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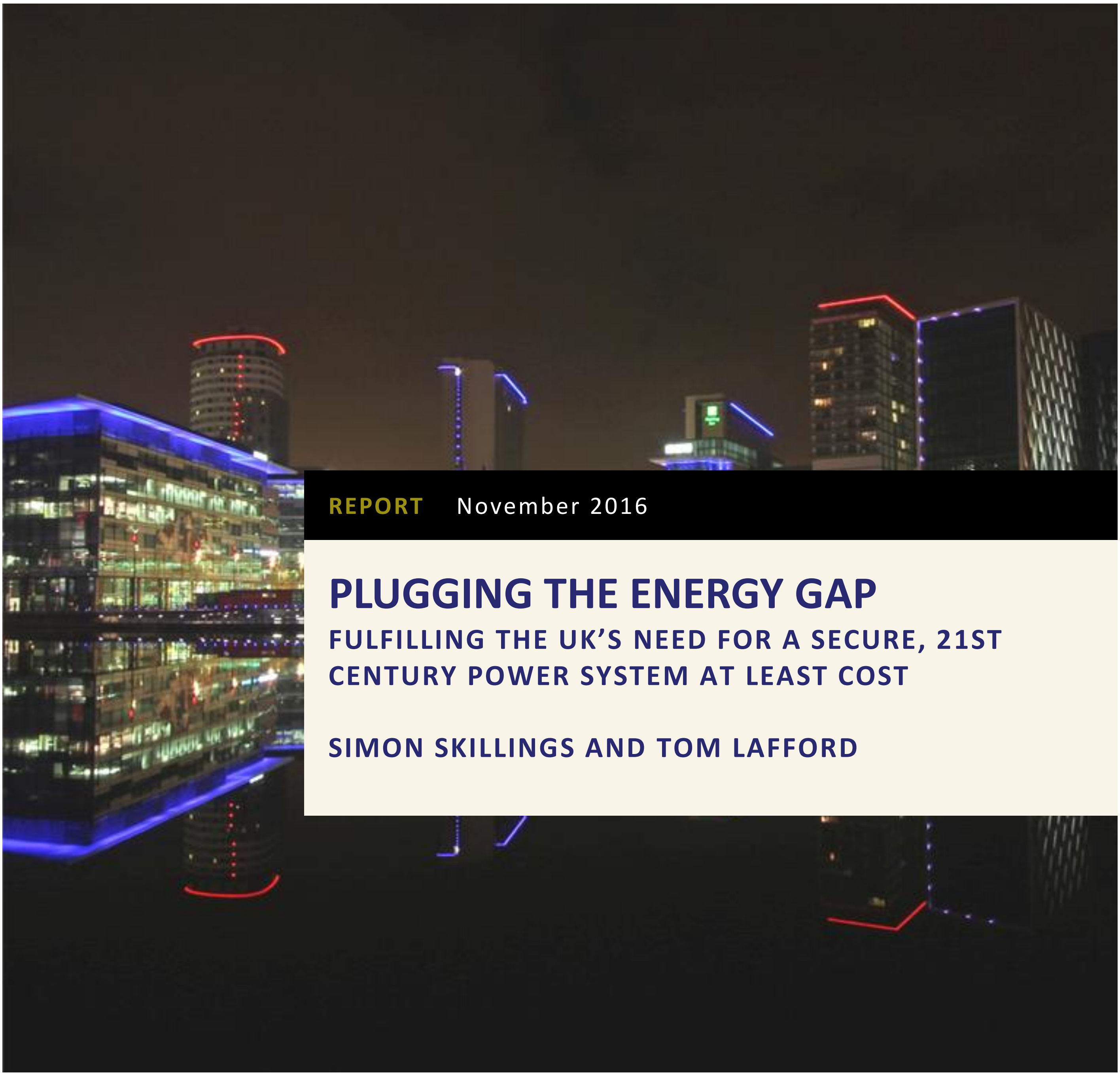

REPORT November 2016

PLUGGING THE ENERGY GAP

FULFILLING THE UK'S NEED FOR A SECURE, 21ST CENTURY POWER SYSTEM AT LEAST COST

SIMON SKILLINGS AND TOM LAFFORD

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About E3G
E3G is an independent organisation working in the public interest to accelerate the transition to a low-carbon economy. E3G specializes in climate diplomacy, climate risk, energy policy, governance and climate finance. We work closely with like-minded partners in government, politics, civil society, science, the media, public interest foundations and elsewhere. E3G is a European organisation with a global outlook and reach. We currently have offices in London, Brussels, Berlin and Washington DC, together with a regular presence in China.
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EXECUTIVE SUMMARY

The Government recently adopted the 5th Carbon Budget and now needs to deliver it as cheaply as possible. This will require the construction of new low carbon generation capacity capable of producing over 150TWh of electricity each year by 2030 – around half of all current output. All plausible scenarios imply that this can only be achieved by deploying a significantly increased volume of renewable generation – likely to be around 50GW, predominantly from a combination of onshore and offshore wind and solar PV.

In November 2015 the previous Secretary of State for Energy and Climate Change expressed concerns that variable renewable generation creates 'hidden' costs for the system and that the power system needs 'baseload' power to operate. Imperial College has undertaken a study which sheds new light on the issue of system integration costs of renewable generation[1]. This adds to an increasing body of evidence that the system integration costs of renewable generation are low and that the power system can operate securely and at least cost with more than 50% of electricity demand being met from variable renewable sources.

System integration costs are predicted to remain less than £10/MWh for a wide range of system characteristics at these increased levels of penetration. This means that it is not only possible to securely operate the power system with high levels of renewable generation, it represents a cheaper option than employing any alternative generation solution.

This study shows that under the current trajectory onshore wind will be at least 22% cheaper than nuclear with offshore wind and solar PV providing savings in excess of 4% and 8% respectively. Actual savings are likely to be even greater as system flexibility improves[2].

The important conclusion from this study is, therefore, that **the cheapest way to decarbonise the power system involves large volumes of variable renewable generation even when taking system integration costs into account**. The Government can proceed with investment in renewable generation without risking unnecessary escalations in system costs and a burden on consumers.

[1] Imperial College London (2016) Whole-system cost of variable renewables in future GB electricity system

[2] Very conservative estimates were used in the modelling for the costs of the renewable technologies whilst we also consider that most of these costs are already, at least partially, accounted for in the cost of generation.

The requirement to transform the electricity system so that it is clean, efficient, flexible, and fit for the 21st century is an opportunity rather than a challenge. The economic dividend goes beyond the direct benefits of reducing a core input cost to the economy and minimising consumer bills. With a clear energy policy there will also be significant investment in supply chain capacity and infrastructure across the UK regions, capitalising on an already strong and diverse sector and contributing to a sustainable, cost-effective industrial strategy. In addition, the UK has the opportunity to become a key player in worldwide markets for the new technologies that underpin modern power systems.

However, these benefits will not arise unless the Government takes action:

- The Government plan to deliver carbon budgets should maximise the advantages for consumers and the economy. It can do so by providing a clear trajectory for deployment of low-carbon generation that is consistent with delivering long term carbon budgets at least cost.
- The Autumn Statement should set out a commitment to developing a new design for the Levy Control Framework in line with the deployment trajectory and announce a timetable for established and less-established technology auctions to commence as soon as possible.
- Ongoing market reform will be essential to support delivery of this plan. The Government should mandate Ofgem to ensure the regulatory regime and market mechanisms create a coherent system that is sufficiently flexible to support cost-effective delivery of the necessary volumes of low carbon generation.

INTRODUCTION

With the carbon budget for 2030 approved, Government now needs a credible plan to deliver it as cheaply as possible.

