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Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

# The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

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**Abstract:** The prospects of UK shale gas development and its role in the energy mix has generated contradictory views. Its inclusion in electricity generation is anticipated to help mitigate the grid carbon emissions. However, there is fear that a shale gas ‘revolution’ might distract policy commitments on the development of low carbon technologies. Others argue that a shale gas ‘boom’ could potentially create a ‘lock-in-effect’ on gas generation infrastructures, thus, further exacerbating the burden on carbon emissions. The uncertainty over the future role of shale gas is worsened by lack of clarity and conflicting estimates on the potential gas resource and reserves. In the midst of these uncertainties, this paper seeks to examine transition pathways incorporating shale gas and their implications on electricity sector decarbonisation and energy security objectives

**Keywords:** Decarbonisation, Low-carbon Technologies, Unconventional Gas, Energy Scenarios, Carbon Capture and Storage

## Introduction

The prospect of a potential ‘boom’ in shale gas development is set to transform the UK power sector and the energy policy landscape. Developments in shale gas have come at a time when the UK is working towards the 80% greenhouse gas emission (GHG) reduction target by 2050 against the 1990 levels (HM Government 2008). Since the power sector accounts for 27% of the total emission (Department of Energy & Climate Change 2011a), the Committee on Climate Change (CCC) proposes that the sector should reduce its grid emission intensity from about 500gCO<sub>2</sub>/kWh to 50gCO<sub>2</sub>/kWh by 2030 and almost zero in 2050 (Committee on Climate Change 2010). In order to monitor the nation’s progress towards the 80% emission reduction target by 2050, the Climate Change Act enacted a system of Carbon Budgets which set a 50% emission target to be achieved by 2025, the mid-point of the fourth (2023-27) carbon budget (Committee on Climate Change 2010). In fact, the climate change policies seek to put a constraint on the increased use of unabated fossil fuels in electricity generation. Currently, the electricity generating capacity is being undermined by the European Union (EU) environmental pollution regulations in the form of Large Combustion Plant Directive (LCPD) and the Industrial Emissions Directive (IED). These policies are set to accelerate the closure of coal plants by 2015 and 2023, respectively, (Committee on Climate Change 2013a). Electricity generating capacity is set to dwindle further due the anticipated retirement by 2023 of the current nuclear fleet which is reaching the end of its operational life. These developments will lead to the loss of almost 20GW of the existing generating capacity, thus, threatening our security of supply over the next decade (Department of Energy & Climate Change 2011a). In order to replace this capacity gap and

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## International Journal of Environmental Sustainability

prepare for the electricity sector decarbonisation by 2030, the government estimates that 40-70GW capacity of low-carbon electricity generation needs to be built through the 2020s (HM Government 2011).

The low-carbon technology penetration anticipated in the 2020s could potentially coincide with the large scale production of shale gas expected in the early 2020s (House of Lords 2014). However, the timeline for shale gas production is still uncertain as its development is still in infancy. Nonetheless, the role of unconventional gas in a carbon constrained future generation mix is debatable. It is envisaged that domestic production of shale gas could contribute to physical security of gas supplies by reducing import dependency (UKERC 2013). The increased use of shale gas in the US is widely believed to have contributed to about 430 million tonnes (7.7%) fall in carbon emissions since 2006 (AEA 2012). This has been attributed by the switch from coal to gas in electricity generation. As a result, demand for coal plummeted in the US leading to increased exports of coal around the globe, thus increasing carbon emissions outside the US (AEA 2012).

Analysis done by the IEA suggests that GHG emissions from shale gas electricity generation are about 2% to 10% lower than conventional pipeline gas outside of Europe (AEA 2012). The emission intensity of shale gas use in electricity generation is estimated to range from 423-535gCO<sub>2</sub>/kWh, which is significantly lower than the carbon footprint of coal, 837-1130gCO<sub>2</sub>/kWh (Department of Energy & Climate Change 2013). Despite its lower carbon footprint compared to coal, the use of shale gas in electricity generation has limited abatement benefits unless used in Carbon Capture and Storage (CCS) applications (UKERC 2013). This implies that the use of significant amounts of unabated shale gas in the UK electricity generation mix in the 2020s and beyond could make it very difficult to comply with the legally binding carbon budgets (Ekins et al. 2013). The use of shale gas in electricity generation could have a short-term impact in reducing GHG emissions but increased government appetite towards this resource has a potential to reduce investment in research, development and deployment of low carbon technologies (Schrag 2012).

It is still uncertain whether a combination of both domestic production and increased imports of shale gas could result in the fall in gas prices in the UK. Forecasts indicate that global gas prices will go up by 55% by 2035 (IEA 2011), but the Energy and Climate Change Committee (ECCC) believe that an increase in unconventional gas production is likely to increase the chance of falling gas prices in the UK (Energy and Climate Change Committee 2011). The International Energy Agency (IEA 2011) believes that the spread of the American experience in unconventional gas production across the globe could reduce the cost of production, thus leading to a decline in average prices. In the event of a decline in unconventional gas prices, its contribution to addressing energy-related challenges could be overshadowed by the potential negative impacts it is believed to have on the environment. The sustainability of shale gas is a contentious issue which has polarized opinions across global communities. This article contributes to this debate by employing the 'Energy Optimization Calculator' to examine the potential emissions, technology development and investment challenges of shale gas use in the UK electricity generation mix and the policy implications on the 2030 and 2050 decarbonisation milestones.

