

The Final Hurdle?: Security of supply, the Capacity Mechanism and the role of interconnectors

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Abstract The UK Government has developed a carefully designed Capacity Mechanism to ensure security of supply in the GB electricity system. This paper criticises the methods used to determine the amount of capacity to procure, and argues that the amount finally proposed is likely to be excessive, particularly (but not exclusively) in ignoring the contribution from interconnectors. More broadly, there has been too little attention to either the political economy, or the option value aspects. Procuring too little is risky, but fear of ‘the lights going out’ can easily become a catch-all argument for excessive procurement, and associated subsidy. The risk of over-procurement, particularly of new capacity on long-term contracts, is that it drives up the costs to consumers; undermines renewable energy by transferring capped resources from renewable to fossil fuel producers; and impedes the Single Market including by weakening the business case for future interconnectors. The paper argues that the development of technologies and markets, particularly on the demand-side and of potentially available – ‘latent’ – capacity - further lowers the risks and increases options. This implies greater potential to defer more capacity procurement – and enhances the value of a more appropriate treatment of interconnectors in security assessments.

Keywords Capacity Mechanisms, procurement volume, interconnectors

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The Final Hurdle?

Security of supply, the Capacity Mechanism and the role of interconnectors

1. Introduction

European electricity markets were liberalised with generous reserve margins and low demand growth. Low gas prices and cheap efficient gas turbines encouraged further gas-fired generation in some countries, supporting the view that the market would deliver adequate investment and security of supply. The EU has encouraged both electricity liberalisation and pressed for a single border-less electricity market. The Third (Energy) Package, with a target date of 2014, aims to deliver this by market coupling of each country through an energy-only auction platform, which as of mid-2014, had successfully coupled most of the markets of North West Europe.

At the same time however, concerns about the adequacy of capacity needed to ensure security of supply have been growing, for a variety of reasons we outline in this paper. This has driven many countries to develop Capacity Mechanisms to reward reliable capacity contributions. The case for and against capacity mechanisms, based on various perceived market, regulatory and political factors, has a long history but is rising in salience with the extent of environmental policy interventions (see the extensive academic discussions on investment adequacy, most recently in the *Symposium on 'Capacity Markets'*, Joskow, 2103, particularly Cramton, Ockenfels and Stoft, 2013). Almost all the discussion about capacity mechanisms concentrates on whether the various market and regulatory/political failures are sufficient to justify a capacity mechanism, and if so, what form it should best take.¹

In this paper we focus on a different issue. We accept the reality of capacity mechanisms emerging in European countries facing a potential or perceived future shortage of suitable (flexible peaking) capacity, but direct attention to a previously largely neglected aspect, namely the volume – and scope – of capacity to secure. We focus in particular on two key dimensions of this choice, namely the assessment of interconnectors, and the option values associated with auction volume and scope over time. We conclude that concerns of capacity shortfall must be balanced against

¹ See e.g. Adib et al. (2008), Batlle et al. (2007), Battle and Rodilla (2010), Bowring (2008, 2013), Chao and Wilson (1987, 2002), Crampton and Ockenfels (2011), Cramton and Stoft (2008), Joskow (2008), Joskow and Tirole (2007); O'Neill et al. (2006); and de Vries (2007). For a more sceptical assessment in the UK context that looks at the welfare impact, see Platchkov et al (2011).

a real and serious risk of procuring too much conventional domestic capacity, too soon, to the detriment of the other goals of UK and European energy policy.

2. The rise of capacity concerns

Security of supply is both an important topic and inevitably politically sensitive. No politician or system operator wants the lights going out. The more reliable generating capacity is available, the lower is the chance of black-outs. The downside is that leaving the capacity choice to politicians or system operators risks leading to excess capacity, as the consumer, not the system operator, bears the costs. One of the main arguments for privatising electricity was to keep politicians out of decision making, leaving the market to decide on the appropriate quantity and type of capacity.

The nature of system inheritance, the early attractiveness of gas generation, and the slow growth of electricity demand, helped for some years to maintain adequate capacity margins in the UK and more widely in Europe. The last decade however has seen erosion of margins and confidence about capacity adequacy. This has been for multiple reasons. Combinations of age and environmental concerns are leading to widespread retirement of coal and nuclear plants. Rising and volatile gas prices have deterred new gas plant. In the UK, the move away from the initial structure of the pool removed all forms of payments for capacity itself.² Growing concern over climate change has moved the emphasis towards a policy-driven encouragement of otherwise uncompetitive low-carbon generation, particularly renewables, much of which is intermittent; this contributes less to supply security whilst also reducing the operating hours for conventional plant, further weakening the incentive to invest in conventional capacity.

Combined with uncertain trends in electricity demand, all this has undermined the former consensus that the unaided energy-only market will deliver

² When the British electricity industry was privatised in 1989, the wholesale price was set by the electricity Pool. The price included a capacity payment that reflected the (assumed) willingness of consumers to pay to keep the lights on. This Value of Lost Load (VoLL) was set at £5,000/MWh (£5/kWh) in 2014 prices. In 2001 the pool was replaced by an energy-only market in which generators would bilaterally contract with customers at an agreed price. If supply were tight generators would raise the price to signal scarcity and their customers would decide how much they were willing to buy. During this period there was ample, arguably excessive capacity, as a result of the “dash for gas” in the 1990s (Newbery, 2005).

the right kind and amount of generation investment. In the UK, assessments around 2010 pointed to a serious risk of a capacity crunch in 2016 as plant is retired, with little confidence that adequate new investment would come forth.³ There are anyway numerous downside risks facing anyone considering investing in plant designed to provide energy for such scarce and uncertain (in both price and duration) occasions, but these commercial risks were heightened as environmental objectives increase the range and unpredictability of policy interventions, such as the renewables targets and the future carbon price. In the face of such uncertainties, waiting makes commercial sense but potentially amplifies further risks to security of supply.

The UK's *Energy Act 2013*⁴ sets out the Electricity Market Reform (EMR), which includes both a structure of long-term contracts for low carbon generation, and a Capacity Mechanism to ensure adequate capacity. Great Britain has thus now moved to a world in which the Secretary of State for Energy & Climate Change, advised by the Department for Energy & Climate Change (DECC), sets the security standard and decides how much capacity is required, which is then delivered through capacity auctions.

Capacity Mechanisms are not new, and are replete with potential pitfalls (e.g. Cramton and Ockenfels, 2011). In the development of the EMR, tremendous effort went into the technical design of the mechanism, drawing on strong analysis (academics expert on capacity mechanisms advised DECC) and international experience from the US, particularly PJM (Bowring, 2013) with extensive consultation, to minimise the risks.

However, far less attention was given to the apparently much simpler tasks of setting the reliability standard and capacity volume to be procured, which ultimately determine the overall cost.

This paper discusses the standard set, its widespread misinterpretations, and then focuses upon the Secretary of State's announced intent (on 30 June 2014) to procure 53.3GW of capacity in the first auction, for capacity delivered for winter

³ E.g. see the regulator's view at <https://www.ofgem.gov.uk/ofgem-publications/40354/projectdiscoveryfebcondocfinal.pdf> and for a history of policy concerns, Pollitt and Brophy Haney (2013)⁴ <http://services.parliament.uk/bills/2012-13/energy.html>

⁴ <http://services.parliament.uk/bills/2012-13/energy.html>

2018-19.⁵ We highlight two particular dimensions: areas of underlying confusion (and opportunity) around indicators and options; and the role that interconnectors play in delivering security of supply, contrasted with the ‘zero net contribution’ proposed by National Grid and accepted by the Government.⁶ The emphasis is on the British situation, though many of the issues raised are of wider application.