On the 20th July the 5th Carbon Budget was approved, committing the Government to 57% emissions reductions by 2032. This was in part recognition of the Paris Climate Change Agreement reached at the end of 2015 which demonstrated the increasing alignment amongst countries on the need to act to reduce carbon emissions and the considerable progress that is already being made. The UK now has the opportunity to create a clean, efficient, 21st century energy system which can not only improve the quality of people's lives, but also drive the economy through investment in cutting edge low-carbon technologies that are rapidly becoming the heart of modern energy systems around the world.

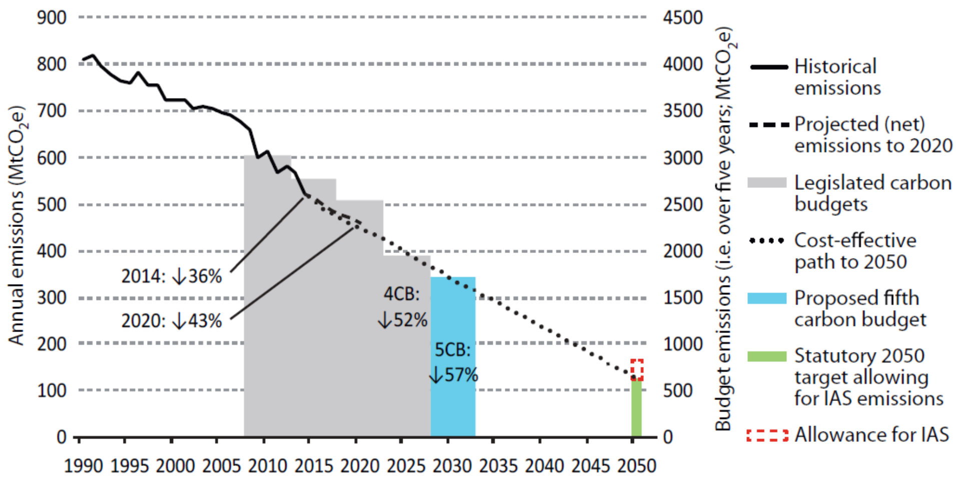

Figure 1. Fifth Carbon Budget emissions reduction pathway[3]

The challenge for Government is to make sure it has a credible plan in place to decarbonise the energy system. Critically, this plan must be deliverable, maintain security of supply and avoid an unnecessary escalation in energy bills – there are some big decisions that need to be taken over the coming months.

The decarbonisation of electricity generation remains a top priority. There are still significant emissions arising from this sector and dramatic reductions can be delivered through proven, deployable technologies. The Committee on Climate Change has recommended a maximum target for the carbon intensity

[3] Committee on Climate Change (2015) **The Fifth Carbon Budget**

of electricity generation of 100g/kWh by 2030 with the recognition that faster progress is desirable[4]. This can only be achieved through the deployment of a significant capacity of low carbon technologies that will generate the electricity that is required[5].

Imperial College has undertaken a study which explores the cost implications of significantly increasing levels of variable renewable generation. The chart below illustrates the extent of the 'low carbon generation gap' that must be filled over the coming decade if a power system carbon intensity of 100g/kWh or below is to be achieved by 2030. This implies that over 100TWh will need to be produced from new low carbon sources by 2030 which represents a major deployment challenge – this is similar to the current low carbon production output and around a third of our current annual demand.

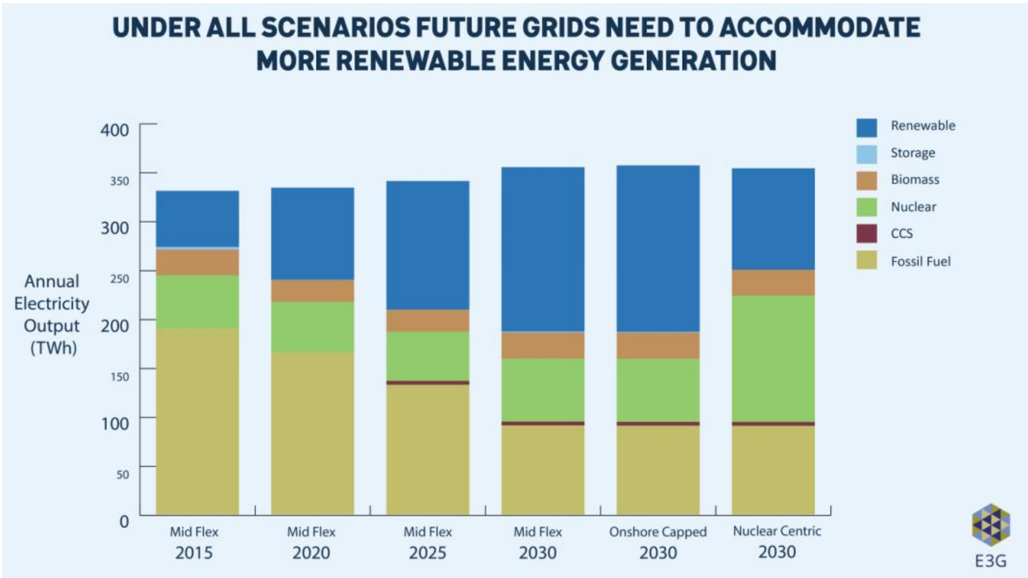

Figure 2. Imperial College London, the future power generation mix under three core scenarios in 2030, and Mid Flexibility scenario in 2015, 2020 and 2025

The previous coalition government undertook an extensive process of market reform to enable least cost investment in low carbon electricity, and the new arrangements were introduced in 2014[6]. The logic of these reforms has not changed, but, unfortunately, current Government policy is failing to take advantage of the new market arrangements to deliver the low carbon electricity that is required. The table below compares a central view of the

[4] The Paris climate agreement is based around the concept of a 'ratchet' in which ambition is progressively increased as new opportunities emerge.

[5] Whilst it is not the subject of this report, investment in permanent electricity demand reduction through energy efficiency is also an essential component of lowest-cost emissions reduction.

[6] The EMR process introduced a CfD, capacity mechanism, emissions performance standards and a carbon floor price.

future, based on an assessment of technology deliverability[7], with two extreme sensitivities for the generation capacity mix in 2030, each of which could be consistent with delivering the target carbon intensity of 100g/kWh, the maximum carbon intensity recommended by the Committee of Climate Change for the power sector in their 5th carbon budget.

Technology (GW)	Current (2015)	Central view	Onshore capped	Nuclear centric
Nuclear	9.4	8.2	8.2	16.4
Gas CCGT	29.3	16	16	16
Coal	18.7	0	0	0
Gas CCS	0	0.5	0.5	0.5
Onshore	9	20	8	12.5
Offshore	5.1	31	39	21
Solar	8.8	20	20	20
Biomass	4	3.4	3.4	3.4
Hydro	1.5	1.5	1.5	1.5
Pumped Storage	2.8	3.7	3.7	3.7

Two key features of the current policy framework are the ‘freeze’ in the development of onshore wind and continued support for new nuclear generation. The sensitivities in the table represent extreme characterisations of these policies in which no further onshore wind is developed (onshore capped) and where nuclear deployment is accelerated to levels which are well beyond current expectations (nuclear centric). In a scenario with onshore wind capped at current levels, and new nuclear deployed at more realistic levels during the 2020’s, increased offshore wind would be required in volumes far beyond the currently stated Government ambition[8], inevitably increasing overall system costs. Even with a dramatically accelerated nuclear program, if it were feasible, significant additional investment in renewable generation capacity would still be required.

The analysis represented in the table above provides strong evidence that renewable generation will form an increasing share of the power market under all credible scenarios. There is an evident policy gap. With the deployment constraints associated with all low-carbon generation and cost risks associated with other low carbon technologies, the Government should want to maintain the option to significantly increase volumes of renewables beyond the central

[7] See section 3.2 of the Imperial College report for an explanation of the assumptions behind the numbers in this table.

[8] A Secretary of State for Energy and Climate Change Amber Rudd (2015) **New Direction for UK Energy Policy (“energy policy reset”)**

view presented above. It is important to recognise that meeting carbon targets at least cost hinges on a relaxation of the current freeze on mature renewables, especially onshore wind development[9], in conjunction with a scaling up of ambition for the deployment of offshore wind.

