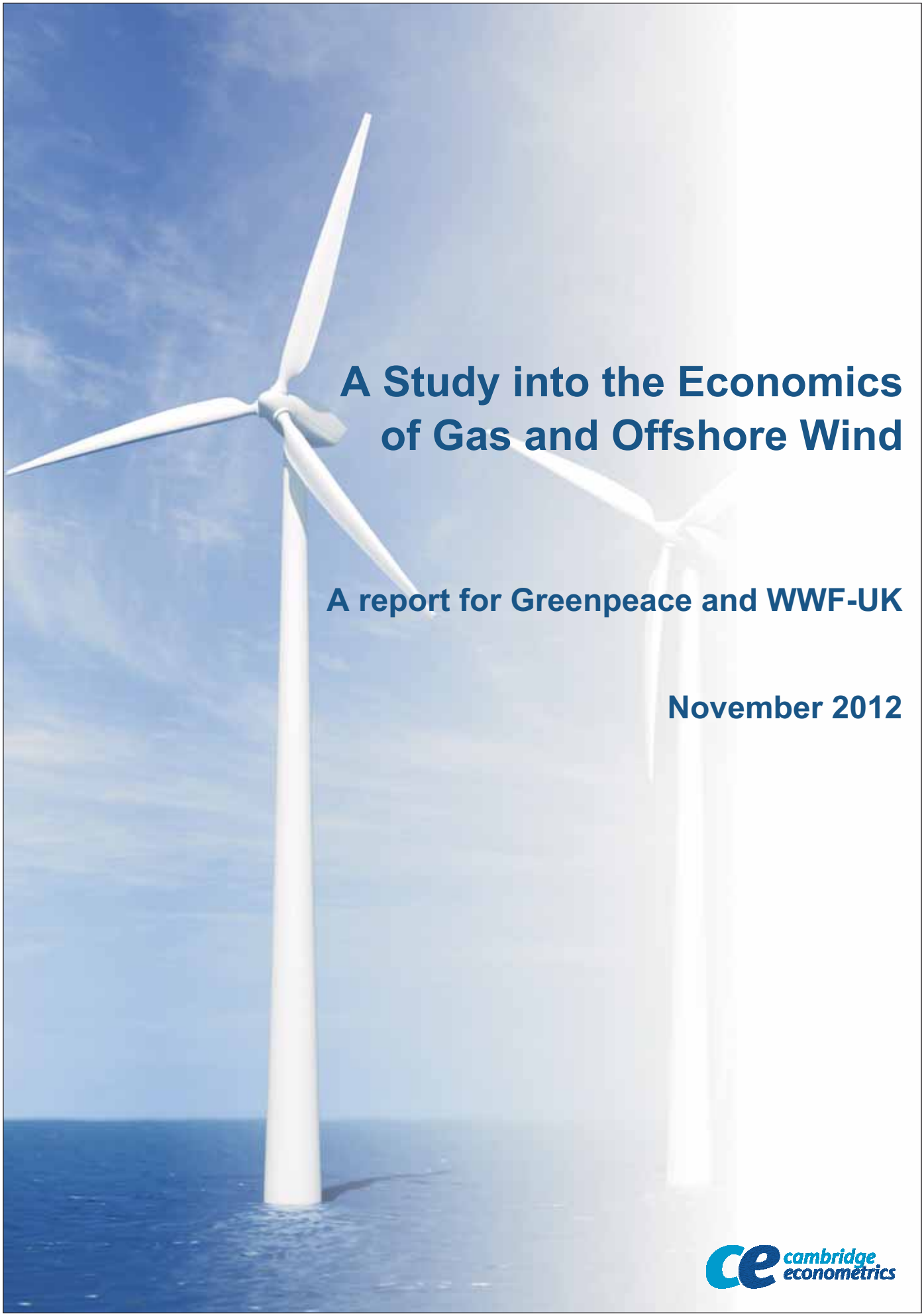

A Study into the Economics of Gas and Offshore Wind

A report for Greenpeace and WWF-UK

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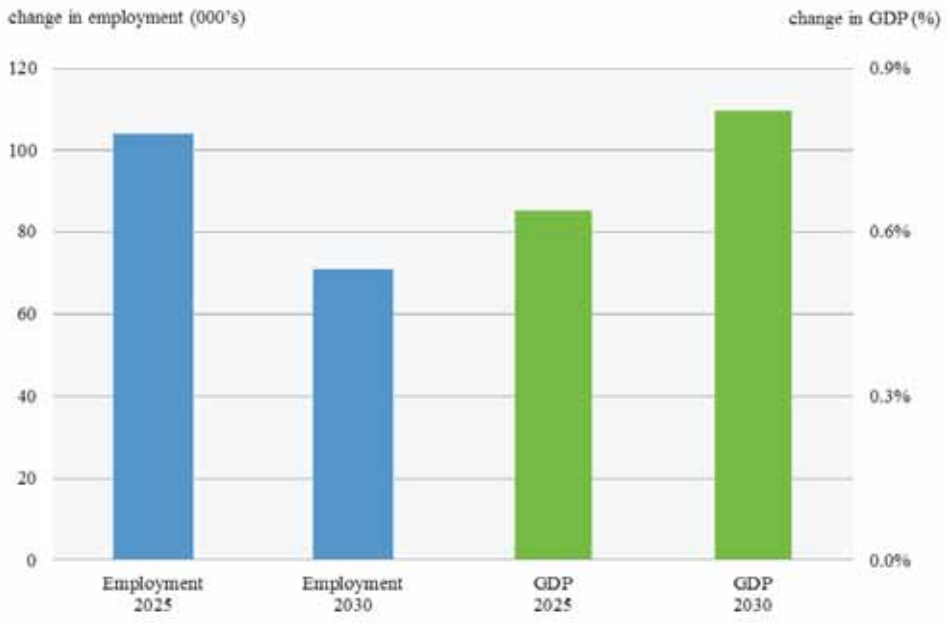
EXECUTIVE SUMMARY

Key findings

- This research finds that, compared to a future power system more heavily dependent on gas, large-scale investment in offshore wind would impact positively on UK GDP and employment. GDP increases by 0.8% by 2030 and there are over 100,000 additional jobs by 2025, falling to 70,000 additional jobs by 2030. The development of offshore wind capacity would stimulate construction and manufacturing demand over the period to 2030. In the longer term, it would prevent locking the UK into natural gas usage and imports.
- However, the scale of the macroeconomic impact depends on the location of the supply chain for offshore wind equipment. If the import content of offshore wind projects were to remain at current levels, the positive impact on GDP would be smaller (0.2% by 2030). Alternatively, if the development of the UK as a major global centre for offshore wind attracted investment in UK-based production, this could boost UK exports and lead to larger GDP gains.
- The impact on GDP and employment by 2025 and 2030 of a high offshore wind deployment scenario, compared to a scenario with high gas-fired generation, is shown in Figure ES.1.

Figure ES.1: Impact on GDP and Employment: WIND Scenario Compared to GAS Scenario



Notes : For Scenario definitions, please refer to Chapter 2.
Employment figures are full-time equivalent.

Background

- Greenpeace and WWF commissioned Cambridge Econometrics to assess the macroeconomic impact of large-scale offshore wind deployment, compared to a future with limited offshore wind power generation in the UK and, in its place, additional gas-fired generation.

The macroeconomic impact of large-scale offshore wind deployment

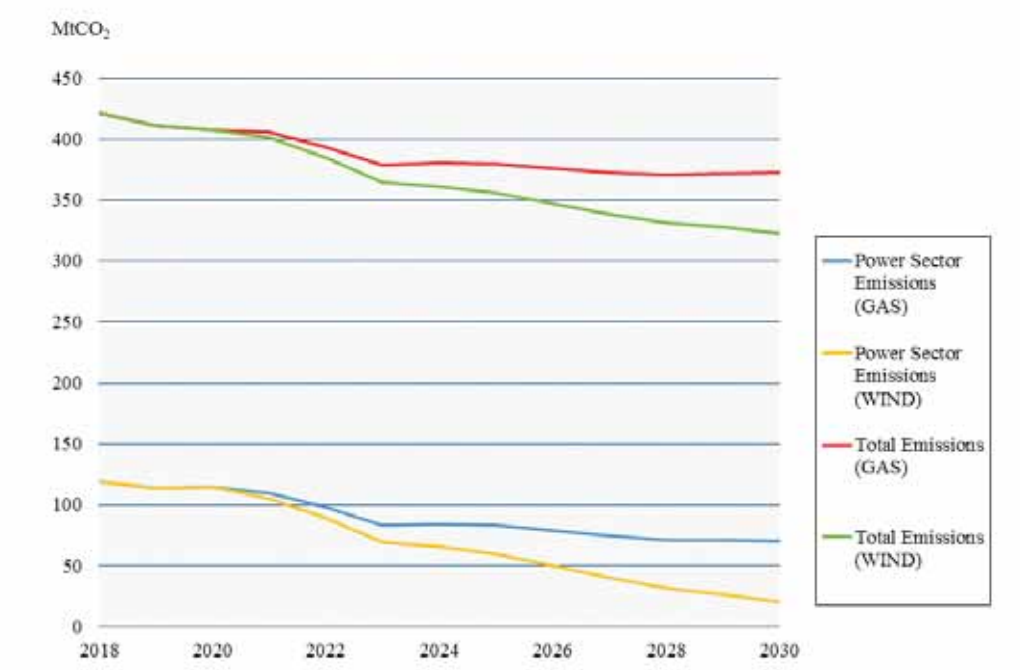
- Our analysis compares the economic outcomes of two alternative power generation portfolios to 2030. The first of these (labelled WIND) is similar to the Committee on Climate Change's (CCC) 65% renewable electricity scenario[1] with large-scale development of offshore wind, while the alternative case (labelled GAS) relies instead on existing and new gas plants to provide the UK's electricity. It should be noted that the scenarios compare deployment of (currently) the most expensive large-scale renewable energy option against unabated gas power generation. In the real world, however, a high renewables scenario would include lower cost technology options, as outlined in DECC's renewables roadmap. The scenarios are described in more detail in Chapter 2.
- The combination of falling capital costs for wind turbines and rising natural gas import prices means that offshore wind is only slightly more expensive than Combined Cycle Gas Turbines (CCGTs), by 2030. As a result, electricity prices in the WIND scenario are only 1% higher than in the GAS scenario in 2030; a very small difference compared to possible variation in relative prices caused by other factors such as changes in gas prices. This challenges the prevailing view that electricity produced by gas-fired plants will be much cheaper indefinitely.
- The model results show several important economic impacts. The construction work for large-scale investment in offshore wind boosts GDP and creates jobs (which are mainly high skilled) in the UK. However, as noted above, currently much of the investment is in equipment that is produced overseas. The GAS scenario also relies heavily on imports (of natural gas) but captures revenues for government through the carbon price floor. In the WIND scenario the UK pays slightly more for electricity but more of the value added of the supply chain is located in the UK. Total UK imports of natural gas are 45% lower in the WIND scenario by 2030, a reduction of almost £8bn annually.
- Despite a small increase in electricity prices, GDP is around 0.8% higher in the WIND scenario by 2030 because the domestic content (construction and manufacturing of offshore wind capacity) of electricity is higher than in the GAS scenario. The relative increase in GDP in the high offshore wind scenario is robust to all the key sensitivities we tested (see below). If a commitment to offshore wind led to major supply chain companies locating in the UK, it is likely that exports would also increase, serving to increase GDP further and create more jobs, but the potential impact of this is not included in the analysis presented here.

1 http://hmccc.s3.amazonaws.com/Renewables%20Review/The%20renewable%20energy%20review_Printout.pdf.

Levelised costs and the import content of gas and wind generation

- The study also assessed the prospective cost structures of gas and offshore wind power generation and compared the levelised costs for projects initiated between 2012 and 2030, with a range of assumptions and at varying discount rates. The findings draw on prior analysis and show that gas-fired generation is currently cheaper, for each unit of electricity generated over the lifetime of the plant, than offshore wind. However, as gas and carbon prices are expected to increase in the future and the unit costs of offshore wind farms are expected to decrease, this difference will become smaller.
- The results also show that a large proportion of the operating cost of a gas CCGT plant over its lifetime is imported because of the large imported fuel cost component (see Appendix D).
- At present a large proportion of the lifetime offshore wind farm cost also goes to imports, as offshore wind turbine manufacturing has so far remained largely outside the UK (see Appendix D). However, in a scenario with high offshore wind deployment, there would be the opportunity to attract investment into the UK supply chain, increasing the proportion of wind turbines that are designed and manufactured domestically.
- There is considerable scope for offshore wind costs, both capital and operating, to fall over time, as economies of scale and learning effects drive costs down. In addition, as offshore wind projects become established, the risk premium associated with the borrowing cost for offshore wind will be reduced; this is currently a major cost of offshore wind relative to new gas projects.

Figure ES.2: UK CO_2 Emissions



Notes : For Scenario definitions, please refer to Chapter 2.

Impact on CO_2 emissions

- UK power sector CO_2 emissions in the WIND scenario would be one-third of those in the GAS scenario in 2030, even though some gas-fired power is needed to provide backup when there is insufficient wind to meet power demand.
- The development of offshore wind capacity envisaged in the WIND scenario, coupled with other low carbon sources and measures to deal with the intermittency, meets the CCC's recommended target for the carbon intensity of the UK's power generation target of $50gCO_2/kWh$ by 2030 and would reduce total annual emissions in the UK by $50MtCO_2$ by 2030. The lock in to offshore wind would support decarbonisation consistent with the UK's legally binding emissions target for 2050 and encourage the development of the UK as an offshore wind technology leader.

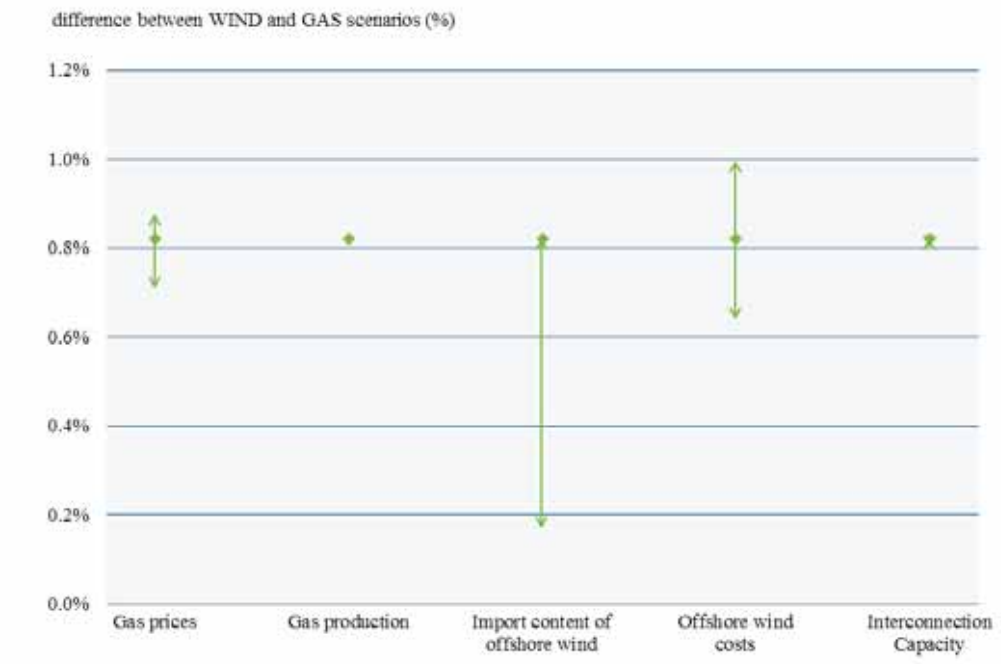
Sensitivity analysis

- To ensure that the results of the economic modelling analysis are robust, the following sensitivity tests were carried out (discussed in full in Chapter 5):
  - ***Natural gas prices:*** The sensitivities are the DECC low and high gas price assumptions. The impact by 2030 on GDP of moving from the GAS to the WIND scenario is 0.7% in a world of low gas prices and 0.9% in a world of high gas prices.
  - ***Domestic gas production:*** Shale gas could reduce the UK's dependence on natural gas imports, but this has no impact on the scenario results. The reason is that increased UK gas extraction represents a positive impact on GDP regardless of whether or not it is used in UK power generation. In the WIND case the gas is sold on the export market (which is not generally feasible for new shale gas in the USA).
  - ***The future costs of offshore wind projects:*** Offshore wind costs are expected to fall considerably as offshore wind capacity is deployed, but it is not clear by how much. Under the low capital cost sensitivity the impact on GDP between the WIND and the GAS scenario increases to 1%, while high capital cost projections reduce the impact on GDP to 0.6%.
  - ***The import content of offshore wind projects:*** If significant offshore wind capacity is deployed in the UK, it is possible that a substantial domestic supply chain will be developed. In the central WIND scenario, the import content of the capital required for an offshore wind project is projected to fall from 63% to 37% by 2030. If the import content of an offshore wind project were to remain at 63%, the positive impact on GDP by 2030 would be reduced to 0.2%.
  - ***The required interconnection capacity to support intermittency:*** The two scenarios contain the same level of interconnector capacity. However, the requirement may be less if there is a high level of gas generation, but our sensitivity test for this assumption did not materially affect the positive GDP impact of 0.8%.
- The results of the sensitivity analysis are shown in Figure ES.3. The results highlight the potential benefits of reducing the import content, and capital cost, of offshore wind projects, but still show that substantial emissions reductions could be made in the WIND scenario without a negative impact on the economy, even under conservative assumptions on import content and capital cost reductions for offshore wind. The assumptions tested on interconnection capacity, gas production and the

price of gas have only a small impact on the economic results. These are described further in Chapter 5 of this report.