3. The ‘value of lost load’, ‘loss of load expectation’, and the reliability target

In December 2013 DECC set a reliability standard to ensure what has traditionally been called ‘Loss of Load Expectation’, or LoLE, of no more than 3 hours per year. This corresponds roughly to an assumed ‘Value of Lost Load’ (VoLL) of £17,000/MWh, or over three times the 2013 value assumed when GB previously had capacity payments in the Pool.⁷

One immediate problem is that these terms do not in fact refer to losing any load. The Standard does not in any way mean that the lights would go out for three hours each year. It means, rather, that on average over a long period of time (a decade or so) *the System Operator would have to take some actions to prevent* a loss of load for an estimated average three hours a year.

According to the GB regulator Ofgem (2014), these actions include:

- asking generators to exceed their rated capacity for a short period;
- invoking ‘new balancing services’, mainly contracts to reduce peak demand or offer on-site (embedded) backup generation;⁸
- cutting any exports through interconnectors to zero, and requesting imports;

⁵ At <https://www.gov.uk/government/news/britains-energy-security-strategy-now-fully-in-place>

⁶ At <http://www2.nationalgrid.com/UK/Our%20company/Electricity/Market%20Reform/Announcements/June%202014%20Auction%20Guidelines%20publication/>

⁷ See note 4. The new (and much higher) value was estimated by London Economics (2013) primarily from stated preference choice experiments for the willingness to accept (WTA) outages. Domestic WTA was about £10,000/MWh but willingness to pay to avoid outages was only 20% of this. As SMEs had a WTA nearly four times as high as domestic customers the average was estimated at £17,000/MWh. Leahy and Tol (2011) use a different approach and estimate the average VoLL for Ireland at €12,500 (£10,000)/MWh.

⁸ “The new balancing services are Demand Side Balancing Reserve (DSBR) and Supplemental Balancing Reserve (SBR). ... These services will act as a safety net to protect consumers, only to be deployed in the unlikely and extreme circumstances of there being insufficient capacity available in the market to meet demand.” National Grid announced its tender for these new services on 10 June 2014

(<http://www.nationalgrid.com/uk/electricity/additionalmeasures>)

- and, if these measures are not enough, reducing voltage (“brown outs”).

The System Operator can thus take such ‘mitigation actions’ in ‘stress periods’ by calling on a combination of demand-reduction responses, and what we can term *latent capacity*. The latter refers to the potential to increase generation which is not part of normal operation, or is otherwise not available in the present market - but which could be called on at costs far less than that of forced blackouts, or indeed of new generation. Latent capacity could involve distributed back-up generation and distributed storage, and the potential volume appears to be very substantial.⁹

These actions would be invoked before finally having to selectively disconnect some loads (NOT switching off all the lights). Obviously, the system should not rely on having to operate ‘under stress’ for extended periods, since all these options are costly, and some (notably storage) may only be available for limited durations. But clearly, ‘*Loss of Load* Expectation’ is a misnomer: it is a statistical measure of the probability of having to invoke mitigation measures. And it is *these measures* that the reliability standard implicitly values at around £17/kWh – well over a hundred times the typical consumer price of electricity per unit. It might reasonably be wondered if consumers would prefer the occasional brown out (if that) rather than paying effectively £17/kWh.¹⁰

Yet given this terminological confusion over “loss of load”, perhaps understandably, the Secretary of State chose to procure 53.3 GW for the GB’s first capacity auction, targeted for delivery in 2018, with the vast majority of this to be auctioned in December 2014. This was the top end of the range recommended by National Grid.

⁹ There is no official data for GB, but the LSE Grantham Institute commissioned a report by Npower (at https://www.npower.com/idc/groups/wcms_content/@wcms/@corp/@iac/documents/digitalassets/iandc_pdf_futurereport2.pdf) which notes: “Many organisations maintain stand-by generation ready to come into operation if the power supply fails. ... There is no official data on the amount of capacity which exists in this form because it has never before played a public role, but EA Technology has estimated the total capacity of emergency diesel generation at 20GW.” The US evidence is that auctions can mobilise large amounts of such capacity. Spees et al (2013) note that the PJM capacity mechanism procured 4.8 GW of new generation, 11.8 GW of demand response, and 6.9 GW of increased net imports.

¹⁰ This doubt would be increased by observing that the lights do actually go out quite often in some areas, but because of storm damage to pylons or disturbances on the distribution network, but so far in the last few decades, never because of inadequate generation capacity.

This paper argues that the level of capacity chosen will likely prove to be excessive, and might result in securing unnecessary new plant that risks unnecessarily high costs falling on future electricity consumers, along with other adverse consequences discussed below. Three factors inform this view:

- i. the security standard has been set too high given the range of ‘mitigation measures’ already available;
- ii. the range of options to deal with stress events can be further broadened; and
- iii. National Grid chose to ignore the contribution that interconnectors provide.

Ignoring the contribution of interconnectors implies that GB is pursuing a policy of autarky and will over-procure domestic capacity, at exactly the same time that the EU Target Electricity Model is charged to deliver a fully integrated European electricity market (also by the end of 2014) -a point made strongly by Mastropietro et al (2014), who point at the EU Security of Supply Directive (2005/89/EC), which states that “Member States shall not discriminate between cross-border contracts and national contracts”.

4. The contribution of interconnectors: the principles

Interconnectors allow physical imports of power that create additional options for meeting domestic demand. Logically then, interconnectors must enhance security of supply except in the most extreme combinations of contractual and physical circumstances.¹¹ The benefits of interconnection will tend to increase with the scale and geographical reach of the interconnected countries. Newbery et al (2013) estimates the value of a fully integrated EU system at €12.5 - €40bn/year by 2030 – roughly €25 to €80 per capita by 2020 – compared to reliance on national autarky.

The challenge lies in connecting such broad collective gains to cooperation with the national perspective. Because a country has no control over generation at the other end of an interconnector and countries have in the past (quite understandably) prioritised their own security, a common ‘default’ methodology

¹¹ The exception would be if one is contractually committed to exports even at the expense of domestic security, and the other country is willing to pay more for electricity than the domestic market at the exact time of peak domestic need. This may become an issue if DG COMP requires any capacity market to be open to all other interconnected countries.

appears to be to assume that interconnectors do not make any contribution to national security of supply.¹²

Yet logically, this assumes that security equates to self-sufficiency, a philosophy abandoned in most other markets (including food) long ago. It conflicts with the European Target Electricity Model, which, by integrating cross-border markets, aims for free trade in electricity as with all other goods and services, as well as the earlier EU Security of Supply Directive. Moreover, in the UK context DECC's consultation paper stated unambiguously (DECC, 2013a, para 32):

“The expected contribution from interconnectors will be reflected in the amount of capacity auctioned. For example, if 2GW of imports are expected to be available at times of GB system stress, we will reduce the amount of capacity auctioned in the Capacity Market by 2GW”.

However, this has not as yet been followed through, even though interconnectors predominantly import to GB throughout winter, and would seem even more likely to do so when most needed, given imperfect correlation between GB and continental demand and plant output. The GB ‘conservative’ approach of zero net contributions may have been justified as ‘prudent’ yet other countries, such as Ireland and France include interconnectors in their security assessments.¹³ One possible defence of ‘prudent’ capacity procurement is a countervailing uncertainty in demand: National Grid (NG) projects that demand will decline, with projections spanning a relatively narrow range. A conservative approach on interconnectors could be taken as a hedge against demand proving higher. However adopting a

¹² Ofgem's 2014 Assessment explored a wide range of scenarios for continental imports, anchored around assumed exports of 750 MW to Ireland in all scenarios. Its most pessimistic scenario has exports worsening the assessed LoLE, whereas its most optimistic scenario assumed full imports of 3GW from mainland Europe for a net 2.25GW positive contribution (after exporting 750MW to Ireland).