Numerous stakeholders, such as Citizens Advice[10] and Policy Exchange[11], have found that the freeze on onshore wind development will lead to a large increase in costs to consumers, a conclusion that is echoed in the concerns expressed by the Competition and Markets Authority[12] and the National Audit Office[13] in recent reports.

However, concerns have also been raised that there might be a significant 'hidden' cost penalty associated with the deployment of variable renewable generation, including onshore wind, arising from the variability of the power produced and that the auctions introduced by the recent market reform process [14] will therefore not necessarily identify least cost outcomes. Moreover, it has been argued that the power system cannot operate without new 'baseload' generation to manage the unreliable nature of variable renewables. This report shows that, in the build up to 2030, these concerns are unfounded.

The 'system integration costs' discussion is complex, not least because these costs are an emerging property of the inevitable transformation to a modern, low carbon energy system. It is, therefore, important to understand these costs and the extent to which any restriction on the deployment of renewable generation can be justified.

The Imperial College study sheds new light on the issue of system integration costs of renewable generation by addressing the question: how significant are the system integration costs of variable renewable resources and what are the key factors that affect them? This report summarises the key conclusions from this analysis and sets out the policy recommendations that follow from the results.

[9] At the very least there will be a need to replace onshore wind generation that is expected to retire before 2030.

[10]Citizens Advice (2016) **Generating Value? A consumer friendly electricity generation policy**

[11] Policy Exchange (2015) **Powering up the future of onshore wind in the UK**

[12] Competition and Markets Authority, (2016) **Energy market investigation, Final report**

[13] National Audit Office, (2016) **Nuclear Power in the UK**

[14] These auctions are used to allocate revenue stabilisation contracts (CfDs) which help ensure projects can be financed cost-effectively.

UNDERSTANDING SYSTEM COSTS

The Government can proceed with full confidence that a significant growth in renewable generation will be the lowest cost approach.

A key aspect of energy policy is to ensure that security and decarbonisation objectives are achieved as cheaply as possible. The direct costs associated with the various low carbon generation technologies – often referred to as the lifetime cost of electricity (LCOE) - will differ but, in general, they are expected to fall with larger and more predictable deployment levels. These cost reductions can be significant as has already been demonstrated by a range of renewable generation technologies and this trend is expected to continue (see Figure 3). Additionally the introduction of competitive auctions around the world have been effective in driving cost discovery and even those technologies which are considered to be mature, such as onshore wind, have demonstrated a significant reduction in costs (13% to 50%) a year after the introduction of competition[15].

Serious concerns were raised by the Competition and Markets Authority around the cost effectiveness of non-competitive allocation processes. The evidence suggests that effective competition would need to be introduced for nuclear and CCS projects if these technologies are to deliver similar cost reductions in future.

The Imperial College study has adopted technology costs that are based primarily on the UK Government Updated Energy Projections produced in 2013. More recent data suggests that these numbers are very conservative and, therefore, the costs of renewable generation could actually be much lower (see Figure 3).

[15] Bloomberg New Energy Finance (2016) **New Energy Outlook**

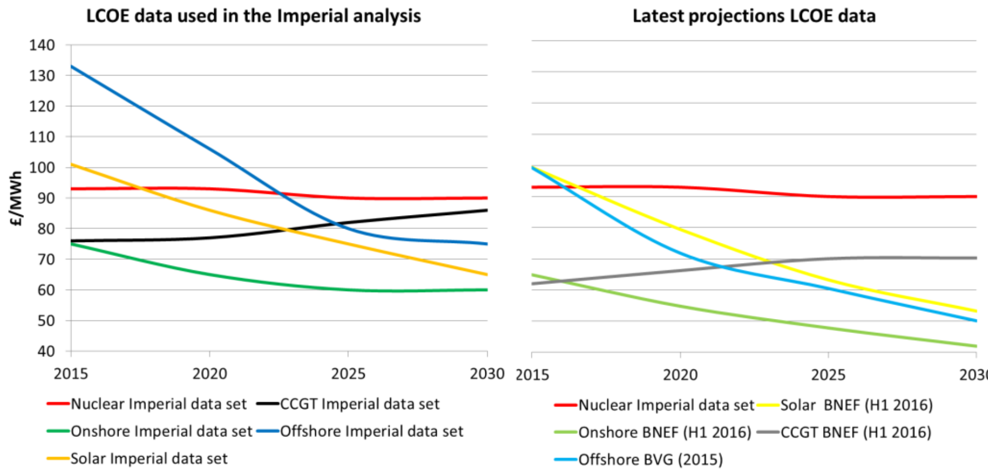

Figure 3. Data used in imperial college report based on DECC 2013 Generation cost report compared with more recent data from Bloomberg New Energy Finance[16] and BVG[17]

Minimising these direct technology costs is, therefore, a critical aspect of energy policy. Whilst the UK has introduced an effective competitive auction market structure, it has failed to develop a clear and transparent strategy for how it will use these auctions to deliver policy objectives. In particular, a steady and predictable deployment pathway is necessary to enable efficient supply chains to establish and to provide the necessary confidence for investors to develop new project opportunities (which will require significant sums of capital to be invested with no guarantee of a return).

At present, there is neither the forward visibility of a low carbon generation deployment pathway that is consistent with 2030 policy targets, nor the commitment to a program of auctions necessary to deliver the required deployment. This policy gap should be addressed.

Whilst the direct costs of renewable generation continue to fall, concerns remain that they create high costs for the systems as a whole. All technologies create a number of system costs and benefits. Fossil fuel generators have environmental and social impacts for which they do not have to bear the costs whilst variable renewable and inflexible nuclear generation increase the costs of maintaining stable and secure operation of an integrated power system.

System integration costs of renewable generation arise for a number of reasons and will change over time and with the properties of the energy system. Additional 'back-up' capacity is required to ensure security of supply when renewable generation output is low. Also, the variability of renewables

[16] Bloomberg New Energy Finance(2016) Levelised Cost Of Energy Forecasts (£/MWh) 2016 - 2045, H1

[17] BVG Associates (2015) **Offshore Wind: Delivering More for Less**

implies that additional resources might be required to balance supply and demand in real time (although this will also be determined by other factors such as the largest credible single loss of generation – typically large nuclear power stations). Other costs will also be incurred from new power network infrastructure, such as reinforcements to the transmission system required to connect remote wind resources.

Unless the power system is sufficiently flexible to efficiently utilise all the potential output of both variable and inflexible generation, some potential output will be curtailed and more low carbon generation capacity will be needed to achieve target reductions in carbon intensity. This issue is the most significant factor when considering the system integration of variable renewables beyond 50% penetration levels, most likely required to go significantly beyond 100g/KWh carbon intensity.

The Imperial College study sheds new light on the issue of system integration costs of renewable generation. This study is able to calculate the 'whole system cost' of each technology (where whole system cost is the sum of the 'levelised cost of electricity'[18] plus the system integration costs) as well as calculate total system costs by adding operation and investment cost in the future GB system. It is, therefore, able to explore how system integration costs for renewable generation are affected by the overall structure of the power system. In particular, the study considers the impact of changes in generation mix and the ability of the system to adapt to changes in supply and demand (system flexibility).

It is important to note that the 'levelised cost of electricity' is the 'direct cost' referred to above that will be revealed by the auction process. It should be noted that some system integration costs, such as those related to network upgrades, are already at least partially borne by the variable renewable generators and thus captured by the levelised cost of electricity calculations. For example, all transmission connected generation directly pay 'Balancing Services Use of System' charges, which reflect the costs of balancing the system in real time including those related to errors in forecasting output from renewable generators. Therefore, the 'whole system cost' calculated by Imperial College will actually be too high since some aspects of system integration costs will be included twice.