- At the sectoral level the differences are also modest. Large-scale development of offshore wind is likely to benefit engineering, manufacturing and construction firms, and also possibly insurance and project financing companies. In contrast, utilities (including gas distribution) would benefit from increases in gas-fired generation.

Figure ES.3: Sensitivity Results for the WIND Scenario: Impact on GDP by 2030



Notes : For Scenario definitions, please refer to Chapter 2.
Diamond shows results under central assumptions.

Chapter 1: Introduction

1

1.1 Policy background

Current UK energy policy

The UK is fast approaching a critical point in energy policy, with decisions made in the next twelve months likely to shape the generation mix for decades to come. It is widely accepted that substantial investment is needed in new capacity, and that government policy will be highly influential in steering the mix of power generation technologies in the UK.

Recent legislation

The government proposed Electricity Market Reforms in July 2011. These identified four basic reforms of the electricity market to attract investment in low-carbon electricity supply and to maintain a secure electricity supply over the long term[3]:

- a new carbon price floor will be introduced from April 2013 to provide a long-term price signal for carbon in power generation
- long-term contracts are to be introduced for low-carbon generation through a 'contract for difference' (CfD) Feed-in-Tariff to replace the Renewables Obligation (RO)
- an Emissions Performance Standard will be set at 450g CO_2/kWh to limit the amount of carbon that coal-fired power stations will be allowed to emit
- a capacity mechanism will be introduced, involving additional payments to encourage the construction of reserve plants or demand reduction measures

European and long-term targets

As part of the Climate Change Act the UK is committed, by law, to reduce its greenhouse gas emissions by 80% in 2050 compared to 1990 levels. To meet the 2050 target, the government has put in place a series of five-year carbon budgets to reduce greenhouse gas emissions, as recommended by the Committee on Climate Change (CCC).

To supplement the long-term 2050 decarbonisation target, the CCC has also set a recommendation for emissions from power generation in 2030 to be less than 50gCO_2/kWh. Although gas-fired generation emits less carbon than the current electricity mix, it is not sufficiently clean to achieve the medium to long-term ambitions for decarbonisation.

As part of the European Renewable Energy Directive[4] the UK is also committed to meeting 15% of its final energy demand with energy from renewable sources, by 2020.

3 http://www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/emr_wp_2011.aspx.
4 Directive 2009/28/EC, see: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=Oj:L:2009:140:0016:0062:en:PDF.

The Energy Bill

The government's draft energy bill, published for pre-legislative scrutiny in May 2012, specifies additional reforms. The draft bill includes plans to initiate a final investment decision (FID) programme to encourage early investment and prevent any delays to investment decisions[5].

At the time of writing, the revised version of the bill is due to be put before parliament in Autumn 2012. The bill will provide the policy framework for many years of future investment in generating capacity. The current debate is whether the legislation and associated policy should favour:

- An increase in gas capacity: Gas plants are cheap to build so have relatively low up-front cost and can provide reasonably low cost electricity under current gas and carbon market conditions. However, they leave the economy reliant on gas imports, vulnerable to volatility and increases in international gas prices, and are too carbon-intensive to meet medium to long-term decarbonisation targets.
- Renewables (in particular wind): Renewables have a higher up-front cost and, at least for now, produce more expensive electricity. However, they do not produce emissions and have security of supply benefits, as, once in operation, they do not rely on fossil fuels for electricity production. Studies[6] also show that considerable reductions in future offshore wind generation costs are possible.

The wider economic context

The current economic climate features heavily in the policy debate, although the effects of the energy bill will long outlast the ongoing recovery. Nevertheless, the economic impact is an important consideration in the future development of the energy system.

Objective of this report

This report is intended to provide input to the current policy debate by considering the economic impacts of policies that favour gas or offshore wind-generated electricity. We construct two illustrative scenarios of the future, based on a primary role for each generation type, and use an integrated energy-economy-environment model of the UK to assess economic impacts in each case, focusing principally on GDP and employment levels. As there is considerable uncertainty in the long-term costs of each technology, the scenarios are tested in futures with different fuel prices and technology costs.

1.2 Report structure

Chapter 2 presents the scenarios that were assessed and the key assumptions in the modelling. The results from the assessment are presented in Chapters 3 (economic impacts) and 4 (environmental impacts). Chapter 5 discusses the sensitivity of results to the key input assumptions and Chapter 6 concludes.

Appendices A-C include a more detailed description of the MDM-E3 macro-econometric model, and tables of the main assumptions and more detailed results.

5 http://www.decc.gov.uk/assets/decc/11/policy-legislation/EMR/5349-electricity-market-reform-policy-overview.pdf.

6 See for example: http://www.thecrownestate.co.uk/media/305094/Offshore%20wind%20cost%20reduction%20pathways%20study. pdf.

Appendix D includes some of the key results of the levelised cost analysis undertaken in the first stage of this study.

Chapter 2: Scenarios

2

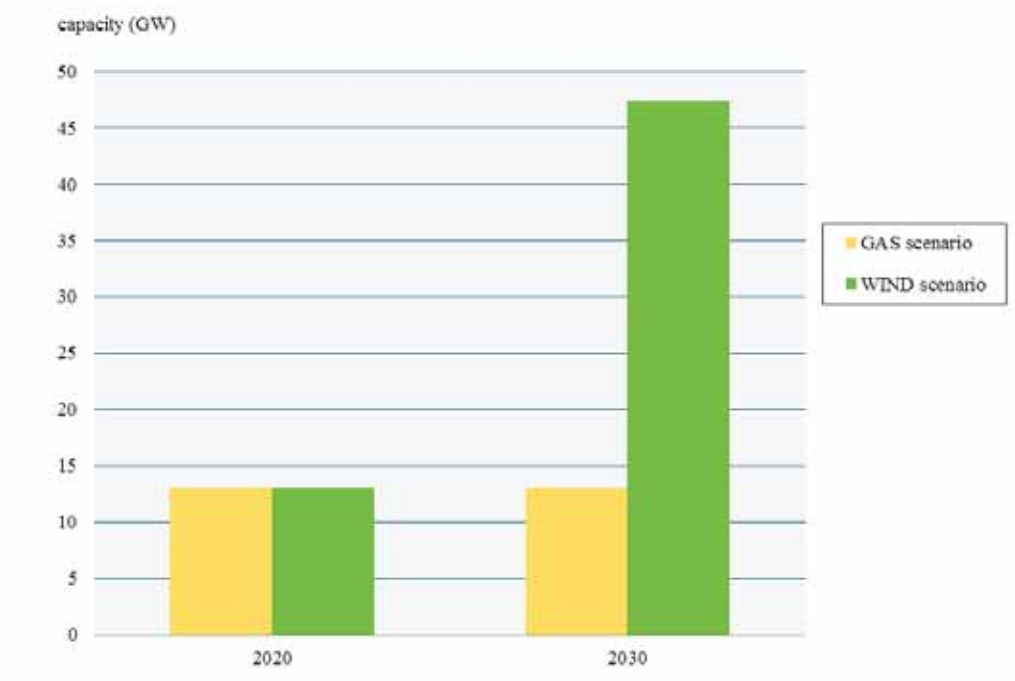
2.1 The CCC's 65% Renewable Energy Scenario (WIND)

Large-scale deployment of offshore wind

This scenario, with large-scale deployment of offshore wind, was built around the CCC's 65% Renewable Energy Scenario that was reported in the Renewable Energy Review[7]. It has the following key features:

- the CCC's 50gCO_2/kWh is met in 2030
- ambitious deployment of renewable energy technologies (3.4GW pa in years after 2020), with 177 TWh of electricity generated from offshore wind in 2030
- there is substantial development of interconnectors, demand-side response technology, pumped storage capacity and back-up gas capacity

Figure 2.1: Offshore Wind Capacity



7 http://hmccc.s3.amazonaws.com/Renewables%20Review/The%20renewable%20energy%20review_Printout.pdf.

The CCC scenario is built on Pöyry's "Very High" renewable deployment scenario as reported in *Analysing Technical Constraints on Renewable Generation to 2050*[8]. For renewable energy technologies this means taking the proposed deployment to 2020 outlined in DECC's National Renewable Energy Action Plan. These are then extended to 2030, based on the "Very High" scenario reported in the Pöyry 2011 study.

For other power generation technologies, the scenario includes projections to 2020 that are consistent with DECC's *Updated Energy and Emissions Projections, 2011*. These have also been extended in line with the "Very High" scenario reported by Pöyry. The supporting infrastructure required for this scenario is consistent with the Pöyry report, and discussed in Section 2.3.

In the following chapters, this scenario is referred to as WIND.

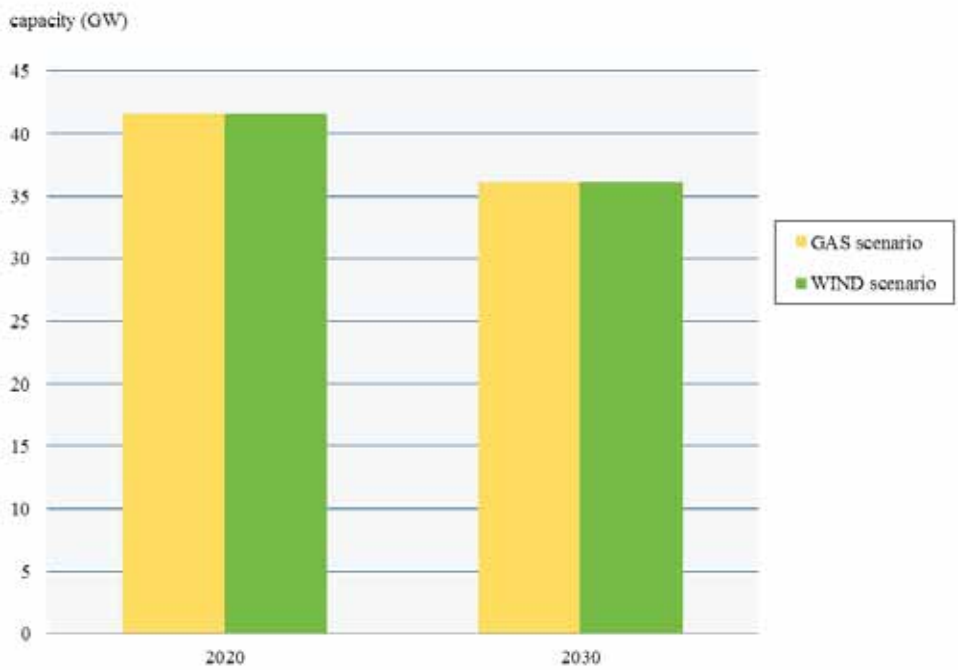
2.2 No Round 3 Offshore Wind Development (GAS)

Increased generation from gas

The alternative scenario excludes the high levels of offshore wind deployment from 2020 onwards (3.4GW pa), in the WIND scenario. This scenario is referred to as GAS in the results chapters. Its key features are:

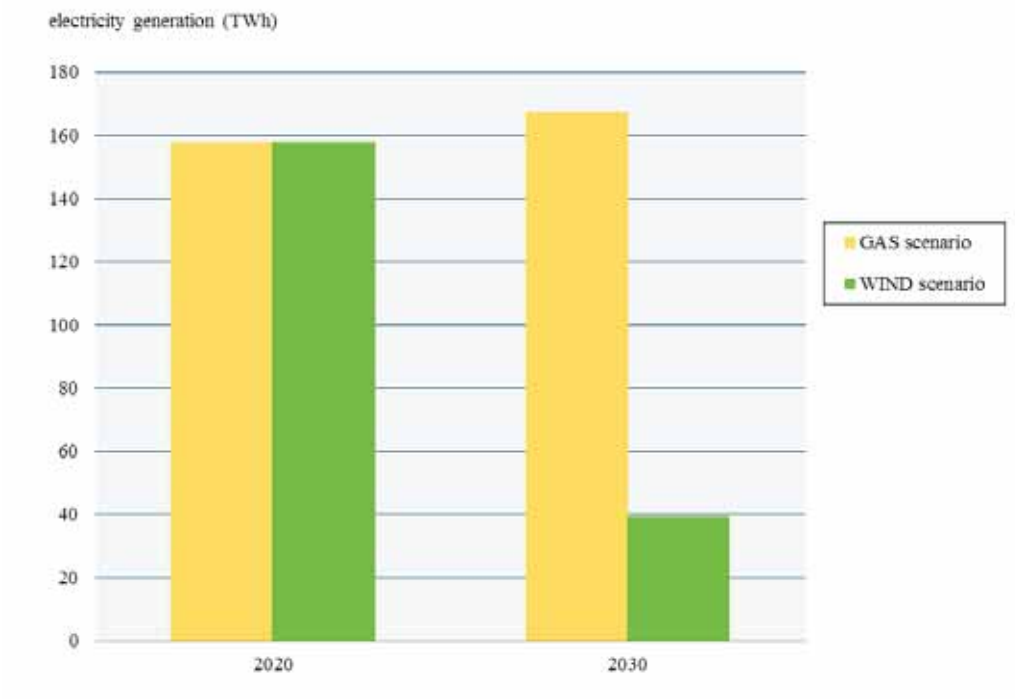
- the CCC's 50gCO_2/kWh is not met in 2030 (the intensity is 150gCO_2/kWh)

Figure 2.2: Gas CCGT Capacity



8 See Table 2.2 for the source of these and the other references used to form the assumptions.

Figure 2.3: Gas-fired Electricity Generation



- there is no further deployment of offshore wind post 2020 and demand is met by the existing gas CCGT capacity

The deployed capacity of all generation technologies is the same in the period up to 2020 as the WIND scenario. This includes deployment of offshore wind and other renewable technologies that are consistent with DECC's National Renewable Energy Action Plan. As Figure 2.1 shows, capacity in offshore wind is 13 GW by 2020 and remains at that level in the GAS scenario. This is broadly in line with the development of nearly all Offshore Round 1 and 2 developments, Round 2 extension developments, and Scottish Territorial Waters (STW) developments. However, none of the expected Round 3 offshore wind projects are deployed - which would be expected to add around 36 GW of offshore wind capacity (see Table 2.1).

For the GAS scenario, gas-fired generation is a substantial part of the generation mix and the gas plants are not required to deal with the intermittent electricity from offshore wind. However, there are still intermittent sources of electricity in the generation mix in this scenario. As a result we assume that the interconnector capacity and pumped storage capacity remain unchanged between scenarios (see Section 2.3), although we do test this assumption (see Section 5.6)

Use of carbon price floor revenues

In this scenario, part of the cost of electricity to consumers take the form of revenue to government from its carbon price floor. The assumption is that these revenues are recycled back into the economy through a reduction in VAT, so that the scenario is directly revenue neutral. A tax cut was selected over government spending, so that the size of the government sector in the economy remains the same in both scenarios. VAT

Table 2.1: Planned Offshore Wind Sites in the UK

	MW Capacity	Status
Round 1		
Barrow	90	Operational
Beatrice Demo	10	Operational
Blyth	4	Operational
Burbo Bank	90	Operational
Gunfleet Sands I & II	173	Operational
Lynn & Inner Dowsing	194	Operational
Kentish Flats	90	Operational
North Hoyle	60	Operational
Rhyl Flats	90	Operational
Robin Rigg	180	Operational
Scroby Sands	60	Operational
Teesside	62	Under Construction
Subtotal	*1,103*	
Cumulative Total	*1,103*	
Round 2		
Thanet	300	Operational
Walney I	183	Operational
Greater Gabbard	504	Operational
Gwynt Y Mor	576	Under Construction
Lincs	270	Under Construction
London Array I	630	Under Construction
Ormonde	150	Operational
Sheringham Shoal	317	Under Construction
Walney 2	183	Operational
London Array II	370	Under Construction
Humber Gateway	300	Approved
West of Duddon Sands	389	Approved
Westermost Rough	240	Approved
Dudgeon	580	Approved
Race Bank	620	Approved
Triton Knoll	1,200	Submitted IPC
Subtotal	*6,813*	
Cumulative Total	*7,916*	
Round 1 and 2 Extension Sites		
Galloper Wind Farm	504	Submitted IPC
Kentish Flats 2 Extension	51	Submitted IPC
Burbo Bank Extension	234	Site Awarded
Walney Extension	750	Site Awarded
Subtotal	*1,539*	
Cumulative Total	*9,455*	

Table 2.1: Planned Offshore Wind Sites in the UK (continued)

	MW Capacity	Status
STW		
Argylll Array	1,800	Exclusivity Agreement Awarded
Beatrice	1,000	Submitted to Marine Scotland
Inch Cape	905	Exclusivity Agreement Awarded
Islay	690	Exclusivity Agreement Awarded
Neart na Gaoithe	450	Submitted to Marine Scotland
Subtotal	*4,845*	
Cumulative Total	*14,300*	
Round 3		
Moray Firth	1,300	Submitted to Marine Scotland
Firth of Forth	3,465	Site Awarded
Dogger Bank	12,800	Site Awarded
Hornsea	4,000	Site Awarded
East Anglia	7,200	Site Awarded
Rampion	665	Site Awarded
Navitas Bay Wind Park	1,200	Site Awarded
Bristol Channel	1,500	Site Awarded
Celtic Array	4,185	Site Awarded
Subtotal	*36,315*	
Cumulative Total	*50,615*	

Source: Renewable UK database.

was selected as it is a tax on consumption, and so it acts to offset the impact on inflation of a carbon price floor, there is therefore a shift in relative prices, with carbon-intensive goods and services becoming more expensive.