¹³ Eirgrid/SONI (at <http://www.eirgrid.com/media/Generation%20Capacity%20Statement%202014.pdf>) in its *All-Island Generation Capacity Statement 2014-2023* states: “The East West Interconnector (EWIC) has ... the capability of importing or exporting up to 500 MW at any given moment. Based on the *Interconnector Feasibility Report*, this interconnector is assumed to add the equivalent of 440 MW of additional generation capacity.” (p8.) Thus EWIC is credited with an 88% contribution to domestic capacity adequacy. The French regulator conducts detailed studies of its connections with other countries, in consultation with them, and concluded that it could rely on a contribution of around 75% of IC capacity at times of tight domestic conditions. See <http://www.rte-france.com/en/mediatheque/documents/operational-data-16-en/annual-publications-98-en/generation-adequacy-reports-100-en>

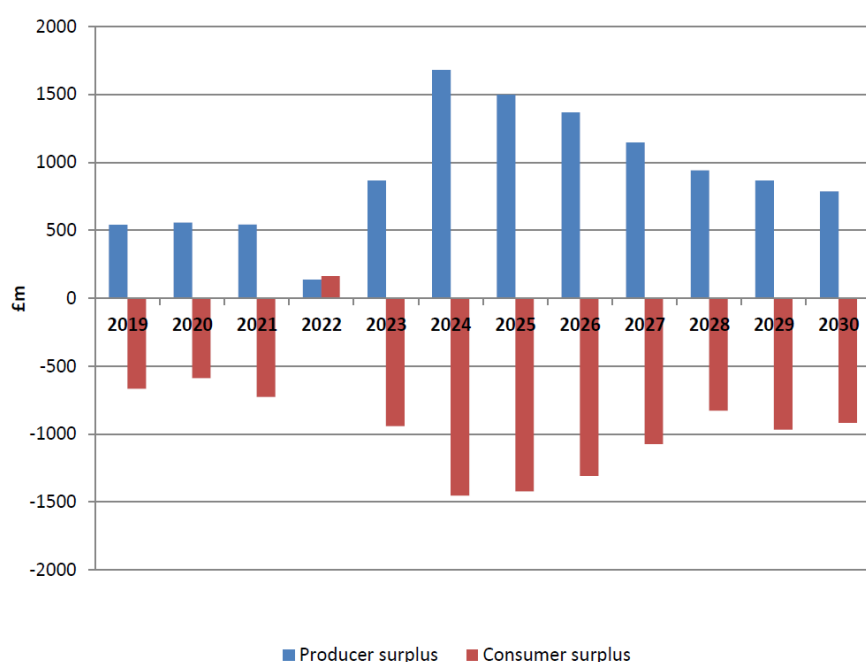
‘conservative’ approach in one area of analysis on the grounds that it may offset lack of confidence in another area, is clearly awkward, and we argue that there are better ways to hedge that avoid excessive consumer bills and other undesirable consequences.

5. Why it matters

The scale of potential gains from a fully interconnected European system have already been indicated as amounting to tens of billions of Euros; neglect of interconnectors in capacity mechanisms would clearly lessen this.

More specifically, as the UK Capacity Mechanism moves towards implementation, the gross consumer cost – the level of payments to generators – is becoming clearer. Figure 1 below, taken from the DECC (2013b) *Impact Assessment*, shows annual transfers of revenue of over £500 million (nearly £2/MWh averaged over the whole year, 4% of the average wholesale price and £7 per household),¹⁴ rising to over £1.5 billion, from consumers to generating companies. The scale of transfer is very sensitive to the auction price, which in turn may escalate rapidly depending upon the additional amount of capacity sought.

Figure 13: Change in producer and consumer surplus as a result of a Capacity Market



Source: DECC modelling

¹⁴ Based on latest data for 2011 from <https://www.gov.uk/government/statistical-data-sets/sub-national-electricity-consumption-statistics-2010-2011>

Figure 1 Transfers from consumers to producers

Source: DECC (2013b)

The estimated *gross* costs have increased in the subsequent assessment. The net Cost of New Entry (CONE) is projected at £49/kWyear, so if NG is charged to procure e.g. 53.3 GW for 2018/19 (as announced by the Secretary of State) and if the auction clearing price were £49,¹⁵ the auction revenue paid by consumers to generators would be £2.6 billion per year. Offsetting this by a hard-to-estimate amount is the impact of higher than otherwise capacity, and associated subsidies, lowering the wholesale price compared to not having a capacity auction. If the numbers are broadly correct, then retail prices might otherwise rise by about £2 billion per year (or an average over the year of £6.6/MWh).

There is a more dramatic way of looking at the cost of over-securing capacity. Suppose that GB could obtain 3 GW in stress periods in 2018/19 from interconnectors and/or other sources, with the result that no new capacity is required, but only retaining 50.3 GW of existing capacity. This would reduce the marginal cost – which is then paid to all – probably by about half. At £25/kW, the cost would fall to just under £1.3 billion. Ignoring for the moment the consequential impact of these different capacities on the wholesale price, the extra 3 GW would cost the difference between the £2.6 billion and the £1.3 billion. This equates to £450/kW *per year*, more than the *total* purchase cost of a peaking gas turbine.

Beyond the potential costs to consumers, there are additional drawbacks to the over-procurement:

Impact on renewables: Under the EMR, renewable energy generators receive a Contract for Difference that pays the difference between the ‘Strike price’ and the wholesale price. The proposal, if followed through, requires consumers to pay fossil fuel generators well over £2bn/yr. DECC (2013b) calculates that the capacity procured will lower wholesale electricity prices (yielding the smaller *net* impact on consumers, as per Fig. 1), but this increases the subsidy required (the excess of the strike price over the lower wholesale price). This puts more strain on the Levy Control Framework (LCF) that caps the overall level of payments. The cost to consumers is the same, but some of total

¹⁵ See National Grid (2014, p98)

accounted in the LCF is absorbed by a net transfer from renewables due to the Capacity Mechanism payments to fossil generators. This will likely reduce the amount of renewables supported within the LCF; what is given by one hand of government is thus in effect taken away by another.

DSR and Interconnectors. DECC plans to include interconnectors in subsequent auction rounds (the same may apply to new potential demand-side categories).¹⁶ However, if the first auction procures an excessive amount at an excessive price, this may reduce the space – or value – accorded to either interconnectors or demand side response in the future.

Newbery et al (2013) estimates that full interconnection in Europe could save Europe tens of billions of Euros annually. But if every EU Member State adopted a conservative ‘self-sufficiency’ approach, they may be driven to Capacity Mechanisms to ensure domestic adequacy, with resulting EU-wide excess capacity. As gas is the cheapest way of providing capacity, the result would be excessive subsidies to gas power stations across Europe. Since gas prices are increasingly aligned across Europe, and gas would often operate at the margin, this would cannibalise the economic value of interconnectors and increase risks facing merchant interconnector investors. The assumption of the need to be self-sufficient could become self-fulfilling in undermining the economics of interconnectors. It would do so at high cost, with excess peaking capacity only needed in each country a few hours per year, when a smaller volume of shared peaking capacity running more hours but supplying over interconnectors would be cheaper.

Given the large sums of money involved, the potential waste in duplicating reserve capacity, and prejudicing interconnection investment, the next section examines the methodology underpinning Security of Supply assessments and capacity procurement, and suggests improvements to NG’s evaluation of interconnectors.

¹⁶ This is clearly stated intent, but at the time of writing it remains unclear how interconnectors will be included in practice (particularly if it were effectively open to existing foreign generators to apply for capacity payments paid for by the British consumer). Unless and until this is resolved, Capacity Mechanism payments remain support to domestic generation that is not available to others in the Single Market.