The Imperial College study has adopted a base case generation mix that represents a pragmatic forecast of the likely deployment potentials for the key

[18] The levelised cost of electricity is the 'direct cost' referred to above that will be revealed by the auction process. It should be noted that some system integration costs, such as those related to network upgrades, will be borne by the renewables generator and will be included in the levelised cost of electricity.

alternative low carbon generation technologies based on their desirability and deliverability (see table below which also includes central assumptions for onshore and offshore wind and solar PV – again based on practical assessments of deliverability). Whilst there is some limited upside deployment potential for these technologies, there is also a considerable downside risk that would require a significant increase in the deployment of renewable generation if carbon intensity targets are to be achieved.

Technology[19]	2020 capacity	2025 capacity	2030 capacity	Comment
Nuclear	8.9GW	7.9GW	8.2GW	One and a half new large nuclear powers stations commissioned by 2030 and existing plant closes to schedule. There is risk associated with the timely delivery of large scale nuclear power stations.
Biomass	3.4GW	3.4GW	3.4GW	Based on conversions supported by existing revenue stabilisation contracts. Sustainable fuelling for large biomass plant remains a serious environmental and economic constraint.
CCS	0GW	0GW	0.5GW	Assumption that one test facility is up and running by 2030.
Onshore wind	13.2GW	16.6GW	20GW	Only achievable if current 'freeze' is relaxed
Offshore wind	10.2GW	16.2GW	31GW	Can potentially be increased beyond these levels – perhaps to around 40GW
Solar PV	12.8GW	16.4GW	20GW	The system may be able to accommodate significantly more solar capacity – possibly up to 40GW

[19] Assumptions used in base case 'mid flex' scenario

The 'onshore capped' and 'nuclear centric' sensitivities described earlier were also investigated to test the impact of these very different generation mixes on the total system costs.

The importance of creating a flexible power system is now widely recognised. The recent 'Smart Power' report from the National Infrastructure Commission[20] set out the benefits of increased system flexibility and indicated an £8bn annual saving. These findings have been echoed in other work by Government[21], the Committee for Climate Change[22] and Ofgem[23]. The impact of system flexibility on system integration costs was therefore explored by the Imperial College study.

Output from flexible fossil-fuelled generation capacity can be adjusted to help market participants and the system operator balance supply and demand. As it is progressively displaced as a result of the need to decarbonise the power sector, new sources of flexibility will be required. This can arise from a number of sources, most notably shifting electricity demand (so-called demand side response), storage technologies (e.g. batteries) and increasing the ability to transfer power between regions (including interconnections between countries). These new sources of flexibility have the added benefit of being able to displace electricity produced from both variable generators and inflexible nuclear generators in periods of oversupply, thereby helping optimise system operation and mitigate curtailment costs.

There are already promising signs that flexibility provided by these new sources is increasing. There are 5GW of additional interconnection already firmly under development and the system operator is already rolling out new commercial services that are attracting storage and demand response products to help balance the system. In addition, the statutory roll-out of smart metering is a key enabler for increasing the flexibility of demand.

The Imperial College study involved a number of scenarios to investigate the impact of varying degrees of system flexibility on the system integration costs of renewable generation in 2030. A 'no progress' scenario is created which represents a useful counterfactual to assess the benefits of flexibility. This scenario only included existing levels of flexibility and did not assume any improvement in the years to come. This is already out of date since the recent Enhanced Frequency Response tender from National Grid will deliver 200MW

[20] National Infrastructure Commission (2016) **Smart Power**

[21] Department of Energy and Climate Change (2012) **Electricity System: Assessment of Future Challenges**

[22] Committee on Climate Change (2015) **Power sector scenarios for the Fifth Carbon Budget**

[23] Ofgem (2015) **Making the electricity system more flexible and delivering the benefits for consumers**

of new storage by end of 2017. This counterfactual is compared with other scenarios described in the table below.

Scenario	Description	Comment
No progress	Current levels of interconnection, no new storage, zero update of demand side response	Broadly the current situation
Low flexibility	10GW of interconnection, 5GW of storage and 25% uptake of demand side response[24]	Can be considered as 'business as usual'
Mid flexibility	11GW of interconnection, 10GW of storage and 50% uptake of demand side response	Likely to require some new policy initiatives
Modernisation	As in Mid Flexibility but with a range of measures to improve system operation (concerning wind predictability, capability to provide ancillary services etc.)	Would involve modernising system operation practises, to meet 21st century standards
High flexibility	15GW of interconnection, 15GW of storage and 100% uptake of demand side response	Would require significant new policy push to increase flexibility

SYSTEM INTEGRATION COSTS OF RENEWABLE GENERATION

The charts below (Figures 5 & 6) illustrate how system integration costs for variable renewable technologies are affected by the different assumptions relating to system flexibility and generation mix. This demonstrates that system integration costs would remain around, or below, £10/MWh for onshore and offshore wind for a wide range of generation mix and levels of system flexibility based on the assumed deployment levels for these technologies in 2030. The costs for solar PV are slightly higher due to additional costs incurred on the local distribution power network. Significantly higher costs only arise in the unrealistic 'no progress' flexibility sensitivity. It is worth noting that a recent study carried out by Aurora[25] highlights how the system integration costs of wind and solar could be reduced by increasing the level of solar PV penetration compared to the assumptions used in the Imperial College study. This works suggests that these technologies are so

[24] This is 25% of total estimated demand response potential

[25] Aurora for the Solar Trade Asociation (2016) **Intermittency and the cost of integrating solar in the GB power market**

some degree complementary and lead to a reduction in system integrations costs for solar PV of £1.7/MWh.

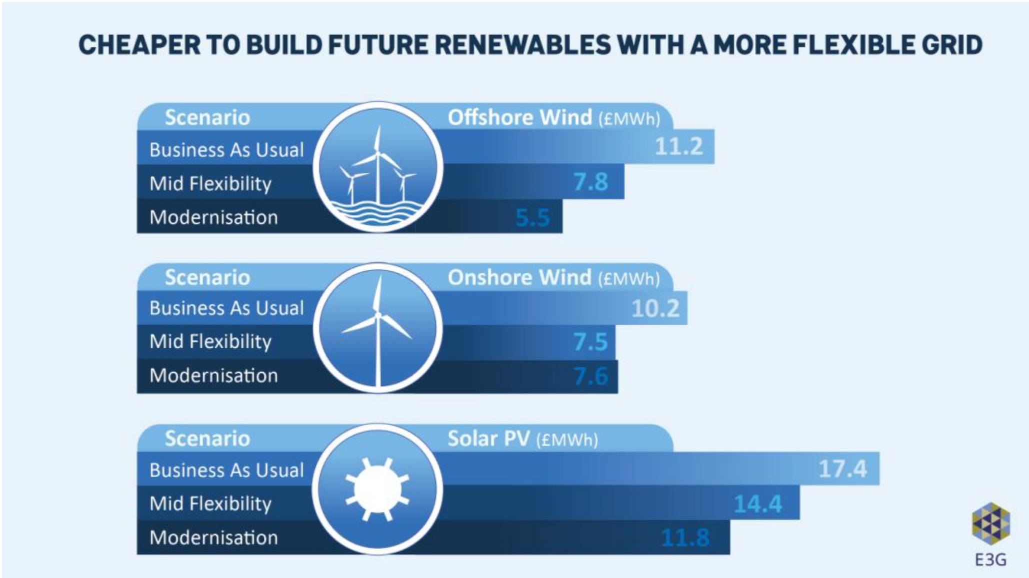

Figure 4. Imperial College London, system integration costs (£/MWh) by technology in three core scenarios at 2030