2.3 Key assumptions and data sources

The main data sources

The results from this study are dependent on a number of key assumptions. To ensure neutrality in approach, we have matched assumptions and baseline projections with DECC and CCC forecasts as closely as possible. Where official government projections are not available, for example estimates of technology costs, results have been taken from established and peer-reviewed studies. Table 2.2 outlines the data sources that were used.

Table 2.2: Data Sources

Assumptions	Source
Baseline economic projections	OBR's forecast to 2016, with the years from 2016-30 based on the latest MDM-E3 economic forecast
Fossil fuel price assumptions	DECC (2010) Fossil Fuel Price Projections[9]
Domestic gas production assumptions	DECC (2012), UKCS Oil and Gas Production Projections[10]
Costs of renewable technologies	Mott MacDonald (2011) Costs of low-carbon generation technologies[11]
Borrowing costs	Oxera (2011) Discount rates for low-carbon and renewable generation technologies[12]
Carbon prices and carbon price floor	DECC (2011) Carbon Values used in DECCs energy modeling[13]
Interconnection costs	Pöyry (2011) Analysing Technical Constraints on Renewable Generation to 2050[14]
Capacity and generation	DECC (2010) National Renewable Energy Action Plan[15]
	DECC (2011) Updated Emissions Projections[16]
	CCC (2011) Renewable Energy Review 65% renewable scenario[17]
	Pöyry (2011) Analysing Technical Constraints on Renewable Generation to 2050, Very High renewable scenario[18]

Notes :
1 http://www.decc.gov.uk/en/content/cms/about/ec_social_res/analytic_projs/ff_prices/ff_prices.aspx.
2 http://og.decc.gov.uk/assets/og/data-maps/chapters/production-projections.pdf.
3 http://hmccc.s3.amazonaws.com/Renewables%20Review/MML%20final%20report%20for%20CCC%209%20may%2011.pdf.
4 http://hmccc.s3.amazonaws.com/Renewables%20Review/Oxera%20low%20carbon%20discount%20rates%20180411.pdf.
5 http://www.decc.gov.uk/assets/decc/11/cutting-emissions/carbon-valuation/3138-carbon-values-decc-energy-modelling.pdf.
6 http://hmccc.s3.amazonaws.com/Renewables%20Review/232_Report_Analysing%20the%20technical%20constraints%20on%20renewable%20generation_v8_0.pdf.
7 http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/renewable%20energy/ored/25-nat-ren-energy-action-plan.pdf.
8 http://www.decc.gov.uk/assets/decc/11/about-us/economics-social-research/3134-updated-energy-and-emissions-projections-october.pdf.
9 http://www.decc.gov.uk/assets/decc/11/about-us/economics-social-research/3134-updated-energy-and-emissions-projections-october.pdf.
10 http://hmccc.s3.amazonaws.com/Renewables%20Review/232_Report_Analysing%20the%20technical%20constraints%20on%20renewable%20generation_v8_0.pdf.

Other important assumptions

The scenarios are intended to illustrate the differences between offshore wind and gas-fired generation. They are not intended to be prescriptive. We make the following simplifying assumptions:

- A conservative assumption is that gas CCGT capacity is the same in both scenarios, acting as a main source of supply (and providing some back-up flexibility) in the GAS scenario and as a back-up to intermittency in the WIND scenario. As a result, only gas power *generation* differs between the two scenarios.
- In the WIND scenario, the following measures are in place to deal with intermittency:
  - 15.4 GW of interconnection capacity
  - 36.0 GW of (back-up) gas capacity (as described above)
  - 4.0 GW of pumped storage capacity
  - smart grid and smart meter investment of £2bn per annum

- In the GAS scenario, there are still measures in place to deal with the intermittency from other renewable sources but, as gas-fired generation is now key to electricity supply in this scenario, there is far less scope for it to serve as back-up capacity. The intermittency measures are therefore as follows:
  - 15.4 GW of interconnection capacity
  - 4.0 GW of pumped storage capacity
  - smart grid and smart meter investment of £2bn per annum
- The GAS scenario does not envisage substantial new gas capacity. Both the GAS and the WIND scenarios include a relatively stable gas capacity growing to around 42 GW in 2020 as new capacity is added to replace falling coal and nuclear capacity, before falling to 36 GW in 2030 as older gas stations are decomissioned (see Figure 2.2). This is based on assumptions consistent with the projections in the DECC UEP, and Pöyry[9].
- The investment differences between the two scenarios therefore represent the investment in additional offshore wind capacity only, and its impact on the supply chain, the electricity system and electricity price.
- It is assumed that domestic gas production is the same in both scenarios and that gas exploration is unaffected by the scale of UK gas CCGT power generation[10]. We take the view that gas extraction is influenced by global demand and world gas prices, which the scale of UK gas-fired generation is too small to affect. In recent years the UK has become a small but growing hub for international gas trade and data suggest that domestic UK production is not affected by domestic demand, since both imports and exports have been increasing while domestic production has fallen[11].
- The scenarios are intended to show different ways of meeting the same projected demand for electricity. Final energy demand in the scenarios is therefore treated as exogenous, despite the slightly higher electricity price in the WIND scenario. The results show the impact of switching generation technology rather than changing the level of total generation. In reality, it is likely that electricity demand would respond to slightly higher electricity prices in the WIND scenario but, by keeping demand consistent, the scenarios show the difference between two technology alternatives that deliver the same amount of electricity to end users.
- The EU ETS allowance price is set by assumption, as UK demand for carbon makes up a relatively small share of total EU demand. Therefore higher UK emissions in the GAS scenario are unlikely to have a large impact on the EU ETS allowance price. The carbon price floor is also given as exogenous (and is higher than the EU ETS price).
- We assume that the flow of income arising from higher purchases of ETS allowances by the UK power generation sector in the GAS scenario goes to institutions elsewhere in Europe, since UK auctioned allowances are fixed in both

9 The Pöyry "Very High" scenario includes 36 GW of back-up gas capacity to deal with intermittency.
10 This is tested as part of the sensitivity analysis presented in Chapter 5.
11 Digest of United Kingdom Energy Statistics 2012 (DUKES), available online at: http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx.

scenarios, and it is assumed that the extra allowances would need to be bought on the EU market. We also assume that all additional carbon price floor revenues in the GAS scenario flow directly back into the UK economy to government and therefore allow government to reduce other taxes. In this modelling exercise VAT is reduced to keep the two scenarios neutral in fiscal terms. In the WIND scenario the carbon price floor has less impact on electricity prices than in the GAS scenario, as less carbon is emitted.

Chapter 3: The Macroeconomic Impact

3

3.1 Introduction

The MDM-E3 model

The two scenarios were assessed using an integrated energy-economy-environment model of UK economy, MDM-E3. MDM-E3 is a macro-econometric model that has been developed for forecasting and for policy analysis. It is particularly well suited for this type of assessment because it includes:

- a technology-based treatment of the power sector, including explicit representation of gas and offshore wind generation technologies
- two-way linkages between the economy and the energy system
- a detailed sectoral representation of the UK's economy, based on the National Accounts framework

The model is described in more detail in Appendix A.

Interpretation of results

Both scenarios assume current policy up to 2020 and therefore produce identical results over this period. The scenarios then consider two alternative future states in the period up to 2030. In the WIND scenario, there is a large amount of investment in offshore wind capacity; this investment stimulates economic growth and creates jobs, but must be paid for through slightly higher electricity prices. The difference between wholesale electricity prices in the scenario is small and by 2030 the wholesale electricity price is just 1% higher in the WIND scenario (see Table 3.1).

Table 3.1: Electricity Prices

		GAS	WIND % diff
Wholesale electricity price (p/kwh)	2020	7.73	0.0
	2025	9.18	3.5
	2030	10.55	1.0
Consumer Price Index (2011=1.00)	2020	1.27	0.0
	2025	1.45	0.3
	2030	1.67	0.2

Notes : Wholesale electricity price is presented in nominal prices.
Sources : Cambridge Econometrics.

In the alternative GAS scenario the investment in offshore wind capacity is not made. Gas-fired generation is a large part of the generation mix and the supply of gas continues to be predominantly met by imports. We have assumed that the sterling exchange rate is the same in both scenarios, so that differences in import demand do not result in devaluation effects.

The net macroeconomic impact, in terms of GDP and employment levels, is a result of two key factors:

- the impact of higher electricity prices on households and businesses
- the impact of the choice of power generation technology on domestic and import supply chains

These factors are described separately in the next two sections. The final section in this chapter describes the combined macroeconomic impacts.

3.2 Price impacts

Electricity costs and prices

The modelling assumes that electricity prices are determined by the cost of generating electricity across the entire mix of generation technologies used in either scenario, including:

- capital costs
- operating and maintenance costs (fixed and variable)
- fuel costs
- carbon costs

It is assumed that any increase in any one of these costs is passed on to consumers in the form of higher electricity prices. The methodology used to determine the necessary increase in prices is similar to that of 'levelised' costs. However, instead of including lifetime fuel and carbon costs and expected lifetime electricity generation (as levelised costs do), the annualised generation costs include the variable fuel and carbon costs on an annual basis, dependent on the fuel and carbon costs and electricity output, in each future year.

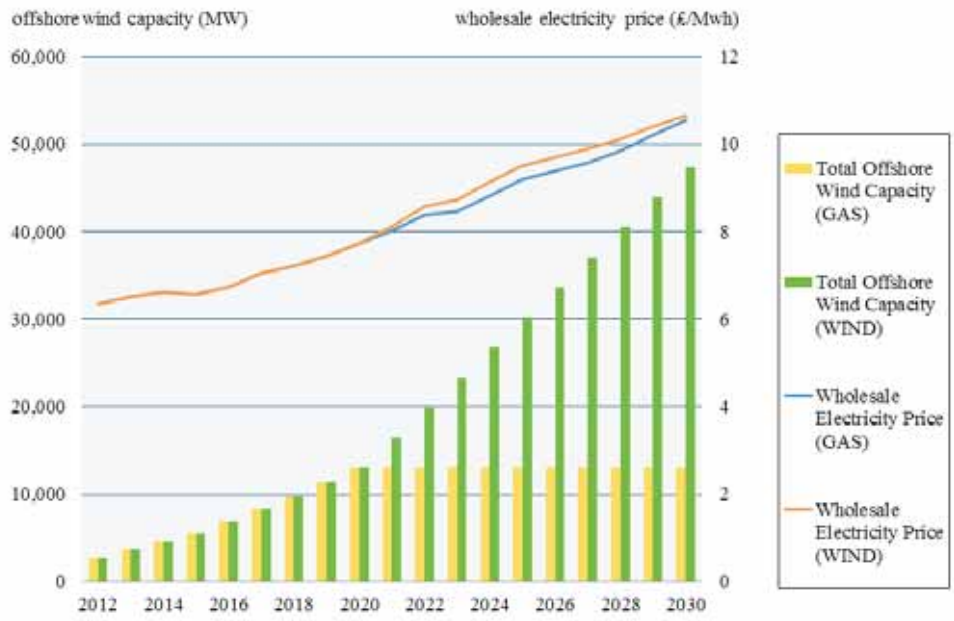
The different cost components vary substantially between the technologies. For offshore wind, capital costs account for by far the largest share, as offshore wind does not have fuel and carbon costs. Moreover, the risk premium associated with offshore wind projects is currently high and, although this is expected to fall over time as deployment of offshore wind increases, borrowing costs are currently a significant contributor to the total cost of offshore wind projects.

For gas generation, fuel costs are the largest single component.

Evolution of costs over time and between scenarios

It is also important to note that these costs change over time and vary between scenarios. In the WIND scenario the capital, and therefore total, costs of offshore wind gradually decrease over time due to learning and scale effects. These cost reductions continue to

Figure 3.1: Offshore Wind Capacity and the Wholesale Electricity Price



Notes : Prices are in nominal terms.

2030, while gas generation costs increase over time due to higher fuel and carbon prices[12].

In the GAS scenario, offshore wind capital costs do not fall after 2020 since there are no increases in capacity after this point. However, the overall cost does fall slightly because of small reductions in operation and maintenance costs as a result of learning and efficiency gains. The cost of gas-fired generation increases as the carbon price and gas price increase, in line with DECC's central price assumptions.

Figure 3.1 shows the impact of substantial offshore wind capacity deployment (in the WIND scenario) on the wholesale electricity price. For comparability with other studies, the input costs are included in Appendix B while a series of levelised costs are included in Appendix D.

Fuel and carbon price assumptions

The estimates of future costs for gas generation are dependent on the assumptions about carbon prices and, in particular, gas prices. These are therefore very important inputs to the analysis. Sources for all the assumptions are provided in Section 2.3, and a summary of the key cost assumptions is given in Appendix B. In Chapter 5 the scenarios are tested under different fuel price assumptions.

12 These figures were derived from Mott MacDonald (2011) Costs of low-carbon generation technologies. See: http://hmccc.s3.amazonaws.com/Renewables%20Review/MML%20final%20report%20for%20CCC%209%20may%202011.pdf.

Other assumptions

The breakdown of the different components of electricity costs is provided in Appendix B. There is also further discussion and sensitivity testing in Chapter 5 relating to the other cost assumptions that are imposed.

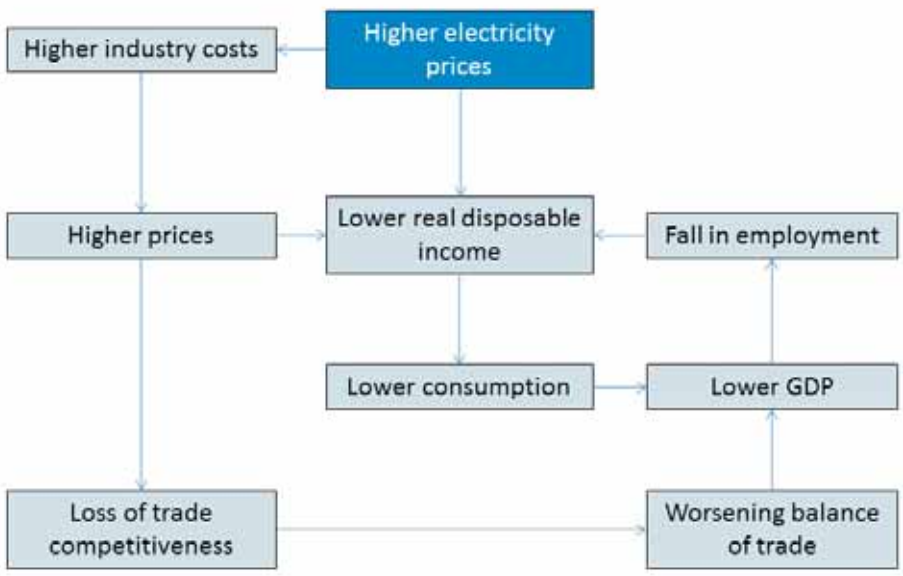
Electricity prices and the wider economy

Electricity is used in almost all sectors of the economy, and accounts for 1-2% of total household expenditure. An increase in the electricity price would therefore be expected to have quite a wide range of effects. Figure 3.2 provides a summary of these expected impacts.

Table 3.1 shows that at the macroeconomic level the impacts on prices are quite small. In 2025, there is a small increase in electricity prices in the WIND case compared to the GAS scenario, and this has a small impact on the Consumer Price Index (CPI): the 3.5% increase in electricity prices is associated with a 0.3% increase in the aggregate price index (taking account of other indirect effects on prices). In 2030, electricity prices are only higher by around 1% in the WIND scenario, and so the effect on the CPI is even smaller.

The reason for higher electricity prices in the WIND scenario is principally due to the cost of the back-up gas in place to deal with higher levels of intermittency, rather than the direct cost of offshore wind electricity generation, which is only slightly higher than gas-fired generation after 2020. The cost of gas-fired back-up generation in the WIND scenario is high because the cost of the capital for the gas-fired capacity and the fixed operating costs are recouped for falling amounts of gas-fired generation.

Figure 3.2: Economic Impacts of Higher Electricity Prices



Although there is a small increase in the wholesale electricity price for the assumed gas price increases, investment in offshore wind capacity reduces the exposure of UK electricity consumers to volatility in the gas price[13].