6. Assessing security of supply: fundamentals

Contrary to common perception, security of supply is not an absolute, but a statistical goal. As noted, the GB standard for reliability is a Loss of Load Expectation (LoLE) of 3 hours per year on average, allowing for the probabilities of mild and also very cold winters. Ofgem (2014) defines LOLE as “the average number of hours in a year where we expect NG may need to take action that goes beyond normal market operations. Importantly, this still does not represent the likelihood of customer disconnections.”¹⁷

LoLE is thus a stochastic measure, to be derived from an analysis of statistics of all the factors that lead to variations in supply and demand. National Grid and Ofgem take account of the probabilistic deviations about the level of demand in any half-hour, and the reliability of each plant on the system, including the amount of wind energy produced in any half-hour. Reliability is therefore a key input, and is measured by the de-rating applied to the nominal capacity of each plant. The risk of system stress events and hence the LoLE calculation starts with a probability distribution of available conventional generating capacity at any future moment, as seen in fig 2. This is confronted with variable wind output and demand to give the net demand facing conventional capacity, from which the LoLE is determined in the bottom right of fig. 2.

¹⁷ At p5 of <https://www.ofgem.gov.uk/ofgem-publications/88523/electricitycapacityassessment2014-fullreportfinalforpublication.pdf>

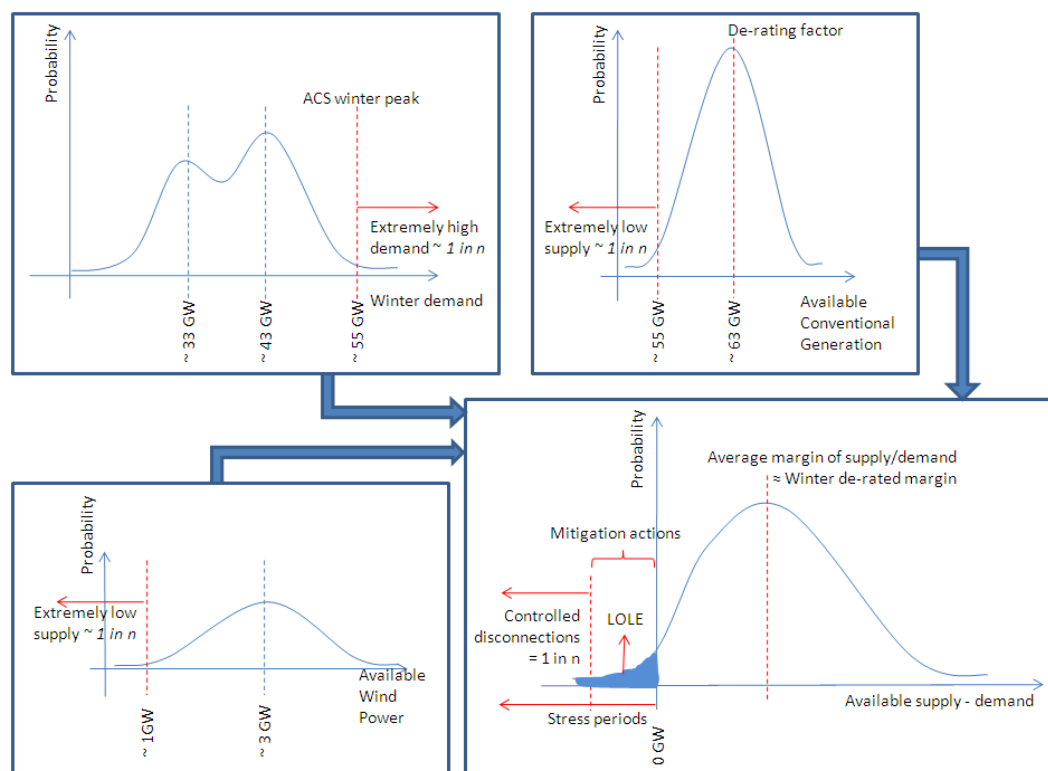


Figure 2 The elements of determining LOLE. Note the values are illustrative and depend sensitively on the future scenario considered and the date.

Source: NG's slides from *Capacity Market Implementation Coordination Workshop* 13 March 2014 at <http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=33666>

National Grid develops four scenarios for assessing security of supply which Ofgem also adopts. Scenarios in NG's approach are intended to capture different possible states of the future, each internally consistent, and each treated on the same par as they are considered uncertain, that is, the decision-maker cannot attach any probabilities to their occurrence. In addition to the four scenarios, both NG and Ofgem consider various sensitivities; "Even during the relatively short time horizon of this analysis, there is significant uncertainty over the security of supply outlook. We assess these uncertainties using sensitivity analysis around NG's scenarios. These sensitivities illustrate only changes in one variable at a time and do not capture potential mitigating effects, for example the supply side reacting to higher demand projections." (Ofgem, 2014).

Whilst the present approach treats demand, wind and generation stochastically, potential imports over interconnectors are considered non-stochastically – with a single assumed level of availability. Thus, there is an intrinsic methodological discrimination between domestic evaluation (estimated stochastically), and the potential contribution through interconnectors. In a probabilistic assessment, this is logically equivalent to assuming certainty of no net

imports in tight conditions. The sensitivity studies illustrated in Ofgem's *Capacity Assessment* show the large implications of assuming interconnectors make a positive contribution. Whilst there are to date less data concerning interconnector flows, there are many reasons why a stochastic approach – or at least, a different approximation – would be better. Zachary et al (2011) show how this might be done.

7. The role of interconnectors: the GB situation

Interconnection enhances security because none of the three main determinants of potential shortfall – peak demand, wind availability, or conventional plant failure - are perfectly correlated between countries. The chance that a demand peak, minimum wind, and plant failures all occur at the same time in two or more neighbouring countries is vanishingly small. Their probability can be (roughly) estimated, but plant outages should remain uncorrelated.¹⁸

The present (2014) state of GB interconnectors is as follows:

Table 1 Current GB interconnector capacity

IFA	to France	2 GW
Britned	to NL	1 GW
Moyle	to NI	0.25 GW
<u>EWIC</u>	<u>to RoI</u>	<u>0.5 GW</u>
Total		3.75 GW

By the delivery date of the first Capacity Auction there could be some or all of the additional interconnectors set out in Table 2 with assumed (possibly optimistic) commissioning dates:

¹⁸ The only way in which conventional plant outages would be correlated would be some kind of “common cause” failure, of which the least implausible example would be a prolonged interruption to gas supplies that affected all of western Europe. The paradox, of course, is that in these circumstances Capacity Payments to gas-fired power generators would be worthless as a means of increasing security, at least without much increased levels of gas storage - so in the context of the UK Capacity Mechanism, ignoring the contribution of interconnectors on grounds such as this makes no sense.

Table 2 Future possible GB interconnectors and their capacities¹⁹

Moyle repair to NI	0.25 GW	Nov 2017 ²⁰
NEMO	to Belgium	1 GW
<u>Eclink</u>	to France	1 GW
Total commissioned 2019		2.25 GW
		to be operational by Q4 2016 ²²

Thus by winter 2018-19 and on an optimistic assessment, GB could import up to 6 GW in stress periods or about 10% of peak demand. These proposals and their commissioning dates are indicative and may not be realised. Beyond the date of the first capacity delivery, there is an interconnector to Norway under discussion, NSN, of 1.4 GW that might, optimistically, be delivered in 2020.²³

Several factors support the likelihood of net imports when needed. Moving to Market Coupling has (as expected and intended) increased the responsiveness of interconnector flows to relative price differentials, so that power flows to where it is most needed. This has been robustly empirically observed and indeed – as expected - there have been no cases of exports through coupled GB interconnectors against the direction of relative prices. Historical data underline significant surplus collective capacity between countries to which GB is connected, the minimum collective historical “margin” being 16GW, at peak demand during 2012.

