Risk managing cost-effective decarbonisation of the power sector in Great Britain

FINAL RESULTS

October, 2012

This project is funded by the European Climate Foundation
Contents

• Objectives and the methodology
• Baseline analysis results
• Sensitivity analysis results
• Annex - Assumptions
Objectives of the analysis

**WHAT IT IS**

- An attempt to change the way people think about technology choices from cost minimisation to risk management
- Something different from traditional ‘equilibrium’ modelling studies
- Credible and interesting from the member state (MS) perspective as well as at a European level
- Provides a focus on the role of Renewables (RES) and gas

**WHAT IT IS NOT**

- An attempt to forecast the future
- An assessment of market design choices (e.g. what drives investment, capacity mechanisms, welfare allocation)
- An analysis of the future role of Emissions Trading System (ETS) and 2030 carbon caps
- An evaluation of nuclear power
- An evaluation of interconnection and optimising resources across the EU
A new approach is needed to move the debate from least cost decarbonisation to cost-effective risk managed delivery of policy objectives

• The Investment Decision Model developed by Redpoint is an agent-based investment model with no perfect foresight, where the investors act based on future expectations of return with a five year period of foresight

• A similar analysis was carried out for Germany and Poland to represent different member state circumstances and reflect EU-wide issues
Overview of the baseline scenarios

- **Technology Support Scenario**
  - Renewables electricity production (RES-E) subsidy continues post 2020
  - Carbon price trajectory of the EC’s Energy Roadmap 2050

- **Carbon Price Scenario**
  - Carbon price is the single driver of decarbonisation
  - RES-E subsidy stops in 2015 – no further development of supply chains

These two baseline policy scenarios reflect competing approaches to delivering power sector decarbonisation in the UK in line with the 50g/KWh intensity target proposed for 2030 by the Committee on Climate Change.
Technology Support and Carbon Price baseline scenarios were stress tested against a range of uncertainties.

<table>
<thead>
<tr>
<th>SENSITIVITY</th>
<th>DESCRIPTION</th>
<th>TESTED BASELINE SCENARIO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electricity demand</strong></td>
<td><strong>High demand:</strong> Only half of electrical efficiency assumed under baseline delivered and higher electrification of heat and transport (483TWh instead of 434TWh)</td>
<td>Carbon Price Scenario Technology Support Scenario</td>
</tr>
<tr>
<td>(High vs Low demand)</td>
<td><strong>Low demand:</strong> Less electrification (395TWh instead of 434TWh)</td>
<td></td>
</tr>
<tr>
<td><strong>Low electrical efficiency</strong></td>
<td>Only half of electrical efficiency assumed under baseline is delivered (468 TWh instead of 434TWh)</td>
<td>Carbon Price Scenario Technology Support Scenario</td>
</tr>
<tr>
<td>(High Demand EFF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>No new nuclear build</strong></td>
<td>No new capacity as opposed to 12.8GW new capacity fixed in both baselines</td>
<td>Carbon Price Scenario Technology Support Scenario</td>
</tr>
<tr>
<td><strong>CCS deployment</strong> (High vs Low)</td>
<td><strong>High CCS:</strong> 21.6 GW deployed earlier</td>
<td>Carbon Price Scenario</td>
</tr>
<tr>
<td><strong>Offshore wind deployment</strong></td>
<td><strong>High offshore:</strong> 41GW deployed earlier</td>
<td>Technology Support Scenario</td>
</tr>
<tr>
<td>(High vs Low)</td>
<td><strong>Low CCS:</strong> only 1.2 GW</td>
<td></td>
</tr>
<tr>
<td><strong>Offshore wind deployment</strong></td>
<td><strong>Low offshore:</strong> 35 GW deployed</td>
<td></td>
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<tr>
<td>(High vs Low)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High/Low electricity demand combined with Low CCS</strong></td>
<td>Combination of above</td>
<td>Carbon Price Scenario Technology Support Scenario</td>
</tr>
<tr>
<td><strong>Low electrical efficiency combined with no new nuclear build</strong></td>
<td>Combination of above</td>
<td>Carbon Price Scenario Technology Support Scenario</td>
</tr>
<tr>
<td><strong>Gas price</strong></td>
<td>75% higher or lower than baseline gas price assumption (60p/ therm) – introduced with no foresight and lasted for five years</td>
<td>Carbon Price Scenario Technology Support Scenario</td>
</tr>
<tr>
<td>(High vs Low)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expensive CCS</strong></td>
<td>CCS costs double</td>
<td>Carbon Price Scenario</td>
</tr>
</tbody>
</table>

1. CCS and offshore wind deployment related sensitivities were tested only for one of the baseline scenarios. This was due to the fact that sensitivity runs were decided on the basis of baseline results and different baselines had different technology mixes.


