.html?dfid=74042; and 'Chapter 7: Combined heat and power', *Digest of UK Energy Statistics* 2016, available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/540963/Chapter_7_web.pdf

[31] The scenarios in the annex assume up to 5GW of DSR, but there are more optimistic projections that suggest 12-28GW will be possible by 2030 (see, for example: Energy UK, 2016, *Pathways for the GB electricity sector to 2030*; and C Dudeney et al, 2014, *Realising the resource: GB electricity demand project overview*, Sustainability First). Apart from National Grid's, the scenarios in the annex all assume 10-12GW of interconnection by 2030, while this could reasonably be 18GW or more (see for example: Poyry, 2016, *Costs and benefits of GB interconnection: A Poyry report to the National Infrastructure Commission*). On storage, all scenarios assume around 4-8GW of storage, while more optimistic estimates suggest 12-15GW are possible by 2030, see, for example: G Strbac et al, 2015, *Value of flexibility in a decarbonised grid and system externalities of low-carbon generation technologies*, Imperial College and NERA Economic Consulting; and G Strbac et al, 2012, *Strategic assessment of the role and value of energy storage systems in the UK low carbon energy future*, Imperial College.

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The Green Alliance Trust
Registered charity no 1045395
Company limited by guarantee
(England and Wales) no 3037633

Smart investment
valuing flexibility in the UK energy market

ISBN: 978-1-909980-72-3

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Acknowledgements
Thanks to Danial Sturge and Micol Salmeri for research support.

We are also grateful to the following individuals for their feedback:

Steve Davies, E.ON; Pete Abson and Paul Lowbridge, National Grid; Dave Jones, Sandbag; Matthew Knight, Siemens; Faisal Bachlani, Statoil; Alex Kazaglis, Vivid Economics; and Rachel Stanley.

We are grateful to the Green Alliance Low Carbon Energy consortium for supporting this work.

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