Table 3. ‘Minimum margin’ statistics for GB + four interlinked countries

	Max Hourly Load, GW	De-rated Capacity, GW	Lowest Margin, %
2010	178	198	20%

¹⁹ See DECC (2014 Table 1) for the considered assessment (other footnotes are to documents that may have an incentive to exaggerate the speed with which interconnections can be delivered).

²⁰ See <http://www.eirgrid.com/media/Generation%20Capacity%20Statement%202014.pdf>

²¹ See <http://www.nemo-link.com/timeline/>

²² See

<http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&sqi=2&ved=0CCAQFjAA&url=http%3A%2F%2Fwww.cre.fr%2Fen%2Fdocuments%2Fpublic-consultations%2Frequest-from-eleclink-for-an-exemption-under-article-17-of-regulation-ec-714-2009-for-a-gb-france-interconnector%2Fdownload-the-appendix-1-eleclink-s-exemption-request&ei=DlyxU6D-BsrD0QXd0YHIAw&usg=AFQjCNETH94MM5mlKQJEm3DBqGwIX-RTKw&sig2=Tjr2Mv6rMNoO41xQII-YpQ>

²³ See <http://www.statnett.no/en/Projects/Cable-to-the-UK/> but DECC (2014) does not include this.

2011	172	197	25%
2012	184	200	16%
2013	173	200	27%

Source: Derived by the authors from ENTSO-E data

GB is already a net importer in average winter conditions, and whilst periods of exceptionally cold weather can be highly correlated across northern Europe, as Zachary et al (2011) demonstrate, combined correlations of temperature and wind between countries in a given hour are necessarily lower and there is little reason for any correlation in conventional plant failures. Indeed the maximum output of thermal plant increases in cold weather, since the output depends on temperature differentials (so incidentally does the carrying capacity of overhead cables increase in cold conditions). Almost all peak period de-rating of GB generators is based on forced outages, where imports can, with high probability, deliver power to replace local losses. National Grid (and Ofgem) clearly recognise *in principle* that interconnectors supply extra security of supply,²⁴ so it is hard to see grounds on which their contribution should be ignored by NG when recommending the amount of capacity to procure.

A particular source of confusion arises with respect to Northern Ireland (NI), because it predominantly imports from GB, and as part of the UK, GB should be prepared to deliver power to NI when they have a stress event (just as England is assumed to be able to import from Scotland in stress events), irrespective of its own needs.²⁵ Formally, NG assumes a ‘net zero’ for GB comprised of 750 MW exports to NI offset by equivalent imports from the continent. Yet just because NI on average imports from GB does not mean that it would import at times of GB system stress – NI is integrated with the Irish grid, and to a great deal of wind capacity, with wind patterns which typically take hours to a day to sweep across Ireland and on to GB. Correlations *in stress periods* are high but well below 100%. The statistical contribution of NI to GB security is by no means -750MW, and the “net zero” approach for GB is indeed implicitly assuming very little contribution from the

²⁴ <http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=32371>; and Ofgem’s factsheets on interconnectors at <https://www.ofgem.gov.uk/ofgem-publications/87961/electricityinterconnectorsfactsheet.pdf>

²⁵ Northern Ireland is part of the SEM and as such it would defeat the purpose of that arrangement if trade with the Republic of Ireland over EWIC were treated any differently to that with Northern Ireland.

continent.²⁶ What is required is a measure of the de-rated import capacity of all the interconnectors on a basis of statistically likely availability during times of greatest GB system needs.

7.1. Existing studies on interconnector contributions

These generic arguments are backed up by more specific studies, including those commissioned by the government. The Panel of Technical Experts (DECC, 2104) noted that DECC itself had commissioned a report on interconnectors from Pöyry (2012). The report developed various scenarios using Pöyry's proprietary electricity dispatch model, Zephyr, which endeavours to simulate the hourly prices in each country and hence model interconnector flows (although one should be cautious in placing much reliability on predicted flows in any hour).²⁷ The report estimates the capacity credit that interconnectors provide in Section 4.7 by first estimating the LoLE with the interconnectors, and then determining what additional capacity would be needed to provide the same LoLE in their absence. Pöyry finds that interconnectors provide 2.3 GW of effective capacity or 62% of their nominal 3.7 GW capacity even in the worst case of tight conditions abroad (with table 1 capacities). BritNed has a 97% contribution but France has only 65%, reflecting tighter margins in France in cold periods.

Pöyry (2012, p62) also notes: "6GW of additional interconnection leads to about 3GW less firm capacity built." That suggests that the proposed interconnectors in Table 2 have a de-rated value for the Capacity Mechanism of at least 50% and so might contribute an extra 1 GW to the existing 2.3 GW net GB import capacity to give 3.3 GW by 2018. While there is some uncertainty over the commissioning date for this new capacity, Pöyry's estimates suggests that *existing* interconnectors are equivalent to 2 GW of domestic de-rated capacity, which is equivalent to 100% of the existing Continental interconnection capacity (and exporting 750MW to Ireland).

²⁶ Pöyry (note 31) notes: "Since load loss in the SEM [Ireland] and GB often coincide (or to put it another way the SEM has load loss when Britain is unable to supply it with power), the capacity credit of interconnection with Ireland is negative" although in their Fig 97 the SEM is shown contributing a positive amount of 11% of the 740MW interconnection (and higher in some other scenarios).

²⁷ "The Zephyr power model is an economic dispatch model based on optimisation of all power stations and renewables in Europe, allowing detailed investigation of the impact of wind and intermittent renewables, plant generation and profitability, wholesale market prices, emissions and interconnector usage and revenues." Pöyry (2012)

A proper capacity assessment needs to measure the de-rated import capacity just as it estimates the de-rated capacity of domestic generation. This is not so straightforward to estimate, as unlike domestic supply interconnector flows are subject to market forces not just in GB but also across the whole Continent. At present the GB System Operator (NG) does not monitor these closely enough to estimate their capacity contribution in future stress events. NG and Ofgem will need to include our neighbours' market conditions when estimating the de-rated capacity of interconnectors.

Pöyry (2013) also provided a report to Ofgem in which it concluded that "GB low capacity margins (below 20%) show a medium level of correlation with low capacity margins in Ireland and France. On the other hand, *very low capacity margins (below 10%) in GB do not show a definite correlation with any of the other systems.*" (emphasis added.) This again cautions against using past average interconnector correlations as a guide to importing in GB stress events (i.e. very low capacity margins) where the underlying (and low) stress hour correlations apply.

Redpoint (2013, p9) was asked by DECC to look at the effect of additional interconnection and concluded that "greater levels of interconnection are generally associated with better security of supply. Although both low wind and high demand conditions can be correlated across markets, forced plant outages are generally uncorrelated and hence in times of extreme system stress in GB, most interconnectors are likely to be supplying energy to GB at near full capacity." Redpoint carried out two stress tests, representing a different combination of events that might challenge security of supply:

1. Combination of low wind output, plant outages and high demand due to cold weather that challenge the ability of the system to supply all firm demand and maintain voltage on the grid.
2. Large and rapid changes in wind power output and demand combined with line outages that challenge the ability of the network to respond.

These tests represent extreme but realistic internally consistent sets of events, crucially also taking account of correlations with stress events in countries to which GB would be connected.

Stress test 1 showed unserved energy generally decreasing with the level of GB interconnection. Hence, at times of high stress in GB, interconnectors can be expected to flow electricity to GB and contribute significantly to a reduction in unserved energy. Stress test 2 showed the overall levels of unserved energy are

lower, as expected given that half of the period is characterised by average or above average wind conditions.