### **Shale Gas Resource Estimates: Developments so far**

The Shale gas 'revolution' in the United States has had ripple effects across the globe. The rapid shale gas development in the US, which accounts for about 60% of production (IEA 2011), has significantly heightened speculation over its potential to transform energy markets in other parts of the world. However, the experience in America is not likely to be replicated in other countries due to the regional variations in the petro-physical properties of the shale rock formations, national policy strategies, cost and social acceptance (Ernst & Young 2012). It is also feared that access to land could be difficult due to concerns over population densities and the need for, and

## Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

treatment of, large volumes of water especially in agricultural areas (IEA 2011). Increasing concern over the potential impact of hydraulic fracturing on the environment has prompted some countries in Europe to impose bans on shale gas developments. However, fierce public opposition to unconventional gas development in UK has so far failed to change the policymakers’ enthusiasm and focus towards this resource. Instead, the government is working towards strengthening and extending the existing and well established legal framework regulating the UK oil and gas industry to shale gas to ensure the effective mitigation and management of potential environmental and safety risks.

### The Global Shale Gas Resource prospects

Globally, the TRR of shale gas is likely to be about 7,201tcf, with the largest resource in China, Argentina and Algeria contributing 1,115, 802 and 707tcf, respectively (EIA 2013). The distribution of the global TRR shale gas potential is shown in (Fig.1), representing 10 countries with the highest Shale gas TRR potential and 5 in Europe. Shale gas development in Europe is not expected until after 2020, as time is needed for resource appraisal, development and associated technical, environmental and regulatory issues (IEA 2011). According to the Energy Information Administration (EIA 2013), Europe’s (TRR) is estimated to be up to 470tcf, with Poland and France recording the highest estimates of 148tcf and 137tcf, respectively. In contrast, (Pearson et al. 2012) estimated the European TRR to range from 81.2 to 621tcf with a mean of 250tcf.

The future potential for shale gas resource development is subject to multiple physical, technical, economic and political uncertainties, including the size and recoverability of the physical resource (McGlade et al. 2013). As a result, estimates of the TRR for shale gas resources are bound to be revised upward and downward over time as new information is made available. Despite the great uncertainty over the timetable and economic recoverability of these resources, the potential large scale exploitation of these resources (Fig.1) could have huge impacts on the global gas markets. Such a development could impact greatly on the UK electricity sector expected to be predominantly low-carbon by 2030.

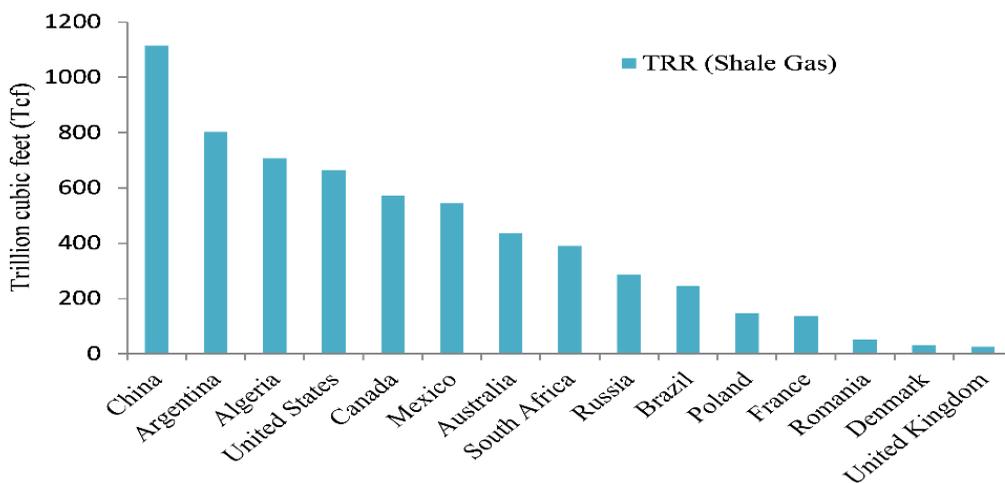


Figure 1: Recoverable shale gas resource (top 10 + Europe)

Source: (EIA 2013)

### UK Shale Gas resource potential

## International Journal of Environmental Sustainability

The current UK shale gas resource studies have been focused on large parts of central Britain covering the Bowland-Hodder unit which extends from Merseyside to Humberside and Loughborough to Pickering (Andrews 2013). Production potential has also been expressed in Jurassic formations of the Weald and Wessex basins of southern England and the Midland Valley of Scotland as shown in (Fig.2). The central resource estimate or the Gas in Place (GIP) for the Bowland-Hodder unit is believed to be around 1329 trillion cubic feet (tcf) (Andrews 2013). The Midland Valley of Scotland's central estimate is believed to be roughly 80.3tcf. These two key area studies indicate a total resource base estimate of about 1409.3tcf of shale gas in the UK (Monaghan 2014). Based on the 10% recovery rate applied on conventional oil and gas fields, the central estimate could provide 140.9tcf of recoverable shale gas (McAlinden 2013). This resource estimate is almost 50 times the UK annual domestic and industrial gas consumption of 2.8tcf (McAlinden 2013). In view of the total in-place gas resource estimate for the UK, the U.S. Energy Information Administration (EIA 2013) estimates the UK's technical recoverable resources (TRR) to be about 26tcf.

Equally important is the reserve estimate; a speculative measure describing the amount of gas that might be extracted given the appropriate technology, economics and other factors (Parliamentary Office of Science & Technology 2011). Currently, no reliable estimate of gas reserves exist in the UK as this is dependent on increased exploration. In 2013, the UK electricity sector used about 18,500 million cubic meters (0.76tcf) of gas for electricity generation (Department of Energy & Climate Change 2014), thus it is imperative that sufficient information on reserves is developed in order to measure the potential role of shale gas in electricity generation.