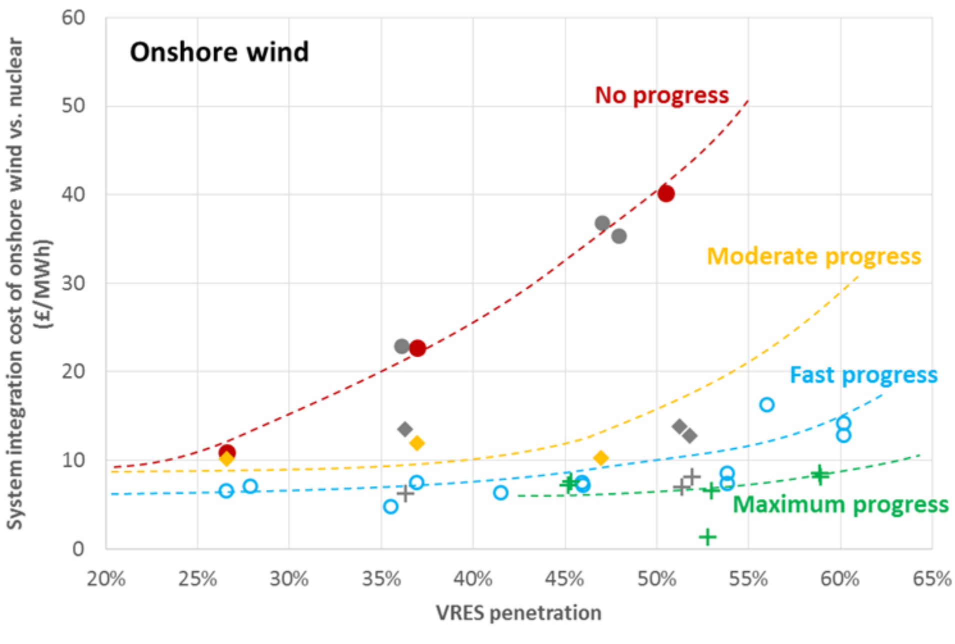

Figure 5. System integration cost of onshore wind as a function of penetration of variable renewables: curves inferred from this Imperial College study and previous work undertaken for the Committee on Climate Change

These are extremely important results since they demonstrates that system integration costs remain relatively low for a wide range of system conditions out to 2030, including the situation in which there are significantly higher levels of renewable generation compared to today.

The levelised costs of renewables are significantly lower than for new nuclear capacity. With system integration costs for renewables in the region of £10/MWh, the whole system costs of renewable generators remains lower than the cost of nuclear. This provides evidence, therefore, that for a wide range of system conditions a significant increases in variable RES penetration is a cheaper way forward than further increasing new nuclear capacity (see diagram below).

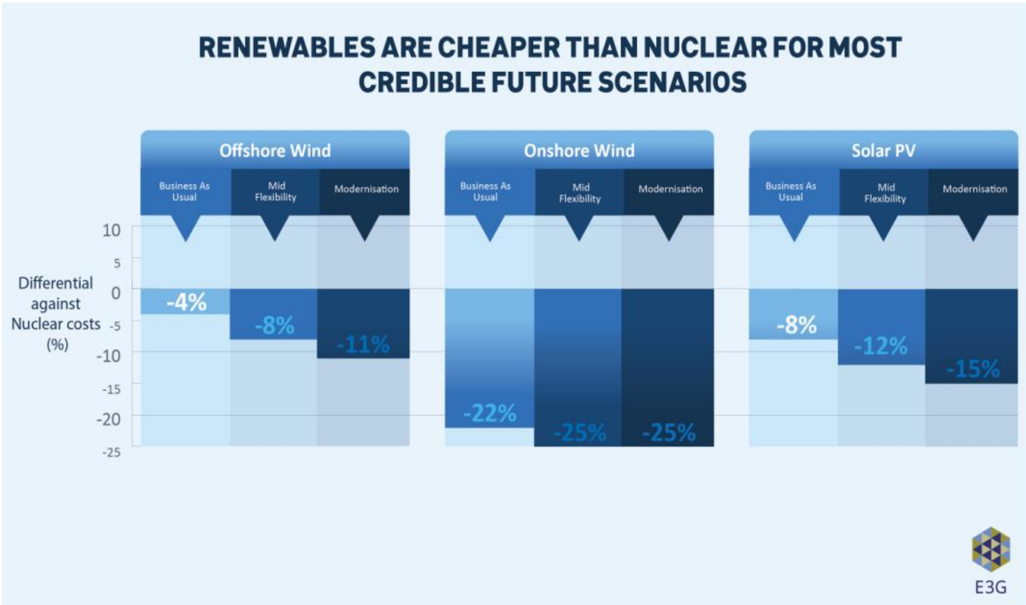

Figure 6. Imperial College London, system integration costs by technology in three core scenarios at 2030 compared with nuclear

There are many factors that will affect the real-world choice between technologies beyond merely cost considerations. However, the analysis clearly demonstrates that system integration costs do not present an obstacle to the secure and least cost decarbonisation of the power system using large volumes of renewable generation.

This is very good news for the Government since it is clear that a significant growth in renewable generation will be required to deliver carbon budgets under all credible scenarios. The Government can, therefore, proceed with full confidence that a significant growth in renewable generation is the lowest cost approach and thus the most desirable for consumers and businesses.

RECOMMENDATIONS

Costs of variable renewable generation will continue to fall faster than expected provided competitive auctions are used to support cost discovery and a clear, predictable deployment pathway is established.

The Government is committed to producing a plan (the 'Emissions Reduction Plan') which sets out how it will deliver carbon budgets out to 2032. Renewable generation is necessary, deliverable at scale and, importantly, desirable whilst minimising costs to consumers remains a priority. What is more, there is evidence that costs will continue to fall faster than projected provided competitive auctions are used to support cost discovery and a clear, predictable deployment pathway is established.

The Emissions Reduction Plan is an opportunity for Government to capture these benefits for consumers and the economy as a whole. It should contain a commitment to procure low-carbon generation through regular auctions at levels consistent with meeting the carbon budgets and plugging the energy gap. This requires clear expectations for the deployment of low carbon technologies since this is required to drive cost-effective investment in project development, leading to direct benefits for local communities, the UK's industrial strategy and the creation of an efficient and competitive supply chain capacity. The plan must carefully consider the delivery risk that each technology faces since no one technology can be relied upon to deliver what is required.

Recommendation 1: The Government should ensure the Emissions Reduction Plan captures the advantages for consumers and the economy by providing a clear trajectory for deploying low-carbon generation that is consistent with delivering long term carbon budgets at least cost.

However, it is not enough to simply include a commitment to renewable generation in the Emissions Reduction Plan. It is also necessary to provide confidence to investors that a predictable forward programme of auctions is in place that is consistent with the commitments outlined in the Emissions Reduction Plan. The current 'Levy Control Framework' has proven to be poorly designed since it acts neither to guarantee least cost outcome for consumers nor does it provide long term clarity for investors. A new design is needed which addresses these shortcomings.

The upcoming Autumn Statement is an opportunity to signal a new approach to the Levy Control Framework that is consistent with delivering the twin objectives of minimising the costs to consumers of delivering the carbon budgets and driving an industrial strategy consistent with a clean and efficient 21st century energy system. This requires more action than setting out a new structure for the Levy Control Framework. The dramatic reduction in the current pipeline of renewable projects is already leading to the UK losing the industrial capacity that will be essential if the necessary future deployment pathway is to be achieved. This is particularly relevant for onshore wind and solar PV and the Autumn Statement should, therefore, announce a timetable for the next auctions for established and less-established renewable technologies and these need to take place as soon as practically possible.

Recommendation 2: The Autumn Statement must set out a new design for the Levy Control Framework and announce a timetable for auctions for all categories of renewable technologies to commence as soon as possible.

The opportunities associated with developing a clean, efficient and flexible 21st century power system are significant and achieving this transformation is essential if we are to minimise costs to consumers. However, the market arrangements and regulatory structures currently in place are not fit for purpose. Further market reform, building on the EMR process, will be important if the Emissions Reduction Plan is to be implemented at least cost.