Redpoint also found the majority of interconnectors flowing to GB at times of extreme stress, except for France, with an import utilisation below 100%. Redpoint suggested two possible reasons: France (along with Ireland) has the highest correlation of system stress with GB, and has the most interconnection with GB. Full French exports when GB experiences stress are thus more likely to stress the French system.

France already evaluates availability from neighbouring states (see the appendices of RTE, various dates). These reports are similar to Pöyry (2012) in modelling demand and supply in France, Spain, Italy, Switzerland, Austria, Germany, the Netherlands, Belgium, Luxembourg and GB, and it would seem sensible for NG to cooperate with RTE in updating the next report (which RTE needs to do annually) and sharing access to the modelling and data.

8. The cost of regret

National Grid’s capacity report adopts a Least Worst Regret (LWR) approach (which they term Robust Optimization) to recommending a level of capacity, illustrated in Figure 3.

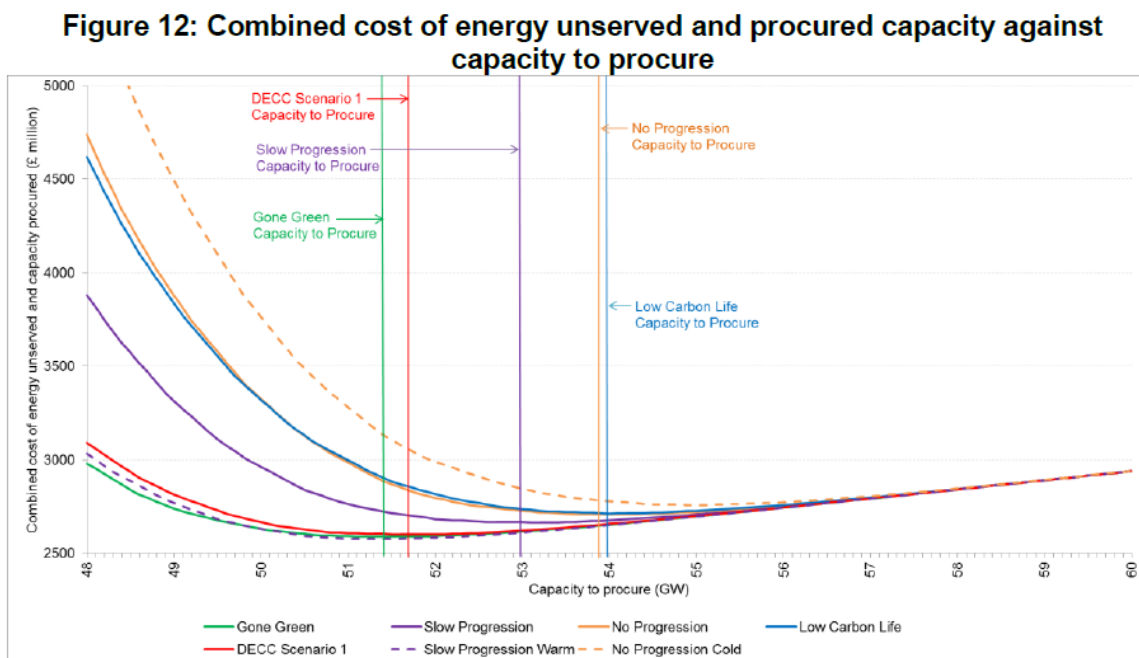


Figure 3 Choosing the level of capacity

Source: National Grid (2014, p50)

As the amount of capacity falls below the desired level (which delivers a LoLE of 3 hours) so the LoLE increases, with “energy unserved” costed at the VoLL of £17,000/MWh.²⁸ This explains why the curves in Figure 4 rise increasingly sharply to the left of the minimum point. There is some danger in assuming that the lights go out below this minimum but actually the costs initially rise slowly, even with the inappropriately high VoLL of £17/kWh. The 53.3GW recommended and chosen is at the flat part of the most pessimistic ‘no progression’ scenario.

However, the cost of falling short of the desired level of capacity is greatly exaggerated by costing shortfalls at £17/kWh, for multiple reasons. First, section 3 noted various actions to ‘keep the lights on’ when demand risks exceeding supply under normal operating conditions. These include a combination of demand-side resources (DSR, beyond those contracted in a Capacity Mechanism), and latent capacity of various types which can be invoked through the so-called ‘emergency actions’, to be valued (after 2016) at *up to* £6,000/MWh – well short of the £17,000/MWh underpinning Figure 3.²⁹ At these substantially lower costs, the curves will not rise as soon or as much for capacities below that chosen, and the minimum cost will be at a lower level of capacity.

Second, the calculations ignore interconnectors, as argued. Finally, it should be possible to increase the volume of cheaper demand-side resources and ‘latent capacity’ in less than four years, in which case it would be sensible to defer some of the possible future required capacity until we have more information about future demands and supply conditions.

9. Implications

9.1 Option values and the proper treatment of uncertainty

Agencies making capacity assessments worry about uncertainty, meaning circumstances in which there is no good objective evidence on the probabilities of various events. This paper has argued that while some of the claimed uncertainties should be treated as risks (which can be assigned probabilities), there will inevitably remain some genuine uncertainties, which loom larger the further ahead one looks.

²⁸ National Grid (2014, p98, point 4)

²⁹ As discussed in Ofgem (2013), Box 1 (p.20), the £6,000 /MWh was the upper range of estimates of the ‘Value of Lost Load’ from industrial customers in the survey by London Economics (2013). It is also above the level of price caps in most neighbouring systems, so that prices at this level should attract flows through coupled interconnectors.

The reason the auction is held four years ahead of delivery (i.e. T-4) is to give time to plan for, build and commission a CCGT. If a delay of one or more years would reduce the level of uncertainty about the 2018/19 capacity requirement, and if it were cheap to delay that decision, then such a delay is likely to be valuable and hence cost-effective.

The UK rules allow for some procurement to be deferred from the T-4 auction to later, notably T-1. Thus, the amount proposed for auction in 2014 for 2018-19 delivery, is $53.3-w-x-y-z-0.4$ GW, where the values for w , x , y and z refer to various distributed energy resources and opt-out plant and the 0.4 GW is the already secured STOR (short-term operating reserve); together these correspond broadly to identified DSR and latent capacity. We note with some surprise that although the Government appears committed to allowing interconnectors to contribute capacity at some future date, the proposed formula does not appear to leave any space in the December 2014 auction for that contribution, and hence risks over-procuring early and leaving cheap later options on the table. The discussion above suggests that these various UK options are more extensive than currently provided for in the auction.

This underlines the importance of seeing the Capacity Mechanism in a dynamic context. If part of the argument for the 'net zero' interconnector assumption was to offset uncertainty about future demand, that uncertainty will be considerably reduced in two years. It also remains to be seen how much of the potential 'latent capacity' might be secured by the New Balancing Mechanism; this in itself will deliver useful information, which increases the value of not committing to too much new capacity in the first auction. The same is true in agreeing how foreign capacity can secure access through the interconnectors under the European auction platform Euphemia (see Mastropietro et al, 2014).³⁰

Another option could include forward contracting for the option to reconnect mothballed plant. In addition, quick-to-build new gas plants can be constructed in two years,³¹ providing sites are secured with planning permission and connection agreements. If such preparatory agreements can be procured cheaply ahead of time (and NG as System Operator would know where best flexible peaking plant would

³⁰ As at the time of writing, Euphemia has not specified the full details of price caps in the intra-day and balancing markets, but one solution would be that interconnector capacity is allocated in proportion to capacity secured under capacity mechanisms by each country rather than total demand.

³¹ Teesside CCGT, then the largest in Europe at 1,870 MW, took 29 months to build (see http://en.wikipedia.org/wiki/Teesside_power_station)

be most valuable), then it would be prudent to under-procure in the T-4 auction, and then decide at T-2 whether more plant were needed in the light of better information.