Figure 2: Prospective areas with shale gas potential in the UK

Source: (Monaghan 2014)

## Methodology

### The Energy Optimisation Calculator; developing energy pathways

## Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

Developing a sustainable pathway to a low carbon electricity supply system requires radical changes to technologies, institutions and business strategies, (Foxon et al. 2010). The impacts of these elements have been employed in the ‘Energy Optimisation Calculator’ to frame electricity generation pathways that incorporate shale gas use in the generation mix. The ‘Energy Optimisation Calculator’ is an in-house excel based tool used to develop electricity generation scenarios for which input variables are determined based on the current UK energy policy developments. The model doesn’t deal with time, instead, multiple runs are done manually for each five year period and data is carried on to the next run. The model calculator uses a baseline scenario with 16 specified generation technologies, emission target (185.8MtCO<sub>2</sub>e) and energy demand (379.2TWh) data based on the 2007 energy policies. Based on the baseline scenario, three key scenarios are developed namely; Sustainable50 which adopts a 50gCO<sub>2</sub>/kWh target using conventional gas in the mix, and the two shale gas scenarios; Shale Gas50 and Shale Gas100 representing pathways which aim to achieve 50gCO<sub>2</sub>/kWh and 100gCO<sub>2</sub>/kWh by 2030 using shale gas, respectively.

The installed capacity distribution and generation profile reflected in these transition pathways is shaped by the following model assumptions:

1. Adoption of a decarbonisation target of 50 and 100gCO<sub>2</sub>/kWh by 2030.
2. Emission grid intensity is close to zero by 2050.
3. Integrating abundant supplies of domestic produced shale gas in electricity generation by 2030 with a 30% fuel price reduction margin.
4. Shale gas emission intensity in electricity generation is 423gCO<sub>2</sub>/kWh.
5. Commercial deployment of CCS begins in 2025.
6. No unabated coal generation post 2025
7. Unabated gas generation reserved for system balancing.

Table 1.1 shows the medium technology cost data input computed in the ‘Energy Optimisation Calculator’ to develop scenarios to explore the role of shale gas on the UK electricity generation sector. An annual inflation rate from 2010 to 2013 has been used to update the cost input date to 2013 level. The emission constraint applied to develop the three transitions is shown in Table 1.2. Beyond 2030, the emission trajectory for the “path to 50g” is lineally interpolated to 2050 where the sector achieves a near zero emission intensity, while the emission trend for the “path to 100g” shows an annual emission decline of about 0.45MtCO<sub>2</sub>e based on the 2020-2030 emission projection (Committee on Climate Change 2013a).

**Table 1.1: Medium technology cost data input**

Electricity generation Technologies	Capital cost (£/kW)	Operation & Maintenance (£/MWy)	Data source
Wind Onshore (Nth of a kind)	1,596	75,396	(Department of Energy & Climate Change 2011b)
Wind Offshore (Nth of a kind)	2,851	181,773	
Renewable (Biomass) CHP	4,272	222,371	
Hydroelectricity	2,417	88,462	(Parsons Brinckerhoff 2011)
Biomass	2,532	152,289	
Pumped Storage	1,958	12,570	
Nuclear (1st of a kind)	4,428	94,688	(Parsons Brinckerhoff 2012)
Biomass with CCS	4,118	131,092	
Gas CCGT (Nth of a kind)	599	22,655	

## International Journal of Environmental Sustainability

Gas CCGT-CCS (1st of a kind)	1,369	39,674	
Conventional CCGT CHP	618	47,214	
Coal (Pulverized Fuel, ASC - FGD)	1,954	60,602	
Coal CCS (Pulverized fuel, ASC, FGD-CCS)	3,354	120,383	(Mott MacDonald 2010)
Wave	3,610	200,000	
Tidal	2,750	37,200	(Department of Energy & Climate Change 2011c)
Solar PV (New built 250-5000kW)	780	20,400	(Department of Energy & Climate Change 2012a)

**Table 1.2: Emission target for pathways (MtCO<sub>2</sub>e)**

Scenarios	2010	2015	2020	2025	2030	2035	2040	2045	2050
Path to 50g	157	131.4	63.5	26.9	20.7	10	5	3	2.6
Path to 100g	157	131.4	63.5	43.9	41.2	39.3	36.9	34.7	32.5

Source:(Committee on Climate Change 2013b)- 2010 to 2030 emission projection

The model depicts the electricity generation transition in five year intervals from 2010 to 2050. The capital investment used to evaluate the power generation mix is amortised over the “technical life (30 years)” using a 10% discount rate. Other input variables used in the model include a physical installation limit (GW) for each technology, which gives the estimated total deployment capacity in line with industry and government ambitions. The model approach sets an installation constraint which allows the maximum feasible capacity to be added in the generation mix at any given time, taking into account the technical, economic, environmental and social factors that impact on technology penetration. This sets the maximum capacity limit for each technology that the model can add to the generation mix to meet the set demand and emission targets.

### The Optimisation Function of the Calculator

The optimisation process aims to develop a least cost generation mix that meets electricity demand at lower grid carbon intensities (Fig.3) and carbon emissions (Table 1.2) in Shale Gas50, Shale Gas100 and Sustainable50 scenarios. Optimisation starts with the generation technologies set in the Baseline Scenario shown in Fig.4 and is modified after every run to generate the three scenarios based on the input variables chosen. When the optimised generation portfolio in each model run fails to meet electricity demand, the model adds the least-cost technologies to the mix. Conversely, if demand is lower, the model removes the most expensive technologies in the mix until the demand is met.

The next stage in the optimisation process assesses the capacity of the assembled generation mix to meet the emission target. If the emissions are met the process ends but if not, optimisation will continue. At this stage the model ‘swaps out’ high carbon intensive technologies for low carbon technologies until the carbon target is just met as depicted in Fig.4. During the optimisation procedure, the model keeps track of the cost of electricity accrued in developing the cheapest technology mix that lowers the average carbon emissions. Once the optimization process is completed, the output module would then show the proportion of capacity (GW)

## Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

required to meet the demand from the assembled technologies and the corresponding electricity generation achieved in TWh/yr.