The Government should mandate Ofgem to ensure that market design evolves quickly to ensure system flexibility begins to increase significantly by the early 2020s and does not act as a constraint on the cost-effective deployment of low carbon generation in this decade or beyond. This should be supported by a broad range of stakeholders who are already calling for a holistic reform of network and system operation arrangements.[26]

Recommendation 3: Ongoing market reform will be essential to support delivery of the Emissions Reduction Plan. The Government should mandate Ofgem to ensure the regulatory regime and market mechanisms are coherent and create a system that is sufficiently flexible to support cost-effective delivery of the necessary volumes of low carbon generation.

[26] National Grid (2016) **Industry Charging Seminars**

KEEPING OPTIONS OPEN

The Imperial College analysis illustrates that relatively modest improvements in system flexibility allow increased volumes of variable renewable generation to be accommodated cost-effectively on the power system. However, this does not mean that we should be complacent. The UK Government should be aiming to create a modern, clean and efficient energy system that takes full advantage of the digitisation of power system operation and the raft of new emerging technologies. Indeed, these technologies should form a key component of a new industrial strategy aimed at creating a competitive 21st century economy and delivering benefits to citizens throughout the nation.

While delivering economic benefits, the delivery of a modern, flexible power system would also enable the UK to accommodate significantly greater volumes of renewable generation than currently considered necessary to meet both our generation gap and the fifth carbon budget (2028-2032). This need may arise from delivery failures on the part of non-variable low carbon technologies, or renewable generation may simply prove, as per current trends, to be considerably cheaper and more reliable than alternative generation technologies. Above all, it may be essential if the UK is to comply with its obligations under the Paris Climate Change Agreement[27].

Imperial College has tested the impact on system integration costs of even more significant increases in the proportion of renewable generation (with offshore wind taken as the technology that can be most readily scaled to high volumes). The charts below show the impact on system integration costs of renewable generation for two sensitivities.

In the first sensitivity scenario large biomass generation capacity is retired by the end of the 2020s (either as a result of sustainability concerns or market dynamics) and must be replaced by other low carbon sources and secondly where the target carbon intensity for the power system is increased to 50g/kWh in 2030. Without biomass, the model predicts an additional capacity of around 7GW of offshore wind would be required to deliver the 100g/kWh carbon intensity target. In the second scenario, all low carbon technologies remain available but the carbon intensity target is tightened to 50g/kWh requiring additional offshore wind capacity of around 14GW.

[27] The Paris Climate Change Agreement commits all signatories to a review progress every 5 years and raise ambition towards meeting the long term goals, starting this process with resubmission of mitigation targets in 2019/2020. (see https://www.e3g.org/library/what-paris-means-for-the-uk)

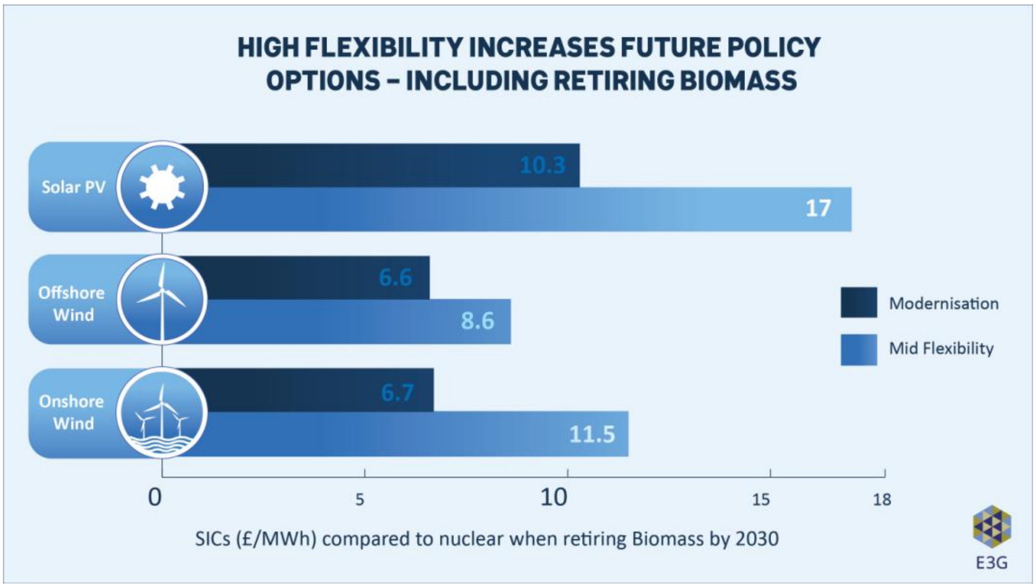

Figure 7. Imperial College London, system integration costs by technology in two core scenarios at 2030 with retiring biomass compared with nuclear

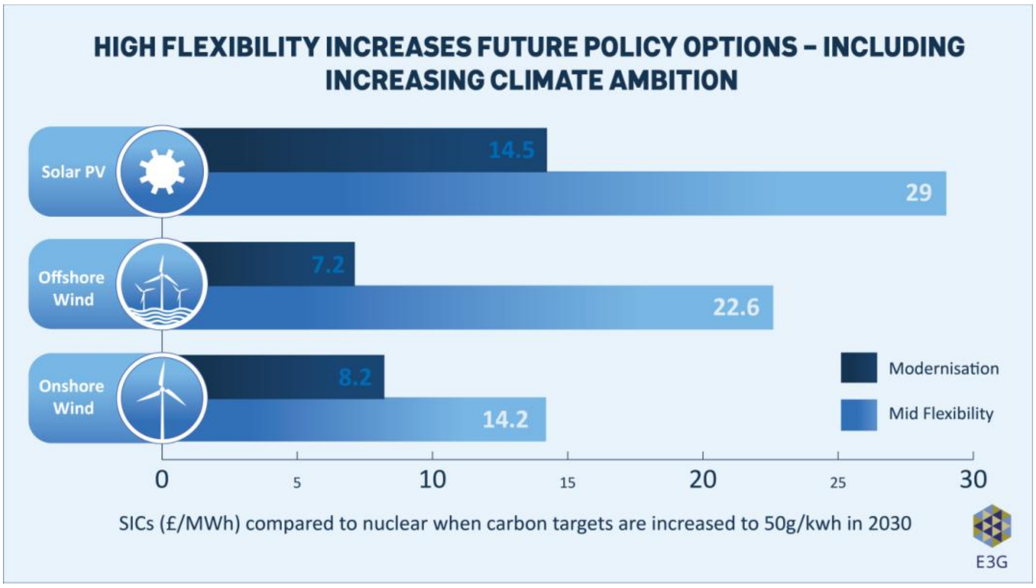

Figure 8. Imperial College London, system integration costs by technology in 50g sensitivity scenario compared with nuclear

Figure 9 illustrates that system integration costs remain low provided there are significant improvements in system flexibility (high flexibility and modernisation scenarios) even in the situation where considerably more offshore wind is required to meet a more ambitious decarbonisation target. Achieving only moderate improvements in system flexibility (mid flexibility scenario) risks constraining the options available and increasing the costs for consumers[28].