The same holds for old coal stations that may be unprofitable without a capacity payment, given the carbon price floor the UK has introduced. If they could be assured that they would secure a (re-)connection agreement at a defined price if and when they secure a capacity contract, then they could bid into that auction with less risk. The alternative of securing a capacity agreement with its obligation to deliver without the assurance of a future (re-)connection agreement would increase the risks to finance from merchant sources.

Ofgem is working to remove any regulatory obstacles that may delay financing and commissioning new interconnectors. The information available in two years would include the results of the studies on interconnector contributions that NG should be required to undertake. It would surely be not too difficult to include interconnectors into a T-2 auction as that gives two years to prepare for such inclusion.

9.2 Interconnectors

A full analysis of the contribution that interconnectors can make to security is complex, as the various studies commissioned from Pöyry and Redpoint demonstrate, but that is true of any combinatorial stochastic modelling and not in itself a reason for ignoring it. Ofgem's recent *Capacity Assessment* underlines the large difference that a positive contribution from interconnectors can make. The problem with assuming zero net flows when deciding on the amount of capacity to procure is not that it is an approximation, but that it is an inappropriate one.

Given that NG seems unwilling to rely on these consultant reports and does not appear to have the requisite modelling information at the time it produced its recommendations for the 2014 capacity auction, the question is what approximations would be most appropriate on interconnector contribution. Ireland already includes the interconnectors in its capacity assessments, and relies on being able to import in its stress events, which, when caused by demand, are highly correlated with high demand in GB. The impact of wind correlations remains to be fully understood, and stress events caused by plant failures are uncorrelated, so interconnectors do provide some contribution to each country separately. It would be reasonable to assume that the SEM may be importing at maximum rates in peak periods, but not in all GB stress events.

This paper has presented extensive and diverse evidence why Continental interconnectors make a positive contribution. Both the observed scale of winter imports through coupled interconnectors, and the results of such modelling analysis has have been done (notably the Pöyry reports) point to interconnector contributions typically above 60% of the rated capacity, with BritNed much higher. So if a single deterministic value is used, a plausible conservative approximation would take the de-rated capacity of the remaining 3-6 GW (depending on the year) as 50% (i.e. 1.5-3 GW with a best guess as 2 GW), as below the most pessimistic Pöyry (2012) estimate, but allowing for more frequent stress events in France with its more rapidly growing peak demand. If different scenarios are considered, as variants to the current default of zero, a more representative alternate could be substantially higher, for example the 75% contribution considered in the alternate scenario for Ofgem's Transmit consultation,³² which lies in the range of the Pöyry estimates.

9.3 Present decisions and future actions

Following the announced decision to procure 53.3GW for delivery in 2018-19, the Government needs to decide how much should be auctioned in four year contracts, and how much set aside for subsequent, shorter-term auctions. The paper highlighted various options for procuring additional 'latent capacity' (over and above the $w+x+y+z$ already allowed for) on relatively short (1 – 2) year timescales. These factors, together with the likely contribution of interconnectors, suggest a strong case to defer more of the auction volume than is currently proposed (or, equivalently, revisiting and expanding the definition of the $w+x+y+z$ contribution). Obviously, these correction values need to be announced before the auction in December 2014.

In addition to these making judgements for the immediate auction, Britain needs better analyses for the future. This might usefully involve commissioning some deeper mathematical and statistical research (e.g. drawing on the work of Zachary et al, 2011, preferably in collaboration with others abroad, through DG ENER, ENTSO-E or ACER), estimating the contributions interconnectors make to reliability in each price zone. GB could also do more to open options for delivering faster additional capacity in a timely way.

³² <https://www.ofgem.gov.uk/publications-and-updates/project-transmit-further-consultation-proposals-change-electricity-transmission-charging-methodology>

It would also be healthy for GB to carefully consider the advantages of an independent modelling capability for reliability and capacity adequacy studies, that is removed from any suspicion of conflict of interest with the role of Transmission System Owners - whose reputation would obviously be damaged by any power shortage, but who expect to pass the cost of almost any degree of avoidance measures through to final consumers.

10 Conclusions

Policy makers and system operators fear black-outs and do not have to pay for avoiding them, so they will almost inevitably err on the side of over-procurement. Consumers are unlikely to appreciate the fine details of capacity assessments, and probably do not yet appreciate the potentially high cost of over-procurement, particularly as this is delayed for four years. That said, the Government may be hard pressed to explain why an annual payment of £2+ billion, mainly to existing conventional power plants, and levied on consumer bills, would really lead to possibly (but uncertain) lower prices in 2018 compared to a hypothetical counterfactual.

This paper argues that the development of the UK Capacity Mechanism has concentrated on the technical design of the market, but overlooked the essential political economy of setting the levels. However well the Capacity Mechanism itself has been designed, the current proposals risk paying the incumbent energy industries for more capacity, at higher unit cost, than is necessary. This derives from three key factors: the setting of the reliability standard (LoLE) and the corresponding 'value of lost load'; the associated terminological confusion (since neither term actually refers to losing load by involuntary disconnections) combined with a broadening scope for 'mitigation measures' that distance such events from actual disconnection; and the proposition that security equates to self-sufficiency, reflected in the 'net zero' assumption of interconnector contributions. While reflecting naturally risk-averse political decision-making, it is not in the consumer interest and also has other costs.

This paper has argued that it is vital to improve the methodologies employed to determine the capacity to procure, if necessary commissioning additional research and data collection. In particular, a fuller appraisal of the potential contributions from demand-side response, latent capacity, and interconnectors are needed, and information about their supply will emerge with the tightening supply situation in 2016. Holding open the option of later procurement therefore has high value and low cost. The appropriate authorities – potentially Ofgem - could facilitate cheap

options that would lessen the pressure to be over-cautious in aiming to procure almost all estimated capacity needs at the T-4 auction in 2014.

Finally, there are important governance issues to consider. The initial hope of electricity liberalisation was that competitive markets would create incentives for adequate capacity, but the original capacity payments were scrapped in 2001 in the New Electricity Trading Arrangements. Diverse assessments led Government and others to the view that political and regulatory risks have shaken confidence that GB's energy-only market would deliver adequate capacity, and that a Capacity Mechanism is needed. At issue in our paper is neither the proposal for, nor the design of, that mechanism. It is rather the underlying fact that, as consumers do not directly buy capacity (which in current market designs is a pooled public good), an authority has to set the required level. This naturally attracts criticism about the politics of public decision-making on what are technically highly complex issues, in which the current arrangement in which the System Operator advises the Government seems likely to lead to overly cautious (and costly) choices. That suggests the need for a technically competent but independent institutional structure to help set the volumes to procure in the Capacity Auctions, perhaps an ISO, as suggested by Strbac et al (2013).