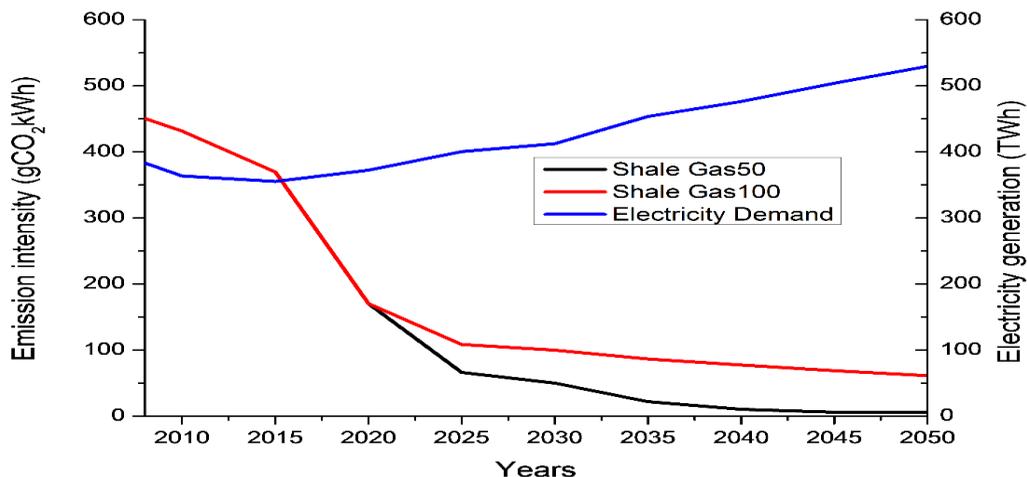


Figure 3: Electricity demand and emission intensity

Source: (Department of Energy & Climate Change 2010)

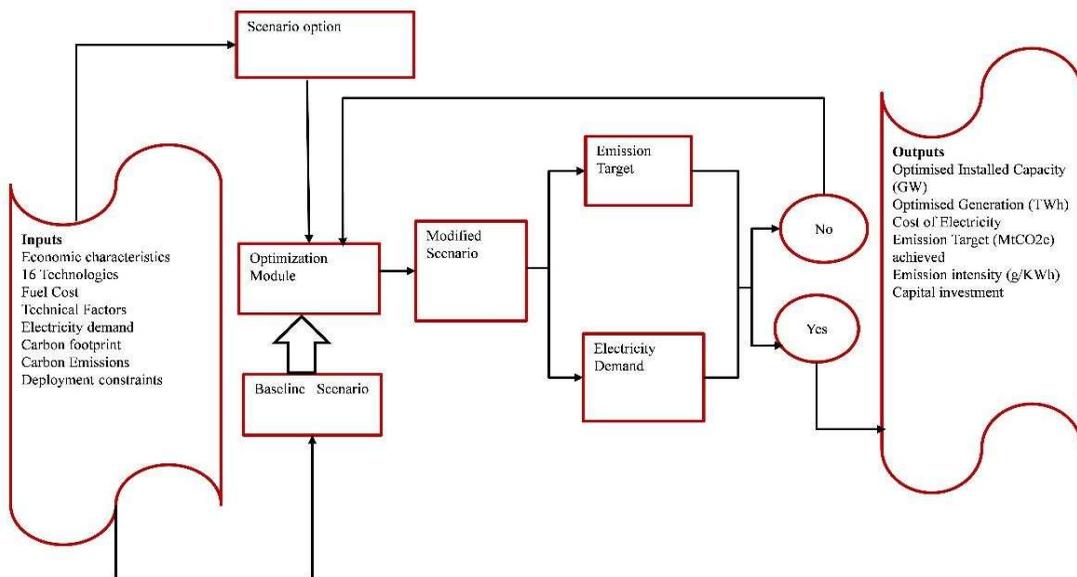


Figure 4: Main components and process flow of the 'Energy Optimisation Calculator'

## Cost of Energy

The cost of electricity (COE) generation methodology is used as a ranking tool to assess the cost-effectiveness of different energy generating technologies, (Short et al. 1995). In order to determine the investment options available across different technologies, the approach used in

## International Journal of Environmental Sustainability

this article considers the lifetime generated energy and costs to determine the price of electricity per unit energy generated.

Through this energy cost estimate, the model captures investment costs, operation and maintenance cost and fuel expenditures over the entire lifetime of the plant. Within the COE analysis, the stream of future costs and generation output are discounted by 10% to the present value. This assessment takes into account the likely impact of the sensitivity on construction costs, fuel costs and discount rates. The model formula used to calculate the COE is given as;

$$COE = \frac{I}{\left[ \frac{(1+r)^n}{r(1+r)^n} \right] * E} + \frac{TOM}{E}$$

where I is the capital investment (cost per kW multiplied by the total installed capacity), r is the discount rate at 10%, E is the annual electricity generation (TWh), n is the lifetime of the plant, TOM is the total operation and maintenance costs.