3.3 The impact on supply chains

Supply chains and multipliers

The basis for the supply chain analysis is that costs to one company are revenues to another company. The assessment is similar in nature to 'multiplier' analysis, an advanced form of which is embedded into the MDM-E3 model's National Accounting system[14].

Each of the cost components described in the previous chapter has associated revenues for firms or individuals outside of the electricity sector. However, the nature of these supply chains, and who ultimately benefits, vary substantially between the different components of the various technologies. Figure 3.3 summarises the key linkages for capital, fuel and carbon costs (maintenance costs are much smaller in size and more widely distributed).

Impacts in these scenarios

A switch from gas to offshore wind generation, as represented by the change from the GAS to the WIND scenario, will:

- increase output in sectors in the supply chain for capital costs
- reduce output in the sectors in the supply chain for fuel costs
- reduce government revenues from the carbon price floor[15]

Import shares

These supply chains are international and not all the companies that stand to gain or lose are based in the UK. Of particular relevance to the scenarios in this report is the level of imports in:

- natural gas
- manufacture of wind turbines

The UK became a net importer of gas in 2004 and, by 2011, imports accounted for 65% of total gas supply in the UK[16]. As UK production of gas is largely independent of gas

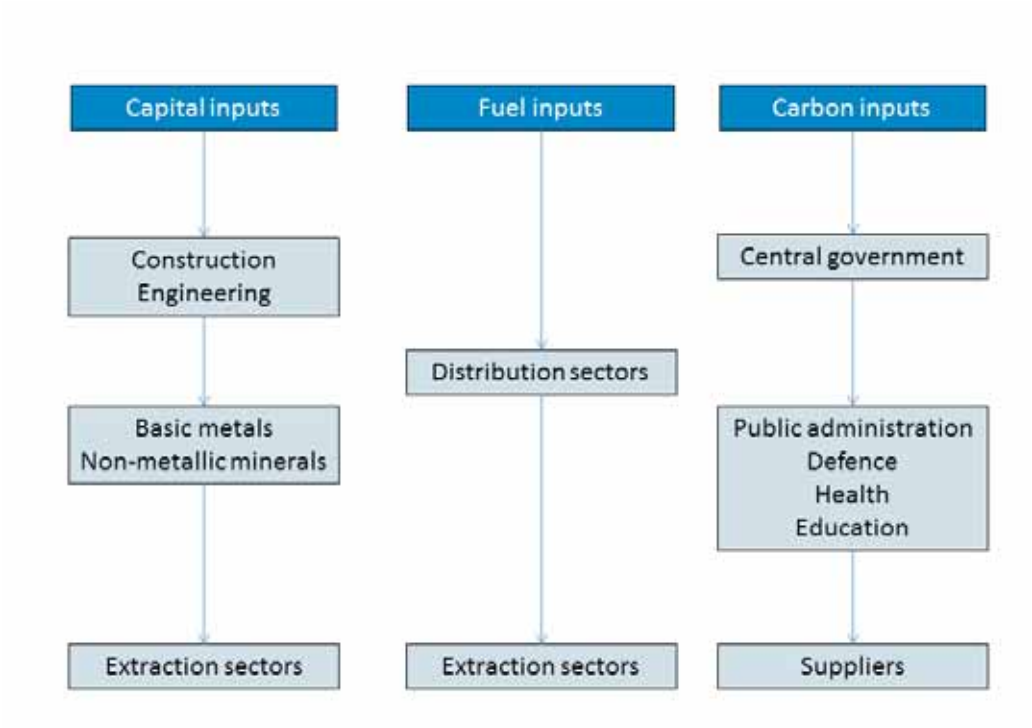
13 A recent report by Oxford Economics shows that a shock in gas prices has a larger negative impact on the UK economy than an oil or coal price shock, see: http://www.decc.gov.uk/assets/decc/11/tackling-climate-change/international-climate-change/5276-fossil-fuel-price-shocks-and-a-low-carbon-economy-.pdf.

14 MDM-E3 includes a full UK input-output table which is required for Type I and Type II multiplier analysis. However, the model's econometric equations allow some of the standard assumptions of multiplier analysis to be relaxed; for example the model allows for changing import shares depending on relative prices, it does not assume fixed returns to scale and it takes into account labour market constraints.

15 Government revenues are made neutral between the two scenarios, through reductions in VAT in the GAS scenario to make the scenarios directly comparable.

16 Digest of UK Energy Statistics (DUKES) 2012. Note that exports are removed from total supply in the energy statistics in DUKES, while in the economic statistics total supply is domestic production plus imports.

Figure 3.3: Offshore Wind Capacity and the Wholesale Electricity Price



demand, an increase in gas demand would be met entirely by imports. This would lead to a worsening of the UK's trade balance and GDP.

On average in 2008, for every one pound spent on electricity about 28 pence went to the gas extraction sector, of which about nine pence was spent on imported gas[17]. This proportion could alter depending on the import content of natural gas, total demand for electricity, the proportion of gas in the electricity mix, the relative price of gas to the electricity price, and the type of electricity consumer (since margins are higher for domestic consumers).

In a recent study on the Robin Rigg offshore wind farm[18], it was estimated that 63% of the capital cost associated with an offshore wind farm was imported. However, it seems likely that if domestic offshore wind capacity increases to the levels in the WIND scenario, more of the investment would flow into the UK supply chain and the import content would fall. There is also a possibility for UK firms to capture a share of the export market, which would serve to increase output and employment (but this is not included in the modelling).

To take account of an expected increase in the domestic production of wind turbines and their components, under our central assumptions the import content of offshore wind falls to 37% by 2030 in the WIND scenario. To test that our results are robust to higher import content assumptions, we have also modelled a sensitivity where the import share

17 Based on data in the 2011 Supply and Use Tables.
18 See: http://www.eon-uk.com/E.ON_Robin_Rigg_UK_content_report_October_2011.pdf.

Table 3.2: Carbon Costs

EU ETS price (£/tCO_2, 2011 prices)	2025	£30.70
	2030	£33.10
Carbon price floor (£/tCO_2, 2011 prices)	2025	£53.00
	2030	£74.20

Sources: DECC (2011) Carbon Values used in DECC's Energy Modelling.

of capital costs for offshore wind remains at 63% throughout the period to 2030 (see Section 5.5).

The carbon price floor

The supply chain related to carbon costs is a special case. The additional EU ETS allowances required in the GAS scenario are assumed to flow outside the UK through payments to other European companies/governments selling allowances. The auctioning of allowances by UK government is fixed in both scenarios. However, the impact of this assumption is likely to be small and by comparison a much larger part of the carbon costs is retained by the UK government as a result of its carbon price floor mechanism.

The modelling assumption is that this government revenue is recycled back into the UK economy through lower VAT rates. The effect of higher revenues from the carbon is therefore fiscally neutral by design.

3.4 Macroeconomic and sectoral impacts

Impact by GDP component

Table 3.3 presents the impacts of the switch from electricity generated from gas to offshore wind. The results show that over the period to 2030 there is a slight increase in GDP in the WIND scenario, compared to the GAS scenario, due mainly to supply chain factors. GDP itself is the sum of its component parts, which are affected in the following ways:

- Household expenditure is dependent on real incomes and is the largest component of GDP. Real incomes fall if the consumer price index increases but the differences in the scenario are small, so there is almost no change overall.
- There is quite a large increase in investment, as the new wind turbines (3.4 GW pa of capacity) that are built in the WIND scenario are not built in the GAS scenario. Instead, in the GAS scenario electricity is generated by using the gas plants more intensively, i.e. their load factor is much higher in this scenario. The benefit of lower overall capital costs in the power generation system in the GAS scenario is reflected in the electricity price.
- Imports increase in the WIND scenario compared to the GAS scenario, but fall slightly as an overall proportion of GDP (from 42.2% to 42.0%). The increase in demand for imports is mainly due to the increase in overall income and import

Table 3.3: GDP and Expenditure Components

		GAS £ bn (2011)	WIND % diff
GDP	2020	1,895	0.0
	2025	2,145	0.6
	2030	2,462	0.8
Household Expenditure	2020	1,137	0.0
	2025	1,283	0.1
	2030	1,461	0.1
Investment	2020	400	0.0
	2025	469	4.5
	2030	581	4.2
Imports	2020	682	0.0
	2025	841	1.1
	2030	1,038	0.6
Exports	2020	694	0.0
	2025	847	0.1
	2030	1,026	0.1
Government Expenditure	2020	341	0.0
	2025	381	0.0
	2030	426	0.0

Sources : Cambridge Econometrics.

intensive investment. In the WIND scenario, gas imports are reduced by 45% compared to the GAS scenario, but this is more than offset by an increase in imports in the engineering sectors (due to higher demand for wind turbines and their component parts), and a modest increase in imports across a number of other sectors, as a direct result of increasing incomes.

- We do not assume that offshore wind supply chain businesses export to other European and world markets, and so the difference in impact on exports is small between the scenarios.

These outcomes to some extent represent a reallocation of money expenditures through changes in the electricity price. For example, the carbon price floor raises electricity prices and reduces real incomes but allows the government to fund a cut in the rate of VAT.

The overall conclusion is, therefore, that there is a modest increase in GDP in the WIND scenario as a result of the offshore wind supply chain being located in the UK, in contrast to the lower investment in the GAS scenario and the higher flow of imports of

natural gas. Although the impact is modest in absolute terms, it is of reasonable size considering that it only represents a choice between two technologies in just one sector in the economy (electricity supply).

Employment results

Overall there is a small increase in employment in the WIND scenario of around 0.2% by 2030. This translates to a net job creation of about 70,000 full-time equivalent jobs (FTEs) in the WIND scenario. This employment impact does not include the potential for extra jobs in the offshore wind supply chain that could be secured through export of offshore wind components[19].

At a sectoral level, the WIND scenario has around 1% higher employment in the construction, engineering and manufacturing sectors. Many of these are high-skilled jobs that will require a skilled and productive labour force. The expansion of the sector would also create jobs in planning and site development, as well as expertise in the financial (project financing) and insurance sectors.

Results at sectoral level

Table 3.4 summarises the sectoral impacts in 2030. The sectors that benefit from increased offshore wind generation are the manufacturing and construction sectors, which are involved in building and installing wind turbines.

Table 3.4: Impacts on Sectoral Output

		GAS £ bn (2011)	WIND % diff
Agriculture etc.	2030	34	-0.1
Mining & quarrying	2030	35	-0.4
Manufacturing	2030	785	1.8
Electricity, gas, water etc.	2030	131	-3.4
Construction	2030	533	0.8
Distribution	2030	444	0.4
Transport & storage	2030	247	0.3
Accommodation & food services	2030	129	0.1
Information & communications	2030	308	0.5
Fin. & business services	2030	1,429	0.3
Government services	2030	643	0.0
Other services	2030	124	0.3

Sources : Cambridge Econometrics.

19 The report "Working for a Greener Britain: Volume 2" suggests that jobs supplying the export market could be substantial. See: http://www.renewableuk.com/en/publications/reports.cfm/Working-for-a-Green-Britain-Volume-2.

Higher borrowing and higher investment in the offshore wind case

Comparison of the offshore wind and gas-fired generation cases is made more difficult because of their very different cost structures: offshore wind involves a large up-front capital investment with low operating costs, whereas gas-fired CCGTs have much higher operating costs. Because we assume that investment costs are recouped (in the form of slightly higher electricity prices) over the lifetime of the plants that are built, the offshore wind case involves a substantial programme of investment in the period 2020-30 which is financed by borrowing that is repaid out of higher electricity prices over the subsequent decades to 2050. In the GAS scenario there is no such additional borrowing to finance offshore wind investment (and, because we assume that the gas plants will be built anyway, there is no additional borrowing to finance investment in CCGTs). Electricity prices increase over the long term in the GAS scenario because of the assumption that both global gas prices and UK carbon prices increase. The gas price and carbon price assumptions are taken from DECC[20], and the low and high sensitivities are tested in Section 5.2.

Some economists argue that levels of investment are constrained and that the additional investment in the offshore wind scenario might crowd out investment elsewhere in the economy, although this seems implausible given that the investments are in the context of EU-wide (if not global) multinational corporations, with access to international finance. We test this hypothesis by removing the positive investment effect from the offshore wind scenario (e.g. by assuming that there is no supply chain in the UK). It is then possible to compare the impact on the economy of the difference between electricity prices in two states of the UK economy, but with the same level of investment.

In this alternative WIND scenario the investment expenditure for offshore wind was removed but the slightly higher electricity prices associated with offshore wind were retained. A comparison of this scenario and the GAS scenario is shown in Table 3.5.

The results confirm that (by design) investment in this adjusted WIND scenario is now the same as the GAS scenario, whereas the comparison in Table 3.3 has investment some 4.1% higher in 2030. In this alternative WIND scenario, GDP is slightly lower

Table 3.5: Economic Indicators (Excluding Positive Investment Effects)

		GAS £ bn (2011)	(alternative) WIND % diff in 2030
GDP	2030	2,598	-0.2
Household Expenditure	2030	1,495	-0.4
Investment	2030	602	0.0
Exports	2030	1,056	-0.3
Imports	2030	987	-0.3
Government Expenditure	2030	426	0.0

Sources : Cambridge Econometrics.

20 DECC (2010) Fossil Fuel Price Projections.

than in the GAS case, as a result of the slightly higher electricity prices that cause a small reduction in real incomes and therefore weaker consumer demand. Furthermore, higher industry costs lead to a small loss of competitiveness and a fall in exports.

Longer-term impacts

The model-based analysis examines the period to 2030, but both costs and benefits continue to accrue beyond this time period due to the effects of locking in to one particular technology.

Table 3.5 shows that the costs of repaying borrowing could have some negative impact on longer-term results. However, it is also important to note that beyond 2030 natural gas prices are expected to continue rising. The value of imported natural gas required in the GAS scenario is therefore also expected to increase further, with electricity prices becoming higher than in the wind scenario within a few years.

Therefore, although it has not been modelled in this study, it is reasonable to expect that longer-term impacts would be at least in line with the results for 2030.

Chapter 4: CO_2 Emissions

4

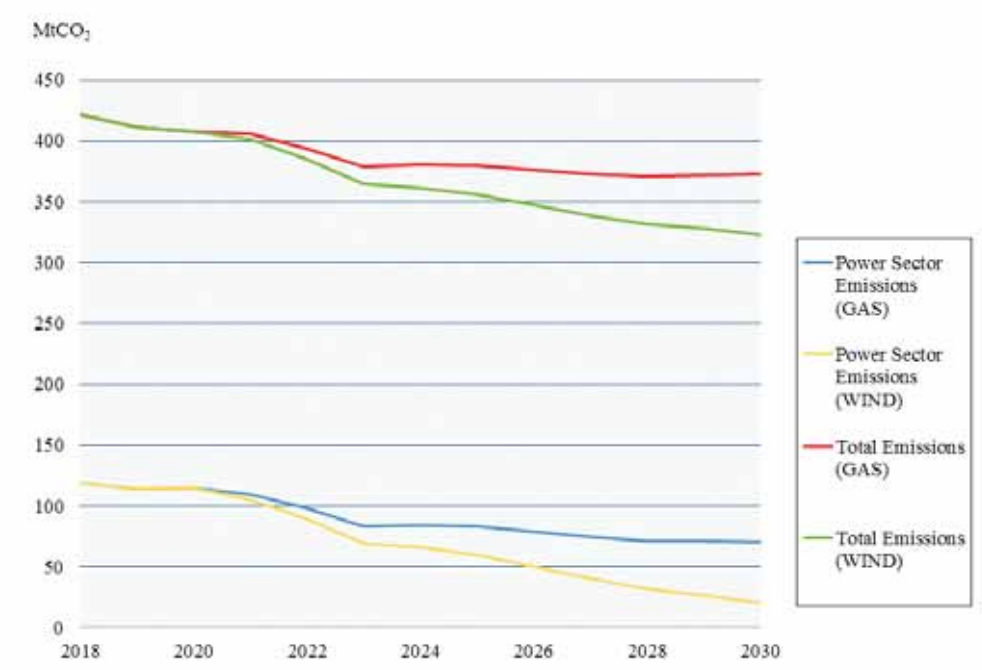
4.1 The impact on CO_2 emissions

The results for emissions are largely given by the design of the scenarios. A large-scale shift to offshore wind means that the CCC's 50gCO_2/kWh is met in 2030, given the overall electricity mix modelled, which is consistent with the CCC's 65% renewable energy scenario. This reduces UK power sector emissions by two-thirds and total domestic CO_2 emissions by around 13% compared to the GAS scenario in 2030, as shown in Figure 4.1.

Over the timeframe modelled (2020-30) CO_2 emissions from the power sector are reduced by 265.7 MtCO_2 and, because of technology lock-in, the longer-term future savings between 2030 and 2050 are likely to be considerable.

It should be noted that the reduction in emissions from the power sector does not technically contribute towards the UK's net carbon accounts or carbon budgets, as the emissions fall entirely within the EU ETS. Since we assume no change in the ETS allowance price (which will influence emissions from other ETS sectors), lower emissions from the power sector result in lower purchases of ETS allowances. However, the considerable reduction in CO_2 emissions in the WIND scenario is in line with the

Figure 4.1: UK CO_2 Emissions



reductions of emissions advised by the CCC and the obligation in the UK's legally binding Climate Change Act to reduce GHG emissions by 80% by 2050.