References

- Adib, P., Schubert, E., and Oren, S. (2008). "Chapter 9: Resource Adequacy: Alternate Perspectives and Divergent Paths." In F. P. Sioshansi (Ed.), *Competitive Electricity Markets: Design, Implementation, Performance*. Oxford: Elsevier. <http://dx.doi.org/10.1016/B978-008047172-3.50013-1> .
- Battle, C., Vazquez, C., Rivier, M., and Perez-Arriaga, I.J. (2007). "Enhancing Power Supply Adequacy in Spain: Migrating from Capacity Payments to Reliability Options." *Energy Policy* 35(9): 4545–4554. <http://dx.doi.org/10.1016/j.enpol.2007.04.002> .
- Battle C. and P. Rodilla (2010), "A critical assessment of the different approaches aimed to secure electricity generation supply", *Energy Policy* 38, 7169-7179. doi: 10.1016/j.enpol.2010.07.039.
- Bowring, J. (2008). "The evolution on PJM's capacity market", ch 10 in Sioshansi, F.P. (ed) *Competitive Electricity Markets: Design, Implementation, Performance*. Elsevier
- Bowring, J. (2013). "Capacity Markets in PJM," *Economics of Energy and Environmental Policy*, 2(2). 47-64.
- Cepeda, M. and D. Finon (2011) "Generation capacity adequacy in interdependent electricity markets" *Energy Policy*, 39 (6), pp.3128-3142. doi: 10.1016/j.enpol.2011.02.063
- Chao, H.P. and R. Wilson (1987). "Priority Service: Pricing, Investment and Market Organization." *American Economic Review*, 77(5): 89–116.
- Chao, H.P. and R. Wilson (2002). "Multi-Dimensional Procurement Auctions for Power Reserves: Robust Incentive-Compatible Scoring and Settlement Rules." *Journal of Regulatory Economics*, 22(2): 161–183. <http://dx.doi.org/10.1023/A:1020535511537>
- Cramton, P. and A. Ockenfels (2011). "Economics and Design of Capacity Markets for the Power Sector." At <http://www.cramton.umd.edu/papers2010-2014/cramton-ockenfels-economics-and-design-of-capacity-markets.pdf> (published in 2012 in *Zeitschrift für Energiewirtschaft*, 36(2): 113–134).
- Cramton, P., A. Ockenfels, and S. Stoft (2013). "Capacity Market Fundamentals." *Economics of Energy and Environmental Policy*, 2(2). 27-46.
- Cramton, P. und S. Stoft (2008). "Forward Reliability Markets: Less Risk, Less Market Power, More Efficiency." *Utilities Policy*, 16(3): 194–201. <http://dx.doi.org/10.1016/j.jup.2008.01.007>
- DECC (2013a). *Electricity Market Reform: Capacity Market – Detailed Design Proposals*, June, at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209280/15398_TSO_Cm_8637_DECC_Electricity_Market_Reform_web_optimised.pdf
- DECC (2013b). *Impact Assessment October 2013* at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/252743/Capacity_Market_Impact_Assessment_Oct_2013.pdf
- DECC (2014). *EMR Panel of Technical Experts' Final Report on National Grid's Electricity Capacity Report* at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/252743/Capacity_Market_Impact_Assessment_Oct_2013.pdf
- Eirgrid/SONI (2014). *All-Island Generation Capacity Statement 2014-2023* at <http://www.eirgrid.com/media/Generation%20Capacity%20Statement%202014.pdf>
- Joskow, P.L. (2008). "Capacity Payments in Imperfect Electricity Markets: Need and Design," *Utilities Policy*, 16(3): 159-70. <http://dx.doi.org/10.1016/j.jup.2007.10.003> .

- Joskow, P. (2013). "Symposium on 'Capacity Markets'." *Economics of Energy and Environmental Policy*, 2(2). v-vi.
- Joskow, P.L. and J. Tirole (2007). "Reliability and Competitive Electricity Markets," *Rand Journal of Economics*, 38(1): 68-84. <http://dx.doi.org/10.1111/j.1756-2171.2007.tb00044.x>.
- Leahy, E. and R. Tol (2011). "An Estimate of the Value of Lost Load for Ireland" *Energy Policy* 39(3), 1514–1520
- London Economics (2013). *The Value of Lost Load (VoLL) for Electricity in Great Britain, Final report for OFGEM and DECC*
at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224028/value_lost_load_electricity_gb.pdf
- Mastropietro, P., P. Rodilla and C. Batlle (2014). "National Capacity Mechanisms In The European Internal Energy Market: Opening The Doors To Neighbours", IIT Working Paper, April at <http://www.iit.upcomillas.es/batlle/Publications.html>
- National Grid (2014). *Electricity Capacity Report*,
at <http://www2.nationalgrid.com/UK/Our%20company/Electricity/Market%20Reform/Announcements/June%202014%20Auction%20Guidelines%20publication/>
- Newbery, D.M. (2005). "Electricity liberalisation in Britain: the quest for a satisfactory wholesale market design", *Energy Journal, Special Issue on European Electricity Liberalisation*, ed. D Newbery, 43-70 <http://www.iaee.org/en/publications/speciali.aspx>
- Newbery, D.M. (2012). 'Reforming Competitive Electricity Markets to Meet Environmental Targets' *Economics of Energy & Environmental Policy*, 1(1), pp 69-82
- Newbery, D.M., G. Strbac, D. Pudjianto, P. Noël, Booz & Co. and LeighFisher (2013). *Benefits Of An Integrated European Energy Market Final report for DG ENER*, July
at http://ec.europa.eu/energy/infrastructure/studies/doc/20130902_energy_integration_benefits.pdf
- Ofgem (2013). Electricity Balancing Significant Code Review - Draft Policy Decision, at <https://www.ofgem.gov.uk/ofgem-publications/82294/ebscrdraftdecision.pdf>
- Ofgem (2014). *Electricity Capacity Assessment Report 2014*
at <https://www.ofgem.gov.uk/ofgem-publications/88523/electricitycapacityassessment2014-fullreportfinalforpublication.pdf>
- O'Neill, R., U. Helman, B. F. Hobbs and R. Baldick (2006). "Independent System Operators in the USA: History, Lessons Learned and Prospects" in F.P. Sioshansi and W. Pfaffenberger (eds.) *Electricity Market Reform: An International Perspective*, Amsterdam: Elsevier, ISBN13 978-0-08045-030-8
- Platchkov, L., M. Pollitt and I. Shaorshadze, (2011). "The implications of recent UK energy policy for the consumer: A report for the Consumers' Association",
at <http://www.eprg.group.cam.ac.uk/tag/l-platchkov/>
- Pollitt, M., Brophy Haney, A., 2013. Dismantling a competitive electricity sector: The UK's electricity market reform. *The Electricity Journal*, 26 (10) 8–15.
- Pöyry (2012). *IMPACT OF EMR ON INTERCONNECTION: A report to Department of Energy and Climate Change* 3 Dec 2012,
at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/252744/Poyry_Report_on_Impact_of_CM_on_Interconnection.pdf
- Pöyry (2013). *Analysis of the Correlation of Stress Periods in the Electricity Markets in GB and its Interconnected Systems: A report to Ofgem*, March 2013

- at <https://www.ofgem.gov.uk/ofgem-publications/75231/poyry-analysis-correlation-tight-periods-electricity-markets-gb-and-its-interconnected-systems.pdf>
- Redpoint (2013). *Impacts of further electricity interconnection on Great Britain*
at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/266307/DECC_Impacts_of_further_electricity_interconnection_for_GB_Redpoint_Report_Final.pdf
- RTE (various dates). *Generation adequacy reports* at <http://www.rte-france.com/en/mediatheque/documents/operational-data-16-en/annual-publications-98-en/generation-adequacy-reports-100-en>
- Spees, K., S. A. Newell, and J. Pfeifenberger (2013). "Capacity Markets—Lessons Learned from the First Decade." *Economics of Energy and Environmental Policy*, 2(2). 1-26.
- Strbac, G, R. Green, C.V. Konstantinidis, I. Konstantelos, R. Moreno, D.M. Newbery and M. Pollitt, (2013) "Electricity Transmission Arrangements in Great Britain: Time for Change?" *Energy Policy*, forthcoming
- De Vries L.J. (2007). "Generation adequacy: helping the market to do its job", *Utilities Policy* 15, 20-35. Doi:10.1016/j.jup/2006.08.001
- Zachary, S. C.J. Dent and D.J. Brashaw (2011). "Challenges in quantifying wind generation's contribution to securing peak demand," at the 2011 Power and Energy Society General Meeting, IEEE available
at http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6039572&tag=1