## Results and Discussions

### Shale gas and the transition pathways

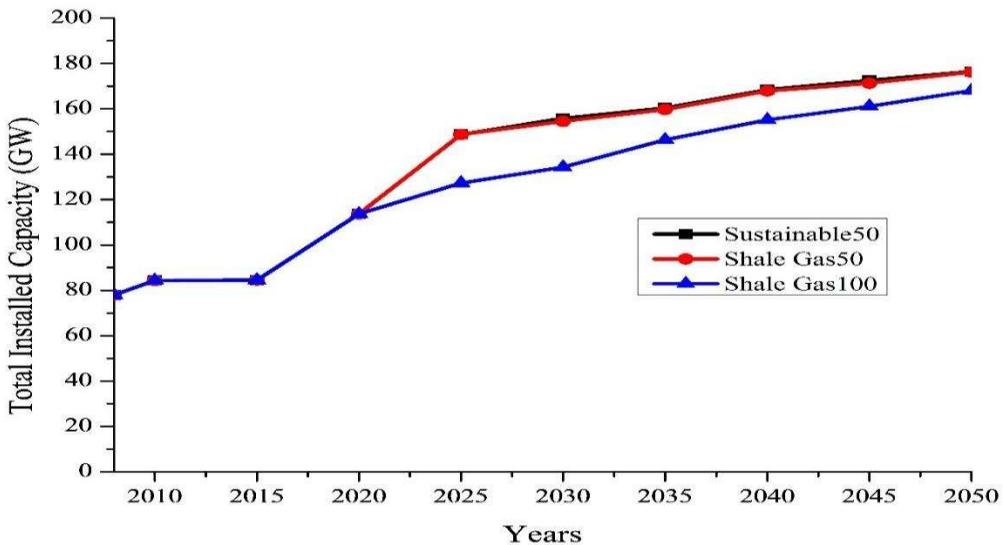
The Committee on Climate Change believes that any path to an 80% reduction by 2050 requires that the electricity generation is almost entirely decarbonized by 2030. Therefore, the 'path to 50g' decarbonisation framework seeks to reduce the carbon grid intensity from the current 500g/kWh to 50g/kWh by 2030 (Committee on Climate Change 2010). Decarbonising the electricity sector is viewed as the most effective way of rapidly reducing emissions as it reduces pressure on other sectors of the economy to decarbonise. On the other hand, the 'path to 100g' decarbonisation target is perceived by government as 'Plan B', likely to be adopted if low-carbon technology costs fall less quickly than anticipated or achievable build rates are lower than expected (Committee on Climate Change 2013a). Developments in shale gas and its benefits to the electricity sector are interpreted in the context of these two deep decarbonisation frameworks.

Due to the 50gCO<sub>2</sub>/kWh emission constraint, the Sustainable50 scenario has 96.1GW renewable energy capacity, which is 61.2% of total capacity compared to the Shale Gas50 scenario with 93.9GW renewable penetration accounting for 61% of total capacity by 2030. Low carbon technology penetration, mainly CCS and nuclear has a total of 17.4GW and 17GW capacity on the system, which is 11.1% and 11% of total installed capacity for Sustainable50 and Shale Gas50, respectively. Unabated gas capacity in Sustainable50 and Shale Gas50 amounts to 40.5GW, which is 25.8% and 26% of total capacity as illustrated in Fig.5 and Fig.6, respectively. Conversely, Shale Gas100 has 74.7GW renewable energy capacity which accounts for 57% of total capacity. Unabated gas capacity and low carbon installed capacity reaches 41GW and 15.7GW by 2030, respectively (see Fig.7). Under the decarbonisation framework, unabated shale gas use is limited, hence its impacts on low-carbon and renewable energy penetration is quite minimal as shown by the results.



## International Journal of Environmental Sustainability

Figure 8 illustrates the impact of the using conventional and shale gas on the overall installed capacities for three energy pathways from 2030 to 2050. Under the decarbonisation frameworks, the results indicate that total installed capacity remains high in Sustainable50 compared to the Shale Gas50 and Shale Gas100 from 2030-2050. This is due to the higher emission intensity (488gCO<sub>2</sub>/kWh) of conventional gas (Parliamentary Office of Science & Technology 2011) applied compared to the 423gCO<sub>2</sub>/kWh for shale gas (Department of Energy & Climate Change 2013). This results in more low-carbon technologies being deployed to compensate for low generation from emission intensive unabated conventional gas. According to the (AEA 2012), the shale gas emission factor is believed to be 2% to 10% lower than liquefied natural gas (LNG) imported from outside Europe. Therefore, this explains the increase in unabated generation in the two shale gas scenarios which curtails the low-carbon technology penetration comparative to the Sustainable50 pathway (Fig.8). The total installed capacity in Shale Gas100 is 17.4GW and 9.9GW lower than in the Sustainable50 and Shale Gas50 scenarios by 2050, respectively. This suggests that the 100gCO<sub>2</sub>/kWh emission intensity trajectory by 2030 allows for more gas generation at the expense of low carbon technologies, hence the lower overall installed capacity compared to pathways with deep emission targets.



**Figure 8: Impact of shale gas on overall installed generation capacities - 2030 to 2050**

The UK electricity demand is anticipated to increase by at least 30% to 100% by 2050 due to the electrification of heating and transportation (Department of Energy & Climate Change 2012b). High penetration of renewables through the 2020s will relegate unabated gas generation to a system peaking role (AEA 2012) by 2030 as the electricity generation base load is dominated by nuclear, biomass and fossil fuels with Carbon Capture and Storage (CCS). The transition to a low carbon electricity system in Sustainable50 and Shale Gas50 show 218TWh and 230TWh of total energy demand supplied from renewables, respectively. Low-carbon technologies contribute 137TWh and 135TWh to the total energy demand in 2030 in the two low-carbon pathways. This is consistent with the government's estimated 30-70GW new low-carbon capacity deployment target required to decarbonise the electricity sector by 2030 (HM Government 2011). This is illustrated in Fig.9 and Fig.10 where unabated gas generation in Sustainable50 and Shale Gas50 is limited to 9% and 10% of total generation in 2030 despite the 25.8 % and 26% installed capacity shown in (Fig.5 and Fig.6). This generation trend from unabated gas is inevitable as Combined Cycle Gas Turbine (CCGT) plants are anticipated to run at extremely low load factors, roughly below the 20% margin (Committee on Climate Change 2013a) as the sector decarbonises.

## Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

However, there are fears that large capacities of under-utilized CCGT plants could hinder future attempts to decarbonise the power sector in the UK due to ‘investment lock-in’ applied to CCGT (Chignell and Gross 2013). Huge investment in shale gas development and new CCGT plants could potentially lock the UK into years of shale gas use, thereby creating a major distraction from transitioning to a genuine zero-carbon grid (Broderick et al. 2011). From an investor’s perspective, the business case for retaining a large fleet of under-performing gas plants on the system could be hard to justify. Thus, the government would have to offer capital incentives to utility operators in order to keep their plants on stand-by to foster both system reliability and security of electricity supply.