4.2 Long-term lock in and uncertainty

Although the economic impacts in the scenario are in general quite small in macroeconomic terms, the impacts on CO_2 emission levels are both large and persistent. This is because of 'lock-in' effects: once a power plant has been installed it is likely to be used throughout its lifetime and, as infrastructure (e.g. gas pipelines) is put in place, may in turn lead to further uptake of the same technology.

The concept of lock-in makes the discussion of uncertainty (see Chapter 5) particularly relevant. These scenarios represent lock-in to two different technologies, each of which will be subject to its own future cost uncertainties (as discussed in Chapter 3) and associated emissions. The substantial investment made into offshore wind locks the UK into a low carbon trajectory that is more consistent with the legally binding 2050 GHG emissions reduction target. By contrast, continued reliance on natural gas could put that target in jeopardy as well as give more exposure of the UK economy to potentially volatile international gas prices.

Chapter 5: Sensitivity Analysis

5

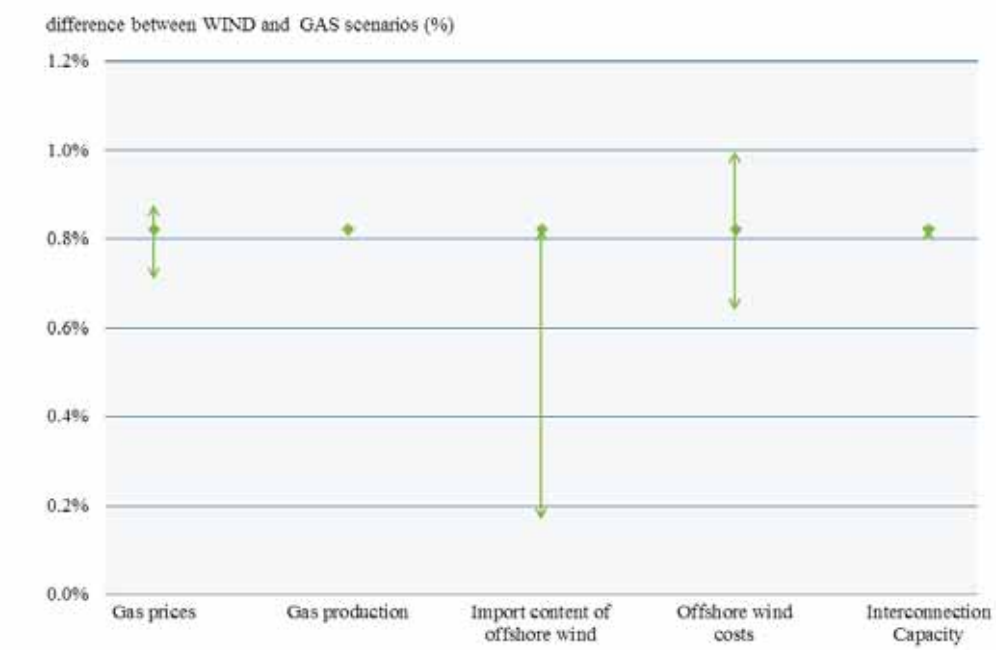
5.1 Overview

The results for the two scenarios reflect the effects of assumptions on:

- natural gas prices
- domestic gas production
- the future costs of offshore wind
- the imported content of offshore wind projects
- the required interconnection capacity to support intermittency

To test the robustness of our results, we modelled the economic impact of the two scenarios using variants of these assumptions. Figure 5.1 shows the range of impacts on GDP in 2030 for each of the sensitivity tests that were carried out. It shows that, in all the sensitivity cases modelled, economic growth is improved in 2030 in the WIND scenario compared to the GAS scenario.

Figure 5.1: Sensitivity Results for the WIND Scenario: Impact on GDP 2030



Notes : Diamond shows results under central assumptions.

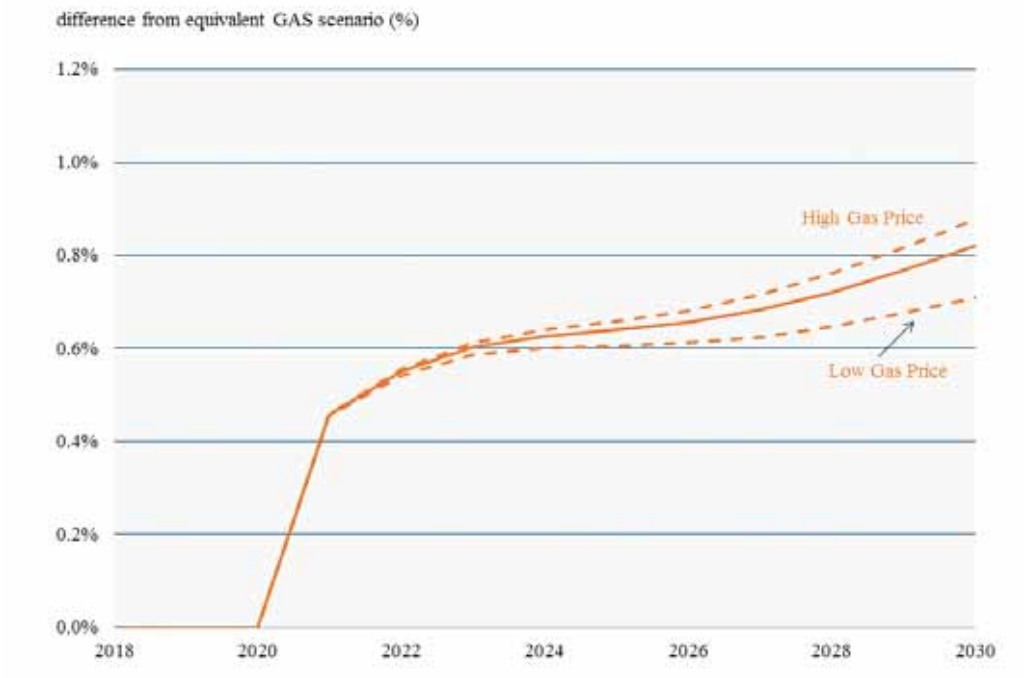
5.2 Natural gas prices

Gas prices respond to: demand factors, which are primarily driven by current economic conditions; and supply factors, which depend heavily on gas exploration and the potential for shale gas production. There is a great deal of uncertainty around current projections, as the global potential and economic viability of shale gas in the UK remain unknown.

Gas prices are a crucial assumption in the modelling as they are the largest cost component of gas-fired electricity, accounting for around 60% of total gas power generation costs by 2020 (see Appendix B). We modelled the impact of lower and higher gas prices based on the low/high figures in DECC's fossil fuel price projections[21,22]. In 2030, gas price assumptions in the high case are 30% higher than the central gas price, and in the low case it is assumed that gas prices are 50% lower than central projections. The impact on GDP of the low and high gas price variants is shown in Figure 5.2.

Under the central gas price assumptions, the time profile of GDP rises sharply in the WIND scenario in 2021, and then increases slowly in the years following. By 2030 GDP is 0.8% above the level of GDP in the alternative GAS scenario. The scenarios are

Figure 5.2: GDP Impact of Gas Price Sensitivities in the WIND Scenarios



Notes : Solid line shows results under central assumptions, dashed line show sensitivity results.

21 DECC (2011), available online at: http://www.decc.gov.uk/assets/decc/11/about-us/economics-social-research/2933-fossil-fuel-price-projections-summary.pdf.

22 DECC fossil fuel prices are broadly comparable to IEA price projections, and so represent a reasonable range of prices to test in the sensitivity analysis.

the same to 2020, and so the impacts of offshore wind deployment start in 2021. In this first year, there is an increase in investment in offshore wind capacity (which is paid for through higher prices over the lifetime of the installed capacity). We assume that capacity continues to increase year-on-year by the same amount, and therefore annual investment stays at approximately the same level. There is also a growing reduction in gas imports in the WIND scenario.

Under all three gas price assumptions, GDP is still higher in the WIND scenario than in the GAS scenario. Under lower gas price assumptions, the relative cost of gas power is reduced; electricity prices are correspondingly lower and disposable income is higher, boosting household consumption and GDP in the GAS scenario. But even under the low gas price assumptions, GDP is around 0.7% higher in the WIND scenario.

5.3 Shale gas production

The UK has been a net importer of gas since 2004 and in 2011 imports accounted for over 65% of the UK gas supply[23]. In recent years, studies have assessed the potential for domestic shale gas production. Shale gas exploration in the UK is still in its early stages, but current figures from the British Geological Survey suggest that there could be as much as 150 billion cubic metres of shale gas in the UK, equivalent to two years of current UK gas consumption. This figure is currently under review. However, even with domestic shale gas production, import dependence on gas is still likely to increase if gas demand continues to grow and the supply from conventional sources falls.

We have assumed that the scale of the UK's gas production, including production from shale gas, does not depend on the choice of fuel for UK power generation. In other words, if UK gas production from shale proves to be economically feasible on a large scale, that gas will be produced whether or not the power generation system shifts towards offshore wind or is based heavily on gas. Greater UK gas production could substitute for imports in the UK's energy balance or it could be exported, depending on market conditions. Under these conditions, the economic impact of greater UK gas production is the same in both the offshore wind case and the gas-fired generation case: the UK's net trade position in gas is improved by the scale of additional gas production and not by its use. As a result, if shale gas production is included in both the WIND and GAS scenarios the difference between the two scenarios remains the same as when shale gas production is excluded.

If there was a large increase in shale gas production globally, this would reduce global gas prices and hence make the gas-fired generation case less costly than it otherwise might have been. However, a recent study by the IEA[24] suggests that gas prices in Europe will still increase, even with an expansion in shale gas. The impact of lower (and higher) gas prices is illustrated by the gas price sensitivity analysis in Section 5.1.

23 Digest of UK Energy Statistics (DUKES) 2012. Note that exports are removed from total supply in the energy statistics in DUKES, while in the economic statistics total supply is domestic production plus imports.

24 IEA 'Golden Rules for a Golden Age of Gas' (2012), see: http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf.

5.4 Offshore wind capital cost reduction

The costs of offshore wind are expected to fall over time. Several recent studies have shown that offshore wind will become a competitive generation technology within the next ten years. For example, the Crown Estates' Offshore Wind Cost Reduction report shows that the cost will fall as a result of:

- learning: as capacity increases it becomes cheaper to install additional capacity as mistakes are eliminated and the construction process becomes standardised
- a reduction in the risk premium associated with offshore wind financing costs
- operation and maintenance costs benefiting from economies of scale
- a reduction in material costs

The Crown Estates study suggests that levelised costs will fall to between £80 and £100 per MWh in projects initiated in 2020, in all but the 'Slow Progression' scenario. By comparison, this study has annual generation costs from offshore wind of £92 per MWh in 2020. In the WIND scenario, the main driver of falling costs post 2020 is a reduction in the borrowing rate from 8.5% in 2020 to 7.7% in 2030[25]. Borrowing rates are assumed to fall as technologies become more established and less risky. Given the high proportion of capital cost for this technology, the lending rate on the capital is key in bringing about cost reductions. Of the £900 per kW reduction in capital costs (including borrowing costs) for offshore wind between 2020 (£5,251 per kW) and 2030 (£4,368 per kW), some £650 is a reduction in the cost of borrowing over the lifetime of the project.

Cost projections in the sensitivities

As offshore wind is a relatively recent technology with little resemblance to past technological innovations, there is considerable uncertainty about learning rates and supply chain development potential. To examine the importance of these uncertainties, we ran two sensitivity tests on the total capital cost of offshore wind.

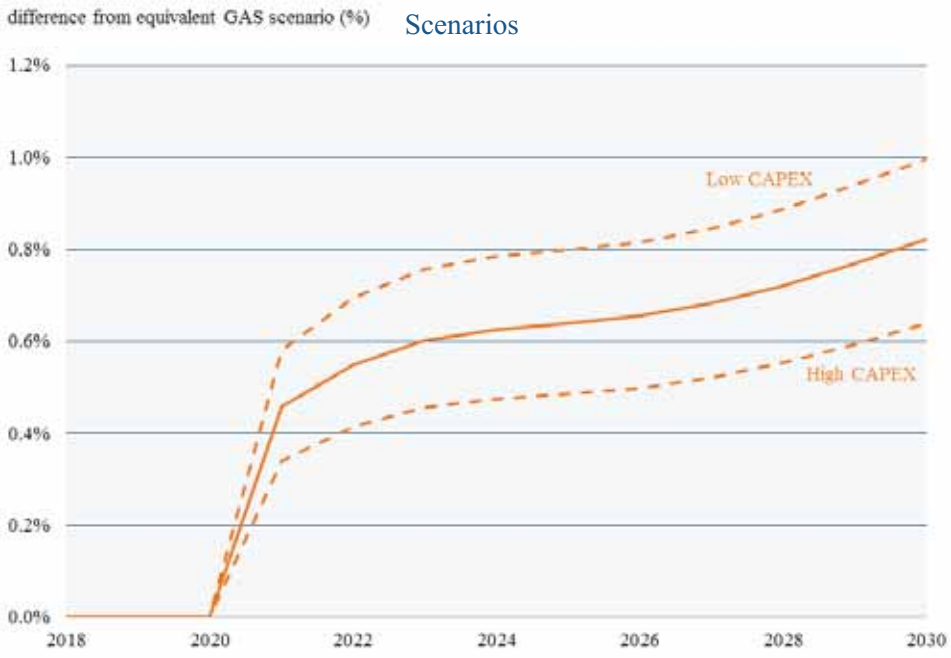
We based our central capital cost estimates on Mott McDonald's Balanced Efforts Scenario[26]. For the high capital cost variant, the high borrowing rate estimates from the study were used, and it was assumed that the capital cost excluding borrowing would not fall beyond the levels estimated for 2020. For the low capital cost variant, the lower bound of the borrowing rates in the Mott McDonald study were used, and it was assumed that the capital cost reduction reported in the study by 2040, would be reached by 2030 (please see Table B.2 in Appendix B).

Figure 5.3 shows the impact on GDP (as percentage difference from baseline) for the high and low capital cost (CAPEX) sensitivities. The chart shows that the impacts on GDP are in fact fairly small for the given range of sensitivities.

25 Oxera (2011) Discount rates for low-carbon and renewable generation technologies.

26 Mott McDonald (2011), Costs of low-carbon generation technologies, available online at: http://hmccc.s3.amazonaws.com/Renewables%20Review/MML%20final%20report%20for%20CCC%209%20may%202011.pdf.

Figure 5.3: GDP Impact of Offshore Wind CAPEX Sensitivities in the WIND Scenarios



Notes : Solid line shows results under central assumptions, dashed line shows sensitivity results.

5.5 The share of offshore wind installations supplied domestically

There is also uncertainty with regard to the proportion of capital equipment that is imported for offshore wind installations. We therefore ran sensitivities with different assumptions for the import content of investment spending on offshore wind. In reality we might expect that the development of offshore wind capacity in the WIND scenario would draw turbine manufacturers and other parts of the supply chain to set up in the UK, and so the import content would differ between the WIND and GAS scenarios. However, as it is assumed that there is no new offshore build post 2020 in the GAS scenario, and the same level of deployment until 2020, the changing level of import content in this scenario becomes irrelevant.

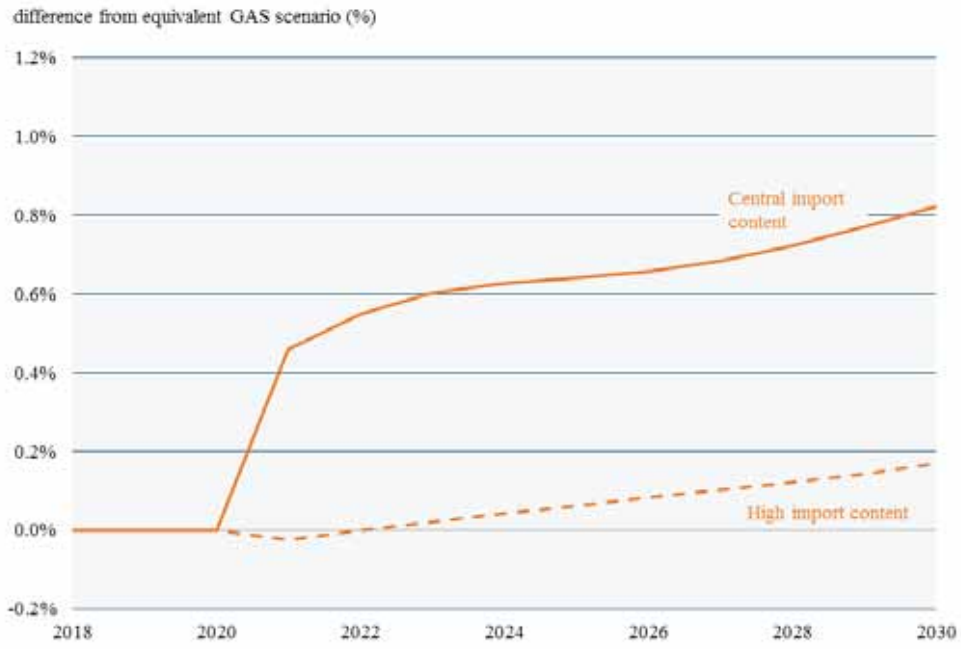
The import share of total offshore wind capital costs in the central import content sensitivity was assumed to fall from 63% in 2010 to 50% by 2020 and 37% by 2030. The 63% figure was taken from the BVG Associates study on the UK content of Robin Rigg offshore wind farm[27]. However, Robin Rigg was built in 2010, and is unlikely to be comparable to offshore wind farms built in 2020 and 2030. In fact, it is possible that the existence of a substantial domestic market for offshore wind would encourage UK investment in the production of equipment, raising the share of UK producers in the market. Therefore, under our central assumptions, we assume that the import content of capital will fall to 50% by 2020 and 37% by 2030.