N.B. Further details of the underlying assumptions can be found in Annex.
Contents

• Objectives and the methodology

• Baseline analysis results

• Sensitivity analysis results

• Annex - Assumptions
In the Technology Support Scenario baseline low-carbon capacity is deployed continuously, while in the Carbon Price Scenario decarbonisation is driven by CCS in 2020s.
Unabated gas capacity remains a significant part of the capacity mix in both scenarios

Technology Support Scenario baseline
Total generation capacity (GW)

Carbon Price Scenario baseline
Total generation capacity (GW)

17 GW of unabated gas capacity retires between 2012 and 2030

32 GW of unabated gas capacity retires between 2012 and 2030 driven by higher carbon prices
However, the generation profile for unabated gas is significantly different in the scenarios, while coal is pushed out gradually.

In GB generation mix, the main trade off is between offshore wind and CCS gas (given nuclear capacity is fixed).

E3G - Third Generation Environmentalism
Installed unabated gas capacity would play a very different role under different scenarios.

**Comparison of baseline scenarios**

Installed unabated gas capacity vs load factors  
(GW vs %)
Under the Technology Support baseline scenario, the emissions reduction trajectory would be steadier due to continuous renewables deployment.
Power sector costs are higher in Technology Support Scenario baseline

**Technology Support Scenario baseline**
Breakdown of power sector costs, £ bn 2012-30 cumulative

**Carbon Price Scenario baseline**
Breakdown of power sector costs, £ bn 2012-30 cumulative
Contents

• Objectives and the methodology

• Baseline analysis results

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• Annex - Assumptions
Relying solely on carbon pricing is an unattractive approach to incentivising investment.

Low CCS deployment means very high carbon prices will be needed to drive rapid deployment in offshore wind.

Ranges of carbon prices:
(€130 to €350/t/CO₂ and above max.; €76/t/CO₂ min.)
Carbon price trajectories: impact of sensitivities in the Carbon Price Scenario

[Graph showing carbon price trajectories for different scenarios, such as EUA (€), Carbon Price Scenario baseline, Low Efficiency - No Nuclear, High Demand - Low CCS, Low Demand - Low CCS, Low CCS, No New Nuclear, Expensive CCS, High Demand, High CCS, Low Demand, Low Efficiency, and Low Demand.]
Total power sector costs under the ‘gas-heavy’ Carbon Price Scenario are more unpredictable and can be much higher.

Technology specific support mechanisms remain critical to decarbonisation in GB alongside a lower carbon price.
In the case of low electrical efficiency and no new nuclear, power sector costs would increase significantly under the Carbon Price Scenario.

**Technology Support Scenario (Low EFF + No nuclear)**
Breakdown of power sector costs

- Costs increase by only 6% if electrical efficiency fails and there is no new nuclear.

**Carbon Price Scenario (Low EFF + No nuclear)**
Breakdown of power sector costs

- Costs increase by 98% if electrical efficiency fails and there is no new nuclear.
Impact of sensitivities on power sector costs in Technology Support Scenario

Overall, costs are more resilient to uncertainties. Biggest risk to costs would come from increased electricity demand, either as a failure to deliver improved electrical efficiency or as a result of higher electricity demand from other sectors. Biggest savings also come from delivering electrical efficiency, hence lower demand.
Impact of sensitivities on power sector costs in Carbon Price Scenario

Carbon Price Scenario
Power sector costs, £ bn 2012-30 cumulative

Risks are significantly more asymmetric, and costs tend to go higher under a gas-heavy pathway. In some cases, costs can be higher than renewables-heavy Technology Support Scenario, especially in the case of low efficiency and no new nuclear.