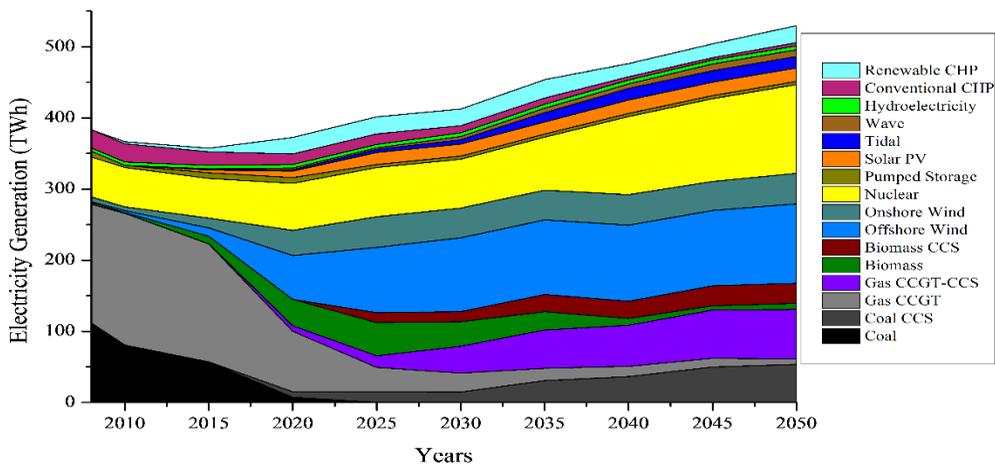


Figure 9: Electricity generation - Sustainable50

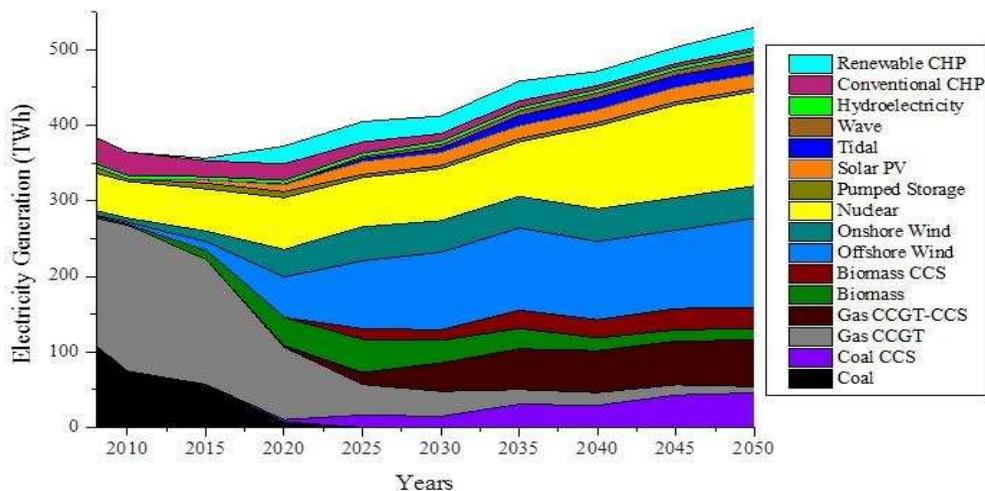
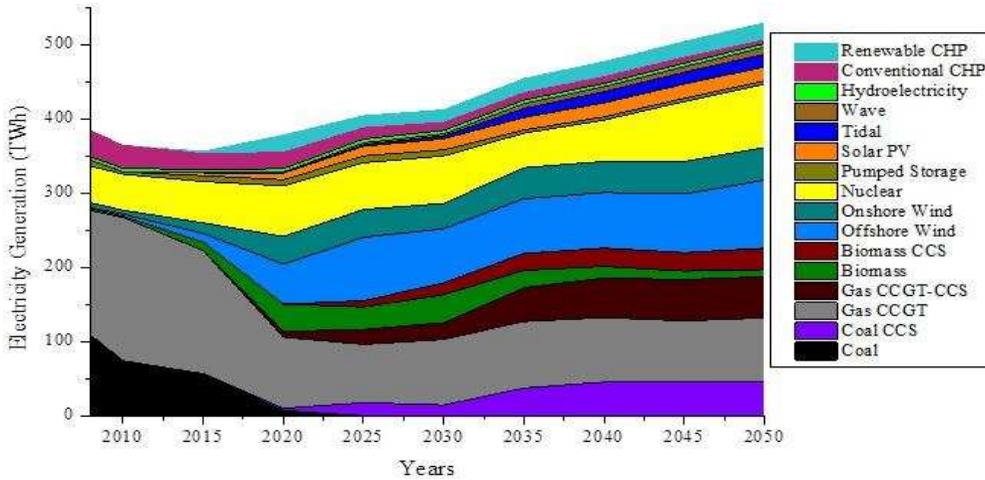


Figure 10: Electricity generation - Shale Gas50

Comparatively, the high emission trajectory target for Shale Gas100 scenario results in CCGT electricity generation totaling 21% (88.4TWh) of total electricity demand, while renewables and low-carbon generation only contribute 45% and 29% (187.6 TWh, 117.7TWh), respectively. The electricity generation profile for unabated fossil fuel highlighted in Fig.11

International Journal of Environmental Sustainability

results in carbon emission intensity of about 61.2g/kWh as the gas plants run at high load factors, about 48% by 2050. This is due to the low emission factor for shale gas (423gCO<sub>2</sub>/kWh) coupled with the 30% fuel price reduction, thus making shale gas generation a favourable option in this scenario. Increased electricity generation from gas reduces the output from renewable and low-carbon technologies, hence the high level of carbon emission intensity through the transition period compared to the Shale Gas50 and Sustainable50 (Fig.3).