Imperial College has also investigated the impact of system flexibility in the years leading up to 2030 by exploring different flexibility scenarios in 2020 and 2025. These flexibility scenarios are summarised in the following table:

Year	2020			2025			2030			
Flex. level	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**	**Base**	**Low**	**Mid**	**High**
New storage (GW)	-	0.2	2	-	2	5	-	5	10	15
DSR	0%	0%	25%	0%	25%	50%	0%	25%	50%	100%
Interconnection (GW)	4.0	7.5	7.5	7.5	11.3	11.3	7.5	9.9	11.3	15.0

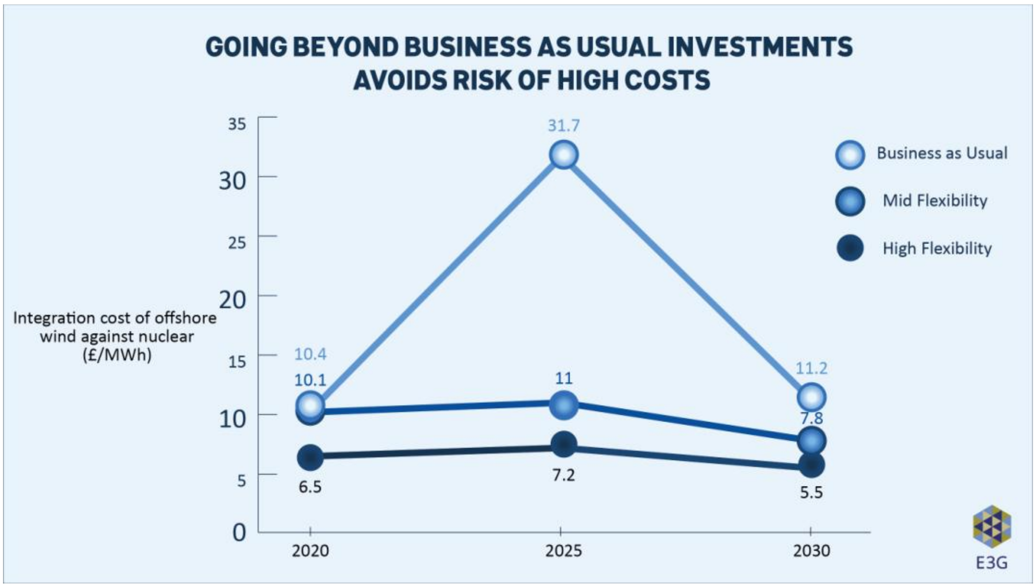

Figure 9. Imperial College London, system integration costs of offshore wind in three core scenarios from 2020 to 2030 compared with nuclear

The chart above shows the impact on system integration costs for offshore wind for these different flexibility scenarios. It is particularly striking that, whilst the 'low' scenario appears adequate to contain system integration costs in 2030, the pathway towards this level of flexibility could prove inadequate

[28] The recent report by Aurora for the Solar Trade Association (**http://www.solar-trade.org.uk/wp-content/uploads/2016/10/Intermittency20Report_Lo-res_031016.pdf**) suggest that increasing levels of solar PV way beyond the 20GWs assumed in this study may further hep to offset the system integration costs of high levels of wind penetration.

earlier in the decade with integration costs escalating to around £30/MWh. This reinforces the risk associated with 'business as usual' developments in system flexibility and the benefits of acting fast to accelerate short term improvements.

The benefits of accelerating the shift towards a modern, flexible power system are considerable and are summarised in the diagram below. Improvements in system flexibility require action by Government to remove unintended regulatory barriers and perverse charging arrangement and help promote development of markets in new products and services, particularly those relating to flexible consumption and storage. Additionally the development of the broader energy network infrastructure could create further options for the least cost decarbonisation of the power system[29].

A clear priority for Government must be the creation of a modern, flexible power system. Capitalising on the opportunities and benefits will require new policy action.

[29] These new markets and infrastructure developments should also create options for the least cost decarbonisation of the heat and transport sectors although these topics go beyond the scope of this report.

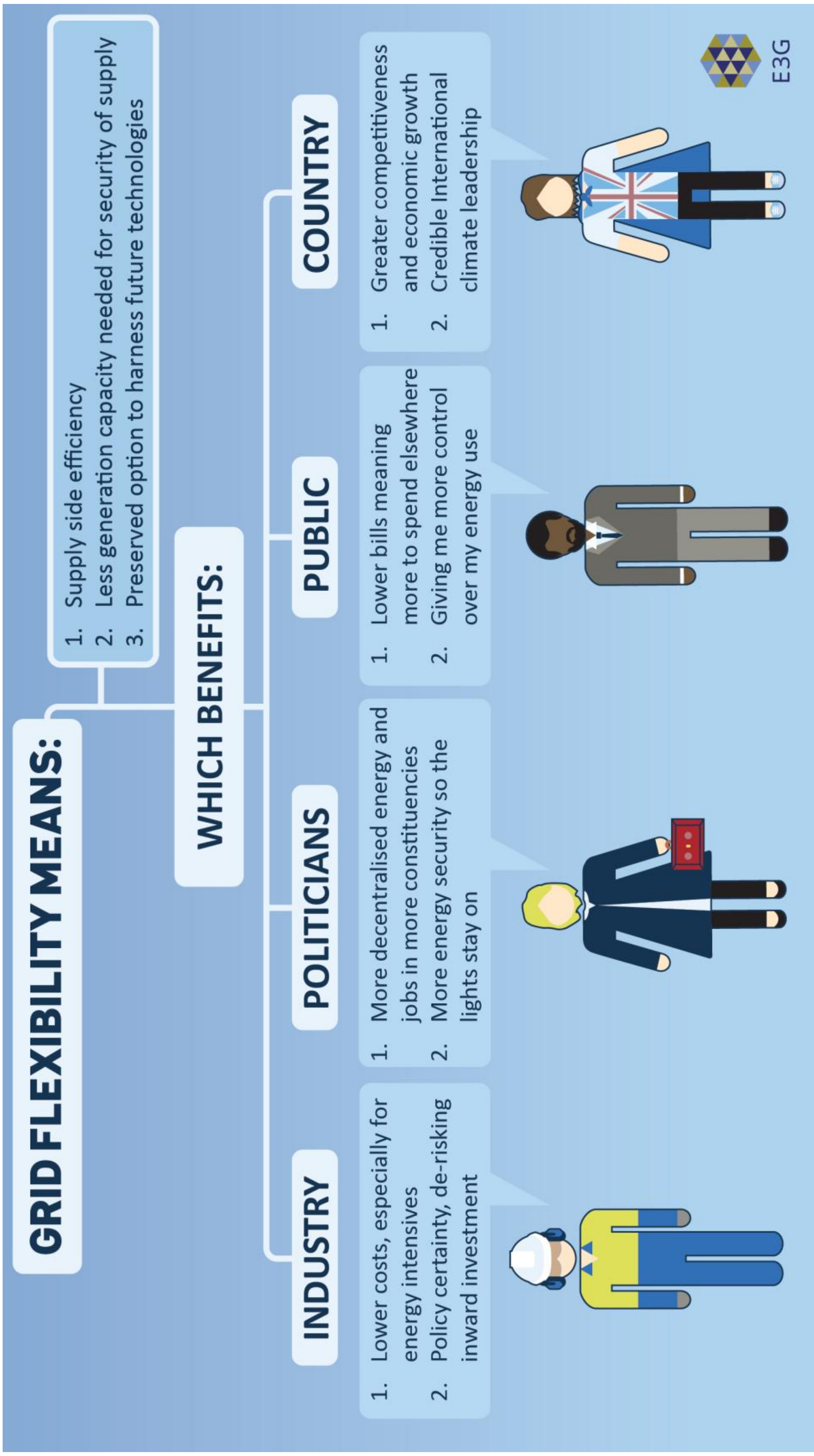
GRID FLEXIBILITY MEANS:
1. Supply side efficiency
2. Less generation capacity needed for security of supply
3. Preserved option to harness future technologies
WHICH BENEFITS:
INDUSTRY
1. Lower costs, especially for energy intensives
2. Policy certainty, de-risking inward investment
POLITICIANS
1. More decentralised energy and jobs in more constituencies
2. More energy security so the lights stay on
PUBLIC
1. Lower bills meaning more to spend elsewhere
2. Giving me more control over my energy use
COUNTRY
1. Greater competitiveness and economic growth
2. Credible International climate leadership
E3G

Figure 10. E3G, The social and economic benefits of increasing flexibility and reducing system integration costs

CREATING A MODERN, FLEXIBLE POWER SYSTEM

Significant work has already been undertaken to illustrate how the power system needs to change. Previous work by Imperial College has compared operational costs for the UK power system with 10GW and 50GW of wind capacity. This demonstrates that, whilst overall operational costs reduce, the proportion relating to the provision of certain system balancing services[30] increases from 1-2% to 25% (see chart below).