27 BVG Associates (2011) UK content analysis of Robin Rigg offshore wind farm.

However, there is a degree of uncertainty about this assumption. In recent years, most of the wind turbine components and offshore wind services have been bought from the eurozone, or from countries with currencies pegged to the euro[28]. If the eurozone crisis has a long-term impact on the value of the euro, exporters based in the eurozone may be more competitive and the UK content of offshore wind equipment might not grow to the extent that we envisage. UK production could also suffer from other international competition, but probably not to the same extent as goods which are traded more easily such as solar panels (which have seen intense international competition), as the offshore wind supply chain to the UK is likely to remain in countries bordering the North and Baltic Seas.

To take account of this uncertainty, we tested a high import content variant, where it is assumed that the import content of offshore wind will remain at 63% (the current estimated proportion) in each year to 2030. Figure 5.4 shows that the GDP impacts are, as expected, quite sensitive to these assumptions. However, the impacts suggest that, even under current conditions whereby offshore wind plants are largely sourced from imports, there would be a small increase in GDP by 2030. Equally, the results suggest that the success of securing the supply chain in the UK is key to the overall magnitude of the economic results.

Figure 5.4: GDP Impact of Import Content Sensitivities in the WIND Scenarios



Notes : Solid line shows results under central assumptions, dashed line shows sensitivity results.

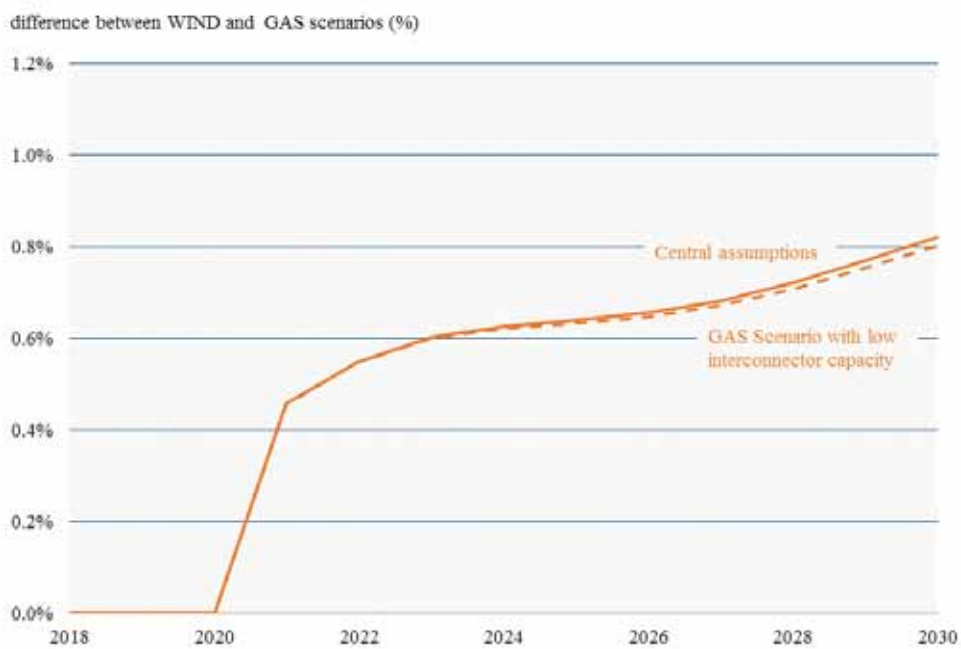
28 BVG Associates (2011) Offshore Wind: Forecasts of future costs and benefits.

5.6 Interconnector capacity

In the GAS scenario, we include the same level of interconnector capacity as the WIND scenario, as a simplifying assumption. This is intended to reflect the fact that there is still a reasonable amount of intermittent electricity supply in this scenario, from onshore wind, offshore wind built before 2020 and various marine technologies. However, this interconnector capacity might be under-utilised in the GAS scenario if intermittency is reduced.

In this sensitivity, we compare a WIND scenario with the interconnector capacity (15.4 GW) to an alternative GAS scenario with just 6 GW of interconnector capacity in 2030. The results show a small positive impact on GDP, which reflects the avoided interconnector cost and (negligibly) lower electricity prices in the alternative GAS scenario. The impact on annual electricity costs is small because the total cost of interconnector capacity is spread over a long lifetime.

Figure 5.5: GDP Impact of Interconnection Capacity Sensitivity



Notes : Solid line shows results under central assumptions, dashed line shows sensitivity results.

Chapter 6: Conclusions

6

6.1 Scenarios and modelling results

The analysis in this report has been carried out in the context of the UK's 2012 Energy Bill. The current policy debate is focusing on whether to promote more actively the development of renewable technologies or to further expand the UK's gas-fired capacity. There are arguments for and against each of these strategies: on the one hand new gas plants are cheap to build, but are reliant on gas imports and vulnerable to rising (and volatile) gas and carbon prices; wind turbines, on the other hand, have a high upfront capital cost, but low running costs and they do not rely on imported gas or produce greenhouse gas emissions. As a nascent technology, there is also scope for offshore wind capital costs to fall and for the UK to become a significant producer of the technology.

Future generation shares

This report focuses on the period between 2020 and 2030. It considers two possible future scenarios.

In the WIND scenario, the UK follows a trajectory outlined by the Committee on Climate Change's 65% renewable electricity generation scenario and makes substantial investment in new offshore wind capacity. This approach has a higher initial cost, requiring substantial investment of which we assume a declining proportion is supplied from overseas (63% in 2012, falling to 37% in 2030). Although the domestic share provides an economic stimulus, all the investment must be financed through slightly higher electricity prices.

In the alternative GAS scenario no additional capacity in wind generation is built and existing gas plants are used instead. This saves on construction costs and imported materials and, in the short term, means that electricity prices are lower. However, on the assumption that gas and carbon prices will rise over the longer term, increased dependence on natural gas imports leads to rising electricity prices in the longer term as the higher fuel cost offsets the benefit of lower capital costs. Gas generation also incurs carbon costs, although the part that is raised through the carbon price floor may be used by the government to cut taxes (transferring welfare from electricity consumers to those benefiting from the tax cuts).

The two scenarios were assessed using a macro-econometric model of the UK economy, MDM-E3, which includes two-way linkages with the energy system. The strength of the modelling approach is that it is able to consider the problem from a systemic and societal perspective, including households and all economic sectors, rather than focusing on the power sector alone.

Future electricity prices

The modelling approach assumes that electricity prices are formed through annual costs that include capital and borrowing repayments, operation and maintenance, fuel and carbon costs. It is assumed that all costs are passed on in the form of higher prices and that capital costs are spread evenly throughout the lifetime of the plant. A single average electricity price is determined by weighting the unit costs of the different plant types.

The model results suggest that after 2020 electricity will be slightly cheaper if existing or new gas capacity is used. However, given the assumptions for future natural gas and carbon prices, the results also suggest that electricity prices are only slightly higher in the WIND scenario, particularly towards 2030. Clearly this result is dependent on the assumptions used, particularly for fuel costs, but it challenges the prevailing view that electricity produced by gas plants will be cheaper indefinitely.

Macroeconomic impacts

The scenarios contain several (sometimes offsetting) factors that influence macroeconomic outcomes.

- Investment in offshore wind boosts GDP, but the scale of impact depends on the import content of the capital required.
- Both scenarios have substantial import requirements: a large proportion of the equipment required to build wind turbines must currently be imported, while higher consumption of natural gas for electricity generation results in higher imports of gas. The difference between the two scenarios for gas imports is the same irrespective of whether substantial shale gas becomes available in the UK.
- Slightly higher electricity prices reduce household real incomes and lead to a reduction in household consumption of goods and services. In effect, the higher investment in offshore wind is financed by a slight increase in payments by electricity consumers, but a higher proportion of electricity costs supports UK-based production instead of buying imported gas.
- Increased consumption of gas leads to higher levels of CO_2 emissions. Part of the cost of gas reflects the carbon price floor policy, and so part of the cost to electricity consumers is transferred to government which, under our assumption, is then used to cut VAT.

The aggregate GDP effects show the net impact of these factors together. The modelling results show that there is an increase in GDP in the WIND scenario, of around 0.8% by 2030, compared to the GAS scenario.

The scenario with offshore wind includes substantial private sector borrowing, as the initial investment is recouped over a 30-year period. Although the modelling only goes out to 2030, in our view it is reasonable to assume that similar effects would persist in the longer term.

Sectoral impacts

Large-scale development of offshore wind benefits engineering, manufacturing and construction firms (with potential positive impacts in the insurance and project finance sectors as well), while gas suppliers are the main beneficiaries in the scenario with increased gas-fired generation. This shift towards manufacturing and construction represents a some degree of rebalancing of the UK economy.

Employment

The scenario results show a modest net increase in aggregate employment levels, creating around 70,000 net jobs. The increase does not include potential additional jobs created through opportunities to export UK based offshore wind technology. The sectoral employment impacts are similar to those described for the effects on output by sector. The employment impact would be larger if the UK supply chain in offshore wind was able to capture a proportion of the export market (this impact has not been modelled).

Environmental impacts

In the WIND scenario, total UK CO_2 emissions are around 13% lower in 2030 than they are in the GAS scenario, and power sector emissions are two-thirds lower. The reduction in emissions from the power sector falls inside the EU ETS, and the result is a reduction in the (international) purchases of ETS allowances by UK power generators. The WIND scenario also reduces the carbon intensity to just below 50g CO_2 per kWh by 2030, in line with the CCC's recommendation, and puts the UK on a low-carbon technology pathway to its long-term, legally binding, emissions reduction target for 2050.

Sensitivity of results to key input assumptions

The main scenarios in this report present two possible views of the future. They were subjected to sensitivity testing on the key input assumptions.

The two most important determinants of results were the assumptions about future natural gas prices and the import content of investment in wind turbines. The sensitivity tests found that:

- Higher gas prices produce more favourable results for the WIND scenario and lower gas prices produce more favourable results for the GAS scenario; given the range of inputs tested, the positive impact on GDP in 2030 in the WIND scenario lies in the range 0.7-0.9% GDP.
- Heavy investment in offshore wind will stimulate a substantial domestic market for wind turbines; failure by UK producers in capturing this market could reduce the positive impact on GDP in 2030 from 0.8% to 0.2%.

6.2 Policy conclusions

There are two main outcomes from the scenarios:

- a clear environmental outcome - the scenario that relies on gas-fired generation has much higher CO_2 emissions and locks the UK into a higher emissions future post 2030
- a modest, but positive, economic outcome - GDP increases as a result of investing in offshore wind as it reduces import spending on gas and could potentially stimulate net job creation in various key sectors of the economy

Both the WIND and GAS scenarios have been put forward as a means of supporting economic growth, either through creating investment-led jobs (offshore wind) or by providing cheap electricity (based on gas). The results in this report suggest that investment in offshore wind could offer a small increase in economic growth over a

gas-based power generation alternative, in particular if a firm policy commitment led to investment in the UK supply chain for offshore wind capacity.

However, it is important to note the long-term impacts of pursuing either policy option; with a 30-year lifetime, plants that are built in the coming decades are still likely to be in operation close to 2050, far beyond the current economic recovery. When projecting this far ahead, there is considerable uncertainty in many of the key decision factors, for example in the capital cost of turbines (or location of their production) or in future prices of natural gas. The long asset life of new power plants also means that there will also be consequences for emission levels well beyond 2030, which is an important issue when considering compliance with the UK's emission reduction targets for 2050.

Appendix A: The MDM Model

A

A.1 Introduction

Energy-Environment-Economy (E3) modelling

MDM-E3[28] is maintained and developed by Cambridge Econometrics (CE) as a framework for generating forecasts and alternative scenarios, analysing changes in economic structure and assessing energy-environment-economy (E3) issues and other policies. MDM-E3 provides a one-model approach in which the detailed industry and regional analysis is consistent with the macroeconomic analysis: in MDM-E3, the key indicators are modelled separately for each industry sector, and for each region, yielding the results for the UK as a whole. MDM-E3 is one of a family of models which share the same framework, general design, methodology and supporting software; the scope of the E3ME[29] model is European; that of E3MG[30] is global.

To analyse structure, the E3 models disaggregate industries, commodities, and household and government expenditures, as well as foreign trade and investment, and incorporate an input-output framework to identify the inter-relationships between industry sectors. The models combine the features of an annual short and medium-term sectoral model estimated by formal econometric methods with the detail and structure of input-output models, providing analysis of the movement of the long-term outcomes for key E3 indicators in response to economic developments and policy changes. The models are essentially dynamic simulation models estimated by econometric methods.

MDM-E3 retains an essentially Keynesian logic for determining final expenditure, output and employment. The principal difference, compared with purely macroeconomic models, is the level of disaggregation and the complete specification of the accounting relationships in supply and use tables required to model output by disaggregated industry.

Econometric approach

The parameters of the behavioural relationships in MDM-E3 are estimated econometrically over time, within limits suggested by theory, rather than imposed from theory. The economy is represented as being in a continual state of dynamic adjustment, and the speed of adjustment to changes (in, for example, world conditions or UK policies) is based on empirical evidence. There is therefore no assumption that the economy is in equilibrium in any given year, or that there is any automatic tendency for the economy to return to full employment of resources.

In summary MDM-E3 provides:

28 Multisectoral Dynamic Model, Energy-Environment-Economy: http://www.mdm-e3.com/
29 Energy-Environment-Economy Model of Europe: http://www.e3me.com/
30 Energy-Environment-Economy Model at the Global level: http://www.e3mgmodel.com/

- annual comprehensive forecasts to the year 2025 for:
  - industry output, prices, exports, imports and employment at an industry level (87 industries); for household expenditure by 51 categories
  - investment by 27 investing sectors for the nine Government Office Regions, Wales, Scotland and Northern Ireland
- projections of energy demand and emissions, by 25 fuel users and eight main fuel types (in all, 11 fuels are distinguished)
- full macro top-down and industrial bottom-up simulation analysis of the economy, allowing industrial factors to influence the macro picture
- an in-depth treatment of changes in the input-output structure of the economy over the forecast period to incorporate the effects of technological change, relative price movements and changes in the composition of each industry's output
- scenario analysis, to inform the investigation of alternative economic futures and the analysis of policy

A.2 Economy

Model disaggregation

The purpose of MDM-E3 is to abstract the underlying patterns of behaviour from the detail of economic life in the UK and represent them in the form of a key set of identities and equations. In a complex system, such as the UK economic system, the abstraction is very great. In any economic model the initiatives, responses and behaviour of millions of individuals is aggregated over geographical areas, institutions, periods of time and millions of heterogeneous goods and services into just a few thousand statistics of varying reliability. The aim of MDM-E3, then, is to best explain movements in the data and to predict future movements under given sets of assumptions.

A key contribution of the approach to modelling the UK economy in MDM-E3 is the level of disaggregation. The macroeconomic aggregates for GDP, consumers' expenditures, fixed investment, exports, imports, etc. are disaggregated as far as possible without compromising the available data.

One reason for disaggregation is simply that it is necessary to answer certain questions of economic interest. Some macroeconomic questions are intrinsically structural and if they are to be answered using a model then it must be disaggregated in some way. The disaggregation of agents and products is crucial in trying to understanding the behavioural responses of heterogeneous agents as it reduces the bias encountered in estimating aggregate relationships.

Sectoral disaggregation

The principal economic variables in MDM-E3 are:

- the final expenditure macroeconomic aggregates, disaggregated by product, together with their prices
- intermediate demand for products by industries, disaggregated by product and industry, and their prices

- value added, disaggregated by industries, and distinguishing operating surplus and compensation of employees
- employment, disaggregated by industries, and the associated average earnings
- taxes on incomes and production, disaggregated by tax type
- flows of income and spending between institutions sectors in the economy (households, companies, government, the rest of the world)

Regional disaggregation

Some variables are also disaggregated by Government Office Region and Devolved Administrations. This applies particularly to value added, employment, wages, household incomes and final and intermediate expenditures. Prices are not typically disaggregated by region, because of data limitations.

The National Accounting system

A social accounting framework is essential in a large-scale disaggregated economic model. The early versions of MDM-E3 were based on the definitions and estimation of a Social Accounting Matrix (SAM) for the UK and its associated input-output tables and time-series data. The principles of SAM have been extended and elaborated in detail in the UN's revised System of National Accounts (SNA). Accordingly we now use the SNA for the accounting framework for the data and the model.