**Figure 11: Electricity generation - Shale Gas100**

Electricity generation trends for unabated gas and gas with CCS shown in Fig.12 highlight the impact of different emission constraints and the introduction of lower emission shale gas in the mix. For all the three scenarios, the generation trend is similar up to 2020 due to the emission trajectory outlined in Table 1.2. After 2020, Shale Gas50 and Sustainable50 continue to decline at an identical rate until 2025. From 2030 through to 2050, the Sustainable50 unabated gas generation profile exhibits a steeper decline compared to the Shale Gas50 due to its higher emission factor which is judged to be 2% to 10% higher than that of shale gas. Thus, generation from lower emission alternatives are opted for at the expense of unabated gas generation to achieve the emission targets. In contrast, the Shale Gas100 generation profile declines slightly by 2025 and increases in 2030 and remains relatively high until 2050 in line with the higher emission target. The generation pattern is reversed with regards to gas with CCS applications. CCS gas generation trend in Sustainable50 and Shale Gas50 is almost identical, with total generation slightly higher than that of Shale Gas100. This is due to deeper decarbonisation required in the two scenarios while increased generation from unabated shale gas in Shale Gas100 curtails generation from shale gas with CCS.

## Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

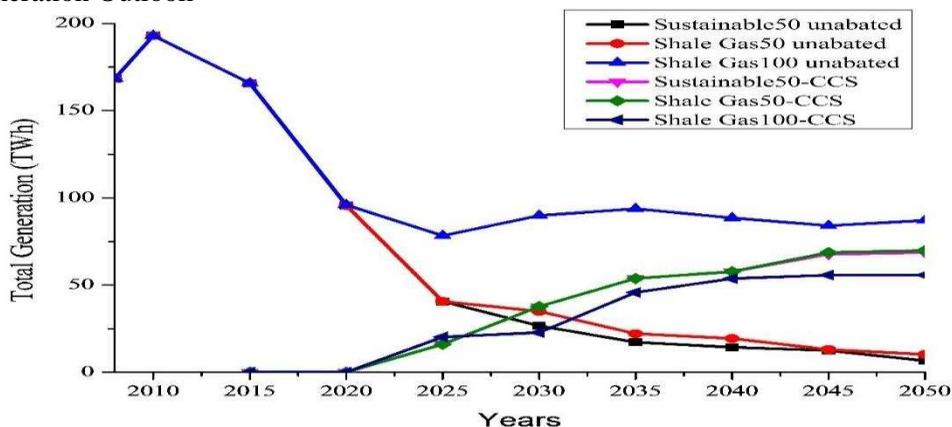


Figure 12: Comparative gas electricity generation - unabated and CCS

A scenario based study by (Jacoby et al. 2012) warned that a shale gas “revolution” could temporarily reduce interest in low-carbon emission technologies such as CCS. In retrospect, (Broderick et al. 2011) envisaged that £32billion investment in shale gas has the potential to displace 12GW and 21GW of offshore and onshore wind capacity, respectively. The economics of the ‘path to 50 and 100’ decarbonisation frameworks are illustrated in Figures 13 and 14 where the level of investment for each low-carbon technology from 2015 to 2030 is displayed. To achieve the 50gCO<sub>2</sub>/KWh by 2030, a £200billion capital investment in low-carbon generation is required for the electricity sector (Committee on Climate Change 2013a; Ofgem 2010). Large scale investment in wind and nuclear is dominant in all three scenarios with Sustainable50 recording £72.3billion in offshore wind compared to £70.8billion and £47.4billion in Shale Gas50 and Shale Gas100, respectively, (see Fig.13 and 14). Both scenarios have identical installed nuclear capacity amounting to £33.2billion. Onshore wind investments are high in Sustainable50 and Shale Gas50, that is £24.1billion and £24.2billion compared to £15.3billion in Shale Gas100.

Fossil fuel and biomass generation fitted with CCS could cost about £19.9 billion in Sustainable50, £17.8billion in Shale Gas50 while £12.1billion could be invested in Shale Gas100. However, it is important to note that CCS is yet unproven at a large scale and the level of deployment to 2030 is still uncertain. The investment proportion for the other technologies in all the three scenarios are shown in Fig.13. The government believes that this investment could be attracted through the implementation of the Feed-in Tariff with Contracts for Difference (FiT CFD), offering stabilized returns for investors in the form of strike prices (Department of Energy & Climate Change 2012c). Therefore, this mechanism has the benefit of providing greater long-term certainty to low carbon investors.