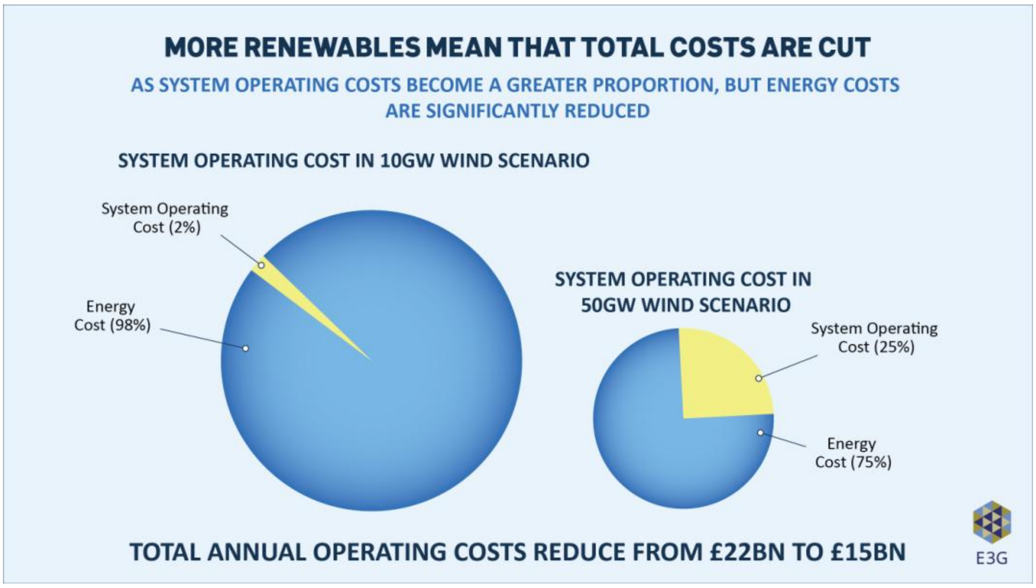

Figure 11. Imperial College London, the effect of additional wind capacity on total annual system operating costs

The focus of the current wholesale market design is to facilitate competition between generators in the provision of electricity to balance demand. To-date, a relatively small volume of system operation services have been procured outside this market, on a bilateral basis by the System Operator. Given the anticipated growth in volume of system operation services, current procurement practices will be inadequate to face the demands of the future energy system and these require urgent reform.

[30] The balancing services referred to in this chart relate to that proportion of overall ancillary services required to ensure the secure and stable operation of the integrated power system by maintaining system frequency within statutory limits following failure events.

There are two important new features that will need to be considered in such reforms. Firstly, the range of system operation services that are procured should be reviewed, and rationalised, to reflect the needs of the modern power system along with the range of technologies that are now available to provide these services. Flexibility services can be provided by variable renewables[31] and will increasingly be provided from non-generation sources such as demand response, storage and network infrastructure.

Best value outcomes for consumers require that effective and fair competition exists between all these service providers. It will be important to move away from a traditional 'predict and provide' mindset since considerable amounts of money could be wasted through long term commitments to infrastructure that is based on assumptions that new sources of flexibility will not emerge. Instead, procurement of updated system operation services should be overhauled to better facilitate investments in smaller scale generation and increased flexibility which will contribute to increasing the overall resilience of the system.

Secondly, the need for system flexibility could vary significantly at a local level – particularly as electric heating and vehicle charging systems become more widely adopted. Markets that reflect these decentralised characteristics of the energy system could allow for more effective competition and increased system optimisation meaning that the energy system is more in line with the needs of individual citizens and businesses.

There has been some discussion as to whether it is important that low carbon generation, and renewables in particular, directly bear the system integration costs they create. The basis of this assertion is that full cost allocation would ensure that auctions for new low carbon generation would reveal accurate levelised costs of electricity[32] and, thereby, minimise overall costs for consumers.

Whilst generation projects are already exposed to some of these costs, there remain others (e.g. back-up generation costs) that are unallocated. The Imperial College analysis shows that system integration costs depend on overall system conditions - which represents a degree of complexity that is very difficult to assess and a risk that any developer is poorly positioned to manage (for example, system integration costs for onshore wind could change if more inflexible nuclear is added to the system).

[31] Offshore wind farms can now ramp output down or up faster than traditional service providers such as Gas CCGTs

[32] In this situation, levelised costs of electricity would equal the whole system costs for each technology.

Given that the analysis suggests that system integration costs remain low in most circumstances, there is a risk that introducing overly complex cost allocation could end up creating inefficiencies and higher costs overall. It does not, therefore, appear sensible for policy makers to pursue perfect allocation of system integration costs for its own sake[33] . However, the analysis does point to a need for continued focus on developing markets for the competitive provision of flexibility products and this should seek to improve cost allocation. The issue of cost allocation should be viewed in this wider context.

The opportunities associated with developing a clean, efficient and flexible 21st century power system are significant and achieving this transformation is essential if we are to minimise costs to consumers. However, the market arrangements and regulatory structures currently in place are not fit for purpose.

Further market reform, building on the EMR process, will be important if the Emissions Reduction Plan is to be implemented at least cost. The Government should mandate Ofgem to ensure that market design evolves quickly to ensure system flexibility begins to increase significantly by the early 2020s and does not act as a constraint on the cost-effective deployment of low carbon generation in this decade or beyond.

Ongoing market reform will be essential to support delivery of the Emissions Reduction Plan. The Government should mandate Ofgem to ensure the regulatory regime and market mechanisms are coherent and create a system that is sufficiently flexible to minimise overall costs.

[33] It has also been suggested that all low carbon resources, including nuclear and CCS, should compete in a single technology neutral auction. It has even been suggested that contract allocation should be combined with the capacity mechanism to create a single procurement process for all resources. It is difficult to imagine how a single auction process would not bias the outcome towards a particular technology, in addition to welfare allocation concerns arising from deployment constraints for cheaper technologies. These proposals should, therefore, be treated with extreme caution.

CONCLUSION

The study by Imperial College is one of a series of recent projects that point to the same conclusion - the approval of the 5th carbon budget has laid bare the large gap in current energy policy[34]. The creation of a modern, flexible power system, based on significant increases in the volume of renewable generation, provides the solution to this problem. Renewable generation can be deployed at scale and will almost certainly be the cheapest way to deliver policy targets out to 2030. Indeed, these cost advantages for consumers could be significant as the costs of all types of renewable generation continue to fall much faster than assumed in the Imperial College study.

The economic dividend associated with creating a modern, flexible power system goes beyond the direct benefits of reducing a core input cost to the economy. There could be significant investment in supply chain capacity around the country and the UK has the opportunity to become a key player in worldwide markets for the new technologies that underpin a modern power system.

The Emissions Reduction Plan represents a critical opportunity for Government to set out this new direction and close the policy gap. The credibility and deliverability of this plan will depend on two important enabling policies. Firstly, there should be a clear commitment to a program of auctions for new low carbon generation in line with our generation gap and carbon reduction ambitions. Urgent action is required for more established technologies, the lowest cost options, to avoid further damaging delivery capability. Secondly, there should be a commitment to develop power markets that are consistent with meeting energy policy objectives at lowest cost.

Action in this parliamentary term is critical if we are to put in train the actions that will create a clean, efficient 21st century energy system.

[34] E.g.Aurora (2016) **http://www.solar-trade.org.uk/wp-content/uploads/2016/10/Intermittency20Report_Lo-res_031016.pdf**; Green Alliance (2016) **http://www.green-alliance.org.uk/resources/Smart_investment.pdf** and Policy Exchange (2016) **https://policyexchange.org.uk/publication/power-2-0/**