The national accounts provide a central framework for the presentation and measurement of the stocks and flows within the economy. This framework contains many key economic statistics including Gross Domestic Product (GDP) and gross value added (GVA) as well as information on, for example, saving and disposable income.

The national accounts framework makes sense of the complex activity in the economy by focusing on two main groupings: the participants of the economy and their transactions with one another.

Units are the individual households or legal entities, such as companies, which participate in the economy. These units are grouped into sectors, for example the Financial Corporations sector, the Government sector and the Household sector. The economic transactions between these units are also defined and grouped within the accounts. Examples of transactions include government expenditure, interest payments, capital expenditure and a company issuing shares.

The national accounts framework brings these units and transactions together to provide a simple and understandable description of production, income, consumption, accumulation and wealth. These accounts are constructed for the UK economy as a whole, as well as for the individual sectors in the Sector Accounts.

Since 1998 the National Accounts have been consistent with the European System of National Accounts 1995 (ESA95). The ESA95 is the European implementation of the International System of National Accounts 1993 (SNA93) developed by the UN to ensure a common framework and standards for national accounts, including input-output analyses, sector accounts and constant-price analyses. The ESA95 was developed to reflect the changing role of government, the increased importance of service industries and the increased diversity of financial instruments. It recognises the wider scope of capital formation, by using concepts such as intangible assets.

Flows of economic dependence

The determination of output in MDM-E3 can be divided into three main flows of economic dependence:

- the output-investment loop
- the income loop
- the export loop

Household expenditure

Consumers' expenditure is estimated at an aggregated level for each of the 12 UK regions covered in MDM-E3 and then further disaggregated to the 51 expenditure categories which relate to the COICOP classification. At the aggregate level regional consumption in real terms is predominantly a function of regional real income.

This relationship is constrained to reflect the idea that expenditure cannot outgrow income levels in the long term, although it is possible in the short term. The other key drivers of regional consumption as defined in the equations are:

- the adjusted dwellings stock
- the OAP dependency ratio
- inflation

In the short run we also consider the effects of:

- unemployment - in the literature high levels of unemployment are linked to sharp falls in consumer spending beyond the fall in consumer spending which can be explained by an associated fall in real gross disposable income that the unemployment would cause; this is explained in the literature by the uncertainty that unemployment induces across a region
- real house prices - we assume here that there is a positive (negative) wealth effect caused by increasing (decreasing) real house prices which causes consumption to increase (decrease) in the short run

Regional and sectoral disaggregation

Regional consumption is then disaggregated further in the disaggregated regional equations which take the main independent variable as regional consumption, which effectively reflects the income effect on consumption (the parameter is restricted to be positive). The other explanatory variables are relative prices in the form of the price of each consumer category compared to the overall price index for all consumer items, this captures the price effect (the parameter is restricted to be negative). The OAP and child dependency ratios are also considered so as to reflect differing consumption patterns arising from changing demographic structure in the different regions.

Feedback from the energy sub-model

For the consumption categories that represent energy products, consumption in each region is determined by applying the growth rate in UK fuel consumption (in energy units) from the fuel user 'households' (or in the case of petrol - road transport) to the real consumption of gas, electricity, coal, petrol and manufactured fuels. The fuel used by households and road transport is derived from the energy and transport sub-models described later. Disaggregated consumption is then scaled to match regional consumption at the aggregate level.

Household expenditure by expenditure category is then mapped to the 41 product categories to derive domestic consumer demand by product category.

Investment

Among other elements such as social-capital formation, public and private sector dwellings and legal fees, the most important element of gross fixed capital formation is the acquisition of new buildings, plant and machinery and vehicles by industry.

Investment in MDM-E3 is treated quite differently to the neoclassical framework which relies on the production function of firms and net present welfare maximisation based on equating the user cost of capital with the marginal product of capital.

However, the neoclassical treatment leads to an unresolved conflict between the implied costless switch between capital and employment and the observation that capital stock adjustments are subject to significant time lags.

In MDM-E3 investment data are divided into 27 investing sector categories at the national level. The national investment equations depend on industry output, which is converted from the 41 industry sectors to the 27 investing sectors. The equations yield the result that an increase in output will lead to an increase in investment. Typically, the investing sectors which are most responsive to changes in output are the capital-intensive manufacturing-based investment sectors such as Transport Equipment.

The investment equations are specified in the Engle-Granger cointegrating form and therefore allow for the impact of the lagged investment and an error correction term, allowing adjustment to the long-term trend.

Government expenditure

Assumptions for government capital spending are used to forecast gross fixed capital formation in the investing sectors relating to Health, Education and Public Administration. Government final consumption expenditure is treated exogenously in MDM-E3 and is based on the plans announced in the Comprehensive Spending Review and Budget statements.

Government revenues from taxes on income and production are inherently endogenous as they rely on consumption and incomes. This duality is an important consideration in scenario analysis. Increased tax revenues are not automatically recycled into the economy. Model operators must decide where additional revenue should be spent. If additional tax revenues are not spent they will, by definition, simply reduce the Public Sector Net Cash Requirement (PSNCR), but this has no further effects on behaviour (for example, it is not assumed that household spending responds to the prospect of higher or lower taxation in future as indicated by the extent of government borrowing in the present).

International trade

MDM-E3 has assumptions for 19 world regions, covering (among other factors) activity (GDP), price levels and exchange rates. The world activity indices are the key drivers of export demand, which is estimated across the 41 product categories. The result is that an assumed change in US GDP growth will affect the products that are most traded with the US, depending on the weighting of US demand in the world demand for UK exports and the responsiveness of UK export demand to the change in the world activity index. The price of exports also affects the level of export demand. To explain historical export

volumes two dummy terms for integration with the EU internal market are significant for 1974 and 1978.

Import volumes are determined by domestic demand and import prices relative to domestic prices. A capacity utilisation constraint is also considered in the short term.

The input-output framework

Input-output supply and use tables (SUTS) provide a framework to make consistent estimates of economic activity by amalgamating all the available information on inputs, outputs, gross value added, income and expenditure. For a given year, the input-output framework breaks the economy down to display transactions of all goods and services between industries and final consumers (e.g. households, government) in the UK. Since 1992, ONS has used the input-output process to set a single estimate of annual GDP and ONS has published the detailed analyses in the SUTS.

The information from the regular releases of SUTS are used in conjunction with the more detailed analytical tables (last published for 1995) to construct the inputs that are required for the MDM-E3 model. An input-output table has been estimated from official data to provide the detail needed to model inter-industry purchases and sales.

The input-output coefficients derived from the SUTS allow intermediate demand to be derived for each product given the final demand at the product level of disaggregation.

Employment

The employment equations for MDM-E3 are based on a headcount measure of employment rather than on a full-time equivalent basis. The employment equations are specified by region and industry. The two main drivers of employment are gross output and the relative wage costs as measured by industry wages relative to industry prices.

Labour productivity

In MDM-E3 assumptions are made for world prices and exchange rates. These are then used to determine import prices, which are one element of the cost to the UK's industries of bought-in inputs. The other element is, of course, the cost of the UK's own production. Unit material and labour costs determine industry output prices. Consumer prices, then, depend partly on import prices and partly on UK industry prices, together with taxes on products. Consumer prices have an influence on average wage rates, as do labour market factors. Average earnings and productivity are then used to determine unit labour costs. Export prices depend partly on unit labour costs in the UK and partly on world prices (reflecting the extent to which prices are set in world markets).

Interest rates and exchange rates

Previous versions of MDM-E3 have sought to include endogenous treatments for interest rates and exchange rates but the inclusion of these specifications often led to increased instability within the model. Recent versions of the model therefore rely on an exogenous treatment for both exchange rates and interest rates. This has important consequences for scenario analysis. For instance, unilateral UK action on carbon taxes might push domestic consumer price inflation to a position where the Bank of England might take deflationary action by increasing the repo rate. Similarly, exchange rates do not change in response to domestic prices, the balance of payments, world prices, Treasury bill rates and so on.

Price formation

Industrial prices are formed as a mark-up on unit costs with an allowance for the effect of the price of competitive imports, technological progress and, in the short run part of

the equation, the effect of expected consumer price inflation. The supply side comes in through the utilisation of capacity as measured by the ratio of actual output to normal output.

For many of the industries the dominant effect is industrial unit costs. However, import prices can affect domestic prices in three different ways. First, by directly increasing industrial unit costs, to the extent that industry inputs are imported. Second, as competitor prices so that domestic prices tend to rise with import prices over and above any effect on costs. Third, as import prices directly affect consumer price inflation and therefore the expectation of future increases in import prices.

Import and export prices play the role of transmitting world inflation to the UK economy through its effect on export and import prices. Import and export prices are determined by world product prices, the exchange rate, world commodity prices and unit cost. For export prices in the short term there is also a supply-side effect which comes through the increases in the utilisation of capacity. A measure of technical progress is also included to cope with the quality effect on prices caused by increased levels of investment and R&D. Restrictions are imposed to force price homogeneity and exchange rate symmetry on the long-term equations.

Consumer prices are determined by import prices and industry prices and the respective weighting of imports and domestic purchases in consumers' expenditure, together with the application of product taxes.

The wage equations

The aggregate consumer price index is assumed to have a positive relationship with wages, such that an increase in prices should lead to an increase in wages. Productivity also has a positive relationship with wages: if employees in an industry are able to increase value added by increasing output for the same input then they are able to command higher wage rates.

The treatment of wages in MDM-E3 partly follows the typical wage bargaining model. The opportunity from not working as expressed by unemployment benefit has a positive relationship with wages as the benefit rate will mean that workers will want to gain sufficiently more than the available benefit transfer to justify employment. In MDM-E3, again following the wage bargaining models, unemployment levels also have an impact on wages: if unemployment is high it follows that wages will be low as there is no incentive for employers to pay an individual more when there are a large number of unemployed willing to work for a lower salary.

The retention ratio term identifies the average real take-home pay for any given salary level. The purpose of this is to simulate the characteristic of individuals operating in a way to make sure that their net pay means they are equally well off following a change in tax. If income tax increases, the retention ratio falls and wages rise to (fully or partially) compensate for the higher tax rate.

In an attempt to understand relationships between wages within one industry but across regions, or within one region but across industries, MDM-E3 also uses external industry wage rates and external regional wage rates to estimate wage rates as a system. The idea is that if wages in a region are increasing for all other industries that are not industry Y, then this should drive an increase in industry Y wages, within the specified region. This argument is then extended for one industry's wages across all the regions. If the oil and

gas industry increases wage rates in all non-X regions, this will have an impact on the oil and gas industry wages in region X.

Wage bills are calculated across region and industry by multiplying the average wage by the number of full time equivalent (FTE) employees. Further key variables, such as the total wage bill, average wage, average wage for a region and average wage for an industry are also calculated.

The treatment of financial stocks and returns in the model is currently quite limited and they have no important effects.

Endogenous technological progress

Technological progress is often represented as exogenous, either as a residual in a neoclassical production function or by using a linear or non-linear time trend approach. Both methods have their drawbacks. The neoclassical approach is somewhat circular in its logic, i.e. to know a firm's production possibilities one needs to model technological progress, but in modelling technological progress one is already making an assumption about the production process. The time trend approach is also unappealing given its atheoretical background.

The approach to constructing the measure of technological progress in E3ME is adapted from that of Lee et al (1990). It adopts a direct measure of technological progress by using cumulative gross investment, but this is altered by using data on R&D expenditure, thus forming a quality adjusted measure of investment.

A.3 Energy

MDM-E3's energy sub-models

Flows in the economic model are generally in current and constant prices, prices are treated as unit-value indices, and the energy-environment modelling is done in physical units. This modelling is described in Barker et al (1995).

MDM-E3 includes a bottom-up sub-model to model changes in the power generation sector's use of fuels in response to policy initiatives and prices. For this study, however, power generation by technology defines each of the scenarios, and it is therefore exogenous to the model.

Economic feedback

Energy-environment characteristics are represented by sub-models within MDM-E3, and at present the coverage includes energy demand (primary and final), environmental emissions, and electricity supply. Energy demand by industries is then translated into expenditure flows for inclusion within the input-output structure to determine economic variables, so that MDM-E3 is a fully-integrated single model, allowing extensive economy-energy-environment interactions.

Economic feedback and policy analysis

The ability to look at interactions and feedback effects between different sectors - industries, consumers, government - and the overall macroeconomy is essential for assessing the impact of government policy on energy inputs and environmental emissions. The alternative, multi-model approach, in which macroeconomic models are operated in tandem with detailed industry or energy models, cannot adequately tackle the simulation of 'bottom-up' policies. Normally such multi-model systems are first

solved at the macroeconomic level, and then the results for the macroeconomic variables are disaggregated by an industry model. However, if the policy is directed at the level of industrial variables, it is very difficult (without substantial intervention by the model operator) to ensure that the implicit results for macroeconomic variables from the industry model are consistent with the explicit results from the macro model. As an example, it is very difficult to use a macro-industry, two-model system to simulate the effect of exempting selected energy-intensive industries from a carbon or energy tax.

The energy sub-model determines final energy demand, fuel use by user and fuel, the prices of each fuel faced by fuel users, and also provides the feedback to the main economic framework of MDM-E3. Fuel use for road transport is solved using MDM-E3's Transport Sub-model. Fuel use for power generation is calculated in the electricity supply industry (ESI) sub-model, which uses a 'bottom-up' engineering treatment.

A.4 Final energy demand

Drivers of energy demand

Final energy and fuel demand by fuel user is modelled by econometric equations, which are estimated using a standard cointegrating technique. The estimation of energy demand occurs in a two-step method. Firstly, the aggregate (i.e. with no breakdown by fuel type) demand for energy for each end-user is determined. Typically, the key dependent variables are:

- the activity of the fuel user, usually taken to be gross output of the sector, but, in the case of households, household expenditure is used
- technological progress in energy use, which reflects both energy-saving technical progress and the elimination of inefficient technologies
- the price of energy relative to general prices
- changes in temperature

In addition, to account for the Climate Change Levy and Climate Change Agreements, we also include the 'announcement' effect of the CCL and the 'awareness' effects on participating industries of the CCAs. The estimates of these effects were derived from a study by Cambridge Econometrics for HM Customs and Excise (CE et al, 2005).

Fuel switching

Fuel users' demand for each fuel is estimated by splitting the estimated aggregate energy demand. To reflect the fact that fuel switching is inhibited by the existing stock of appliances and machinery used in the economy and the available infrastructure, it is assumed that fuel users adopt a hierarchy in their choice of fuels:

- choosing first electricity for premium uses (light, electrical appliances motive power, special heating applications)
- then sharing out non-electricity demand for energy between three fossil fuels (coal and coal products, oil products and gas)

The specification of these equations is similar to that of the aggregate energy equations, except that the estimated variable is the fuel share, and the explanatory variables are:

- activity
- technology measure
- three price terms - the price of the fuel type in question, the price index of its nearest competitor, and the general price index within the economy
- temperature (where relevant)

Aggregate energy demand and the fuel share equations

This method is regarded to be the most suitable given the data available and the relative quality of data at different levels of disaggregation. The aggregate energy demand equations command a higher level of confidence than the fuel share equations. The estimated fuel share equations used to split aggregate demand to yield demand for individual fuels by fuel users fit the data better than equations which directly estimate the demand of a particular fuel by an individual fuel user. This is partly due to high level of volatility in the time series data at this level of detail.

Both the aggregate energy/fuel demand equations and the disaggregated fuel share equations are specified as cointegrating equations:

- the dynamic part of the equation provides short-term responses of energy demand
- the long-term response is captured in the long-term part of the equation, adjusted for the speed of adjustment term (or error correction mechanism)

The equations for final energy demand are estimated on the data in the Digest of UK Energy Statistics (DUKES) published by DECC.

The wholesale prices of fossil fuels such as coal, oil and gas are assumptions in MDM-E3. Wholesale prices are converted to consumer/retailer prices for each fuel user by applying appropriate levies and taxes.

A.5 Emissions

Emission types

MDM-E3 distinguishes 14 air emissions, including the six greenhouse gases currently regulated under the Kyoto Protocol. Emissions data are obtained from the National Air Emissions Inventory (NAEI) and the last year of outturn is typically one year earlier than the energy data, published by DECC, that are fed into the model. For example, the last year of data reported in the July 2010 edition of DUKES is 2009 but the last year of NAEI data, published in 2010, is 2008.

The NAEI data for each year are highly disaggregated and classified by fuel type and activity. The data must be aggregated to the 11 fuel types and 25 fuel users distinguished in MDM-E3 and the guiding principle is that, as far as it practicable, emissions should be classified to the industries that use the fuels associated with the emissions e.g. if off-road vehicles are used mainly for construction, the emissions would be allocated to the fuel user Construction.

Where available, emissions coefficients for individual fuels and fuel users are applied to the corresponding energy demands, to give a first estimate of emissions. A scaling term is applied in the history to ensure that the final output matches official sources. This adjustment is held constant throughout the forecast period. Other emissions are calculated on an implied basis in the last year in which both energy and emissions data are available (2008 in the example above). These coefficients are also typically held constant for the remainder of the period (although they could for example be adjusted to reflect the adoption of emissions-abatement technologies).