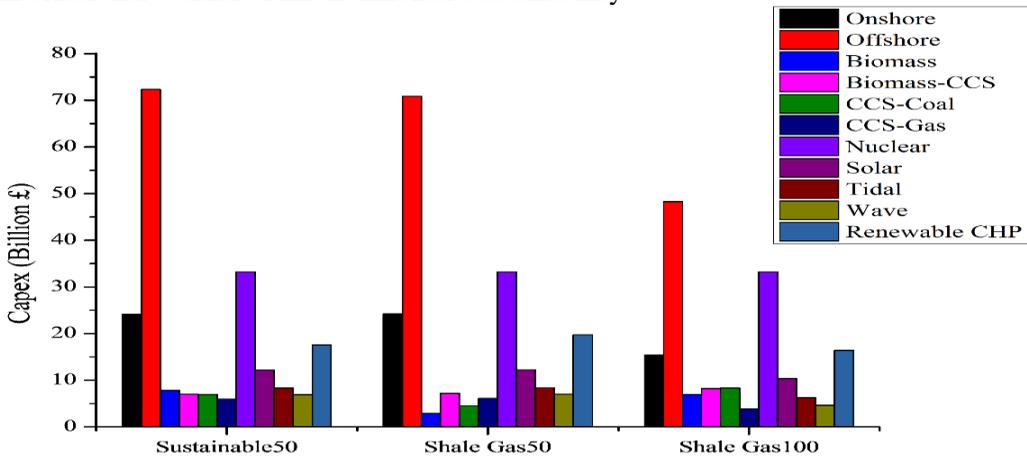


Figure 13: Low-carbon investment for pathways 2015 - 2030

The inclusion of shale gas in the generation mix could play a vital role in substituting imported gas to meet demand for gas fired generation for system balancing, (Committee on Climate Change 2013a). However, the increased government’s enthusiasm for shale gas development, coincides with the low-carbon investment drive targeting the 15% EU renewable energy target by 2020 (HM Government 2009) and the 80% emission reduction target by 2050. As a result, the level of investment for the decarbonisation pathways shown in Fig.14 could be affected as resources are diverted towards the development of shale gas (Schrug 2012). The shale gas industry acknowledges that significant quantities of shale gas are not likely to be produced until around 2025 by which time our commitments on climate change would not permit it to be combusted in any significant quantities (Anderson and Broderick 2014). At the backdrop of our strong climate change policies, the case for low-carbon investment is absolute. Sustainable50 and Shale Gas50 low-carbon portfolios to 2030 would require a total of £202.5billion and £197.4billion, respectively, while the Shale Gas100 would require £151.8billion to meet the decarbonisation trajectories outlined in Table 1.2 for the transition pathways. The investment portfolio for Shale Gas100 is lower compared to the other two scenarios but its overall emission performance could compromise on the UK’s contribution to reduce emission in line with the 2°C global carbon budget and the domestic budget.

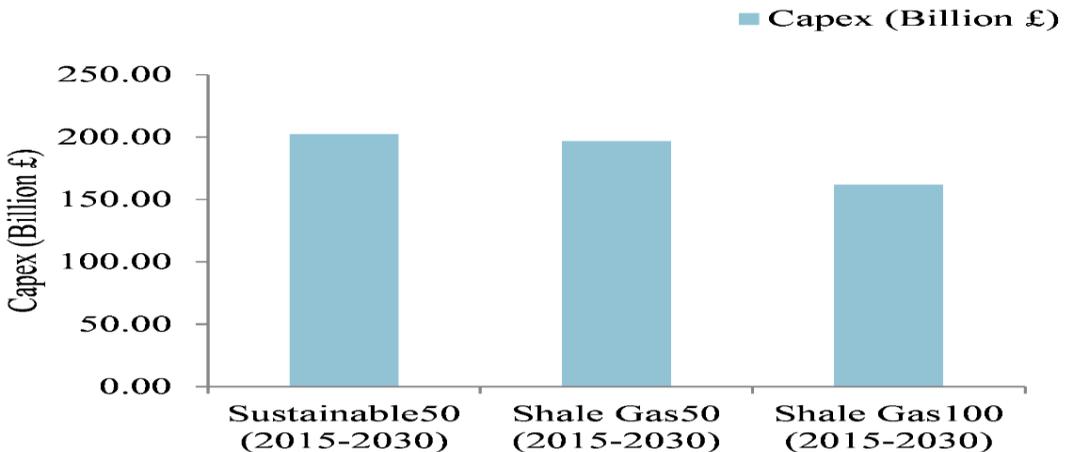


Figure 14: Total low-carbon investment outlay to 2030

## Sithole: The Impact of the “Shale Gas Revolution” on the United Kingdom Electricity Generation Outlook

### Conclusions

This paper has explored the implications of including shale gas in UK electricity generation mix in the context of the decarbonisation policy discourse. This analysis employed three scenarios; Sustainable50 and Shale Gas50 seeking to achieve a 50g/kWh carbon grid intensity by 2030 using conventional gas and shale gas in the generation mix, respectively. Shale Gas100 follows the ‘path to 100g’ targeting to meet 100gCO<sub>2</sub>/kWh carbon grid with shale gas employed in the generation portfolio. The impact of shale gas use on the UK electricity sector is measured in the context of the 2030 decarbonisation milestone, investment and penetration of renewable technologies.

Under the 50g/kWh carbon grid trajectory, unabated shale gas has a very limited role in the generation mix unless used in conjunction with CCS applications. The results suggest that the inclusion of shale gas under the deep emissions cuts will not diminish the requirement for low-carbon technologies to develop a zero carbon electricity sector by 2050. Under this abatement framework, Sustainable50 has a total of 96.1GW of renewable capacity by 2030 while the Shale Gas50 has 93.8GW of renewable capacity. The difference in installed renewable capacities in the two scenarios is a result of the increased generation from unabated shale gas in Shale Gas50 (8% compared to 6%) prompted by the 30% fuel cost reduction and lesser emission factor applied to shale gas. As a result, the level of investment in low carbon technologies in Shale Gas50 is in the order of £197.4billion compared to £202.5billion in Sustainable50 where unabated conventional gas has a very limited role in the generation mix. The penetration of low carbon technologies especially CCS is limited during this period as it is still at the early stages of commercialisation while new nuclear deployment is constrained by investment issues.

The benefits of shale gas can potentially be realized in the event of a 100g/kWh carbon grid intensity being adopted. The relatively higher emission trajectory characterising this pathway limits the penetration of low-carbon technologies. Unabated shale gas generation accounts for 21% (88TWh) of total generation resulting in 74.7GW and 15.7GW renewable and low-carbon installed capacity by 2030, respectively. This is almost 4% less than the renewable technology penetration realised through implementation of the 50gCO<sub>2</sub>/kWh abatement framework. This pathway has the benefit of reduced investment capacity in low-carbon technologies in the order of £151.8billion compared to over £200billion for the other two scenarios. Although the ‘path to 100g’ is compatible with the 80% target by 2050, the danger is that it is likely to put enormous pressure on other UK sectors of the economy to decarbonise. Shale gas use under this abatement level risks the UK’s global commitment to make a fair contribution to avoiding a 2°C rise in global temperatures (Anderson and Broderick 2014).

Despite the mounting calls for the electricity sector to be decarbonized by 2030, UK government has not yet provided a clear margin by which the sector should decarbonise. Therefore, developments in shale gas under the ‘path to 100 g’ have a greater potential to increase the cumulative emissions by 2050, thus compromising on the nation’s contributions to the global emission reduction. Since CCS is yet unproven at a large scale, developments in shale gas without a defined abatement framework will make the electricity sector decarbonisation agenda extremely difficult to achieve.

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