Emissions from non-energy use are linked to fuel-user activity indicators or population growth and are thus not differentiated by fuel. Emissions from land use and land use change are not covered.

Appendix B: Key Assumptions

B

Table B.1 and Figures B.1 and B.2 summarise the main cost inputs to offshore wind and gas generation in each of the scenarios in 2020 and 2030. Table B.2 shows data on the input costs for the calculations of annual and levelised generation costs. Table B.3 shows the data underpinning the CAPEX sensitivities presented in Chapter 5.

Table B.1: Annual Generation Costs

WIND Scenario (high offshore wind deployment post 2020)

	2015	2020	2025	2030
Gas CCGT (£/MWh)	67.50	72.21	92.44	138.85
Offshore Wind (£/MWh)	139.81	96.82	85.24	75.29

GAS Scenario (no new offshore wind build post 2020)

	2015	2020	2025	2030
Gas CCGT (£/MWh)	67.50	72.21	77.38	78.18
Offshore Wind (£/MWh)	139.81	96.82	90.89	85.56

Notes: All figures in 2011 prices.

The annual generation cost of gas in the WIND scenario increases substantially in £/MWh terms because it acts as back-up supply rather than baseload generation.

Source: Cambridge Econometrics calculations based on inputs from Mott MacDonald (2011) Costs of low-carbon generation technologies.

Figure B.1: Breakdown of Gas and Offshore Wind Costs in GAS Scenario

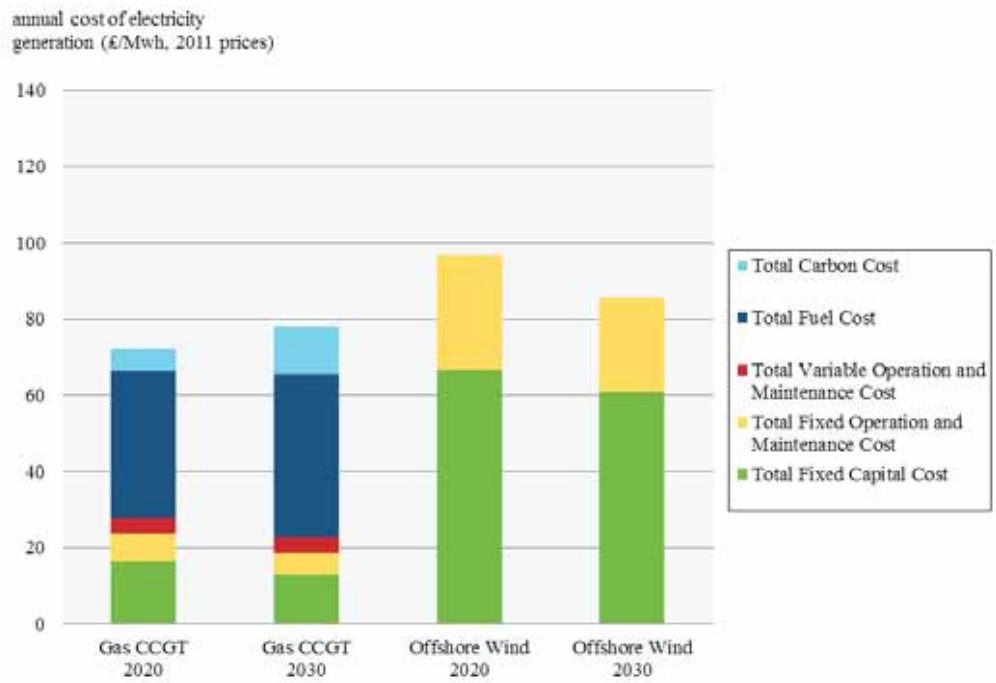


Figure B.2: Breakdown of Gas and Offshore Wind Costs in WIND Scenario

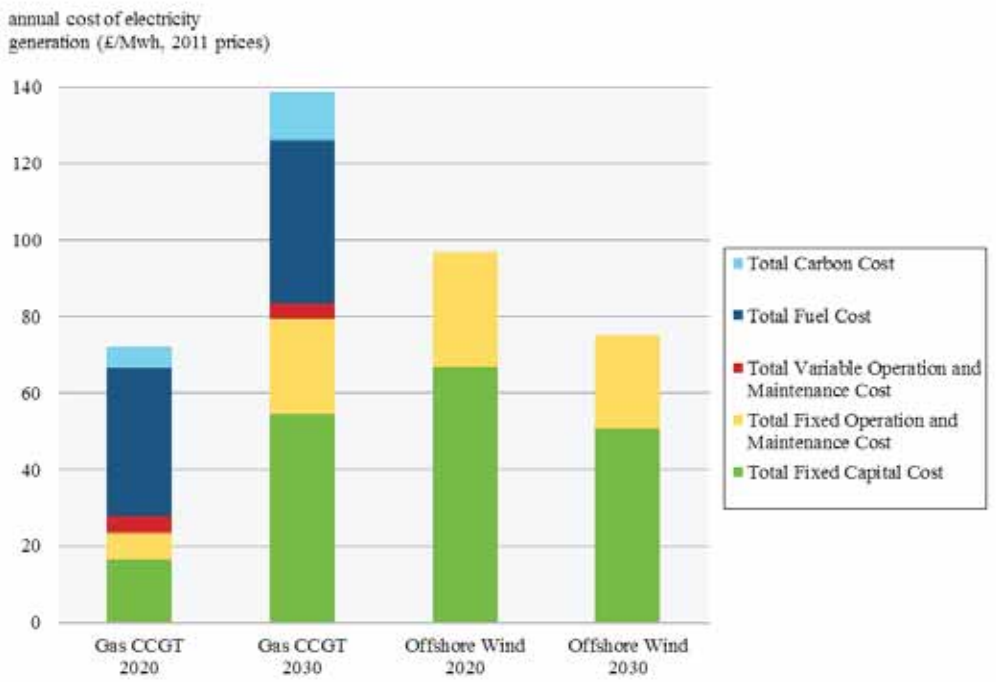


Table B.2: Key Input Assumptions

			2020	2030
Capital cost in WIND Scenario				
	Gas CCGT	£/kW/Year,	62	59
	Offshore wind	£/kW/Year	227	188
Capital cost in GAS Scenario				
	Gas CCGT	£/kW/Year,	62	59
	Offshore wind	£/kW/Year	227	227
Fuel prices				
	Gas	£/MWh	23	25
Carbon prices				
	ETS	£/tCO_2	28.5	33.1
	Carbon Price Floor	£/tCO_2	31.8	74.2
Plant lifetime				
	Gas CCGT	years	30	
	Offshore wind	years	24	

Notes: All figures in 2011 prices.
Sources: Various sources, see Table 2.2.

Table B.3: Key Input Assumptions: CAPEX Sensitivities for Offshore Wind

			2020	2030
High Capital Cost Sensitivity				
	CAPEX (excl. borrowing)	£/kW	2,317	2,317
	CAPEX (incl. borrowing)	£/kW	6,121	5,741
	Borrowing Rate	%	10.00%	8.90%
	Operation and Maintenance Costs	£/kW/Year	103	98
Central Capital Costs				
	CAPEX (excl. borrowing)	£/kW	2,317	2,058
	CAPEX (incl. borrowing)	£/kW	5,439	4,524
	Borrowing Rate	%	8.50%	7.70%
	Operation and Maintenance Costs	£/kW/Year	103	92
Low Capital Cost Sensitivity				
	CAPEX (excl. borrowing)	£/kW	2,317	1,828
	CAPEX (incl. borrowing)	£/kW	4,789	3,609
	Borrowing Rate	%	7.00%	6.50%
	Operation and Maintenance Costs	£/kW/Year	103	86

Notes: All figures in 2011 prices.

Sources: Cambridge Econometrics own calculations based on various input sources, see Table 2.2 for more details.

Appendix C: Key Results

C

Tables C.1 - C.3 summarise key results from the scenarios.

Table C.1: GDP

	2020	2025	2030
GAS Scenario (£bn)	1,895.30	2,144.70	2,462.10
WIND Scenario (£bn)	1,895.30	2,158.40	2,482.30

Notes: Figures are in 2011 prices.
Sources: Cambridge Econometrics.

Table C.2: Power Sector Emissions

	2020	2025	2030
GAS Scenario (ktCO_2)	115,249	83,827	70,029
WIND Scenario (ktCO_2)	115,249	59,965	20,103

Sources: Cambridge Econometrics.

Table C.3: Annual Average Household Electricity Bills

	2020	2025	2030
GAS Scenario (£s)	586.6	770.97	1,064.47
WIND Scenario (£s)	586.6	799.35	1,079.75

Notes: Figures are presented in nominal prices.
Sources: Cambridge Econometrics.

Appendix D: Levelised Cost Analysis

D

The levelised costs in Figures D.1-D.4 are calculated using cost projections and technical characteristics from Mott MacDonald (2011) *Costs of low-carbon generation technologies,* and tested against different discount rates. A learning rate of 10% is included for additional offshore wind capital cost reductions.

Figure D.1: Levelised Cost for a Project Starting in 2020, Under a 7.5% Discount Rate

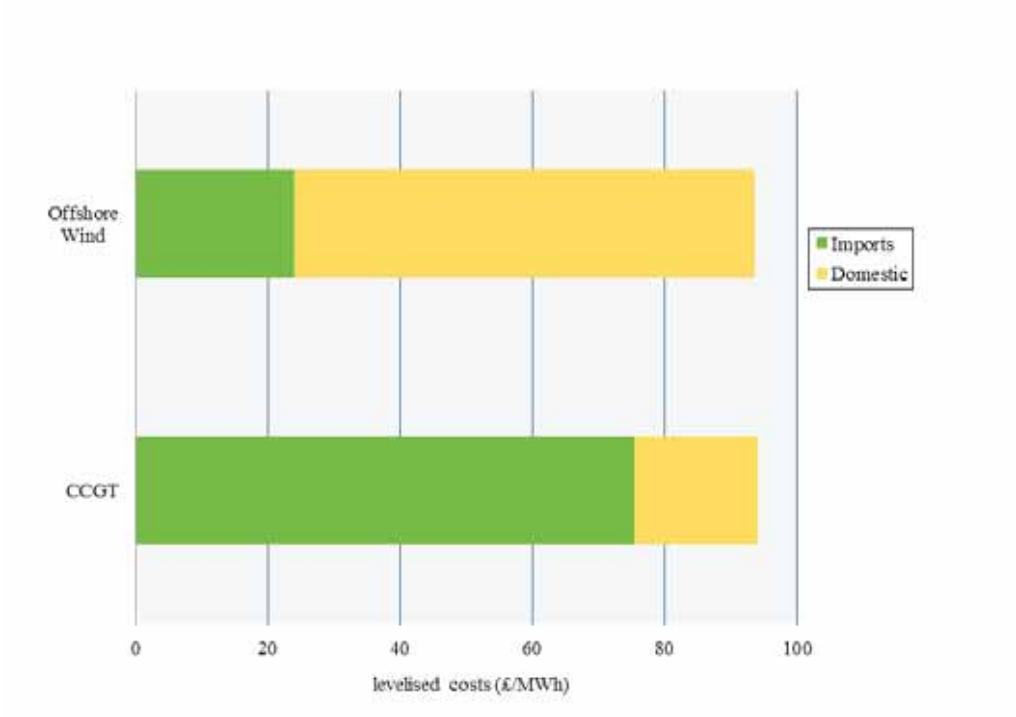


Figure D.2: Levelised Cost for a Project Starting in 2030, Under a 7.5% Discount Rate

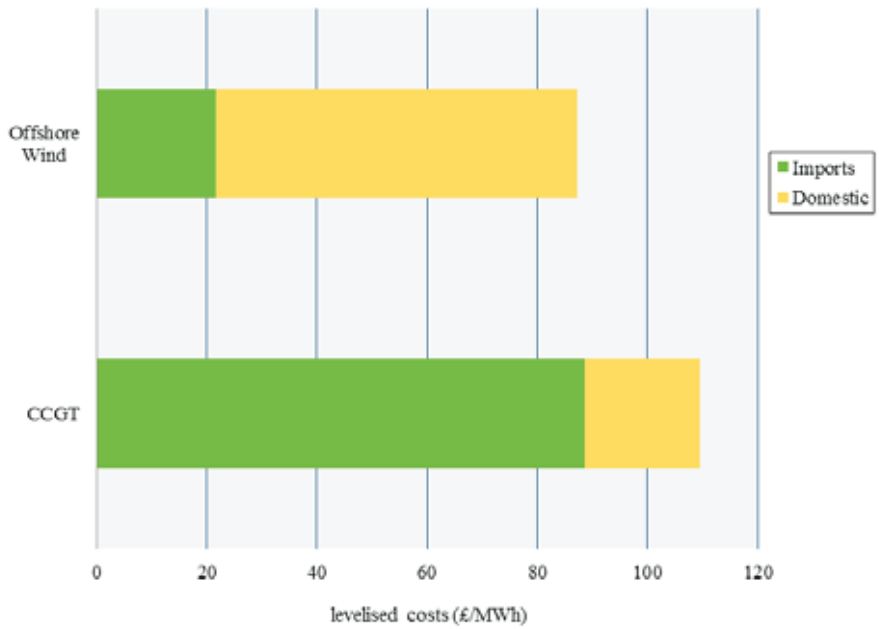


Figure D.3: Levelised Cost for a Project Starting in 2020, Under a 10% Discount Rate

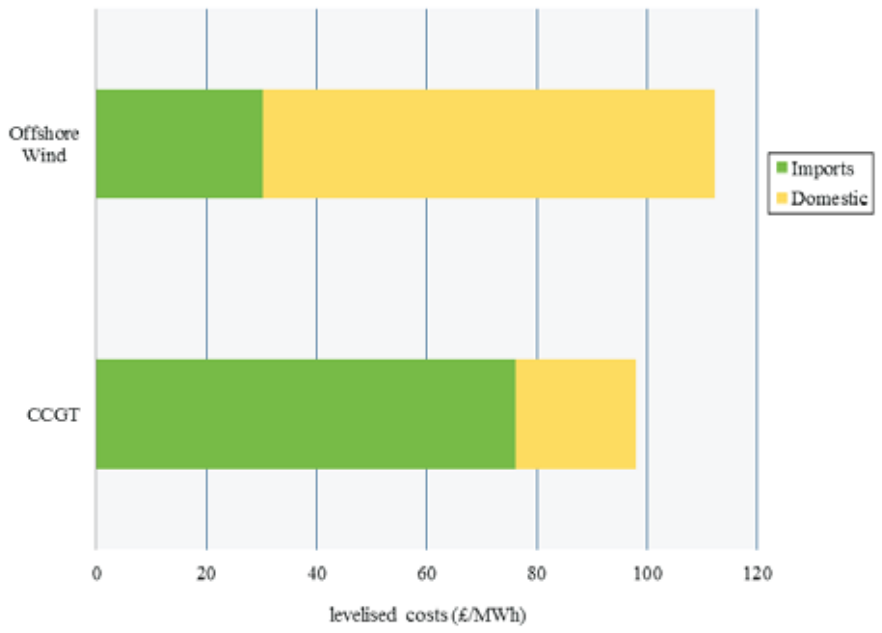
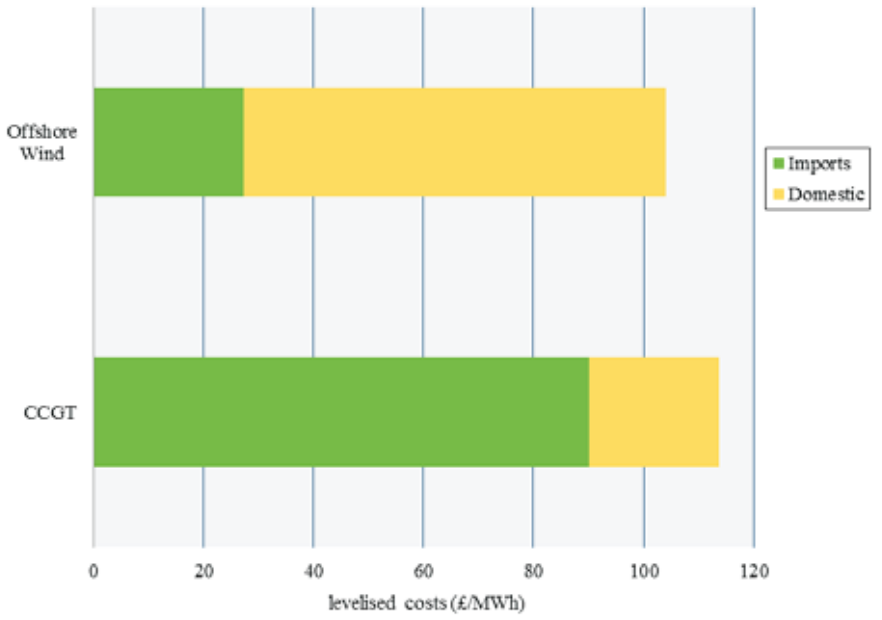


Figure D.4: Levelised Cost for a Project Starting in 2030, Under a 10% Discount Rate



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