Delivering the target in the Carbon Price Scenario baseline costs £297bn in total between 2012 and 2030.
Annual power sector costs: impact of sensitivities in the Technology Support Scenario

Technology Support Scenario
Power sector costs, £ bn 2012-30 annual

- High Demand
- Low Efficiency
- Low Efficiency - No Nuclear
- High Gas
- Low OffWind
- No New Nuclear
- High OffWind
- Low Gas
- Low Demand
- Technology Support Scenario baseline
Annual power sector costs: impact of sensitivities in the Carbon Price Scenario

Carbon Price Scenario
Power sector costs, £ bn 2012-30 annual
Similarly, wholesale cost risks are higher in the Carbon Price scenario.

- **Technology Support Scenario**
  Wholesale costs, £ bn 2012-30 cumulative

  - Cost range: +14% to -9%

- **Carbon Price Scenario**
  Wholesale costs, £ bn 2012-30 cumulative

  - Cost range: +160% to -11%

Under the Carbon Price Scenario, increasing carbon prices push up the costs of gas generation. This results in higher wholesale prices, creating significant rents for low-carbon generators.
Annual wholesale costs: impact of sensitivities in the Technology Support Scenario

Technology Support Scenario
Wholesale costs, £ bn 2012-30 annual

- High Demand
- Low Efficiency
- Low Efficiency - No Nuclear
- High Gas
- Low Gas
- High OffWind
- Low OffWind
- No New Nuclear
- Low Demand
- Technology Support Scenario baseline
Annual wholesale costs: impact of sensitivities in the Carbon Price Scenario

Carbon Price Scenario
Wholesale costs, £ bn 2012-30 annual

- Low efficiency - No Nuclear
- High Demand - Low CCS
- High Demand
- Low CCS
- Low Efficiency
- Expensive CCS
- No New Nuclear
- Low Demand - Low CCS
- High Gas
- Low Gas
- Low Demand
- High CCS
- Carbon Price Scenario baseline
Future value of new gas investment remains uncertain (i)

**Technology Support Scenario**
Unabated gas generation (TWh)

**Carbon Price Scenario**
Unabated gas generation (TWh)
Future value of new gas investment remains uncertain (ii)

**Technology Support Scenario**
Unabated gas load factors (%)

**Carbon Price Scenario**
Unabated gas load factors (%)

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E3G - Third Generation Environmentalism

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Large gas demand uncertainties (particularly in a gas-heavy pathway), raise questions as to the level of new investment required in gas infrastructure.

**Technology Support Scenario**
Power sector gas consumption (bcm)

**Carbon Price Scenario**
Power sector gas consumption (bcm)

The continued consumption of high volumes of gas depends on both the successful commercialisation of CCS technology and gas generation being cheaper than coal.
Power sector gas consumption: impact of sensitivities

**Technology Support Scenario**
Power sector gas consumption (bcm)

**Carbon Price Scenario**
Power sector gas consumption (bcm)
Continued deployment of renewables produces steady reductions in emissions intensity with more predictable delivery.

**Technology Support Scenario**
Emission intensity (g/KWh)

**Carbon Price Scenario**
Emission intensity (g/KWh)

*Policy failure* in the case of Low CCS deployment; High demand and low demand combined with low CCS deployment.
Continued deployment of renewables also delivers higher reductions in cumulative emissions

### Technology Support Scenario
Cumulative CO2 emissions (mn tonnes)

### Carbon Price Scenario
Cumulative CO2 emissions (mn tonnes)
Generation in Carbon Price Scenario: impact of sensitivities (1/2)
Generation in Carbon Price Scenario: impact of sensitivities (2/2)
Generation in Technology Support
Scenario: impact of sensitivities (1/2)
Generation in Technology Support
Scenario: impact of sensitivities (2/2)

PM - High CCS

PM - Low CCS

PM - High Demand EFF

PM - High Demand EFF No Nuclear

E3G - Third Generation
Environmentalism
Contents

- Objectives and the methodology
- Baseline analysis results
- Sensitivity analysis results
- Annex – Assumptions and modelling
The Redpoint IDM constructs detailed market outlooks in the GB power market covering the period of 2012-2030.

The IDM is based on an agent simulation engine that aims to mimic players’ decision-making with regards to their investment decisions in new plant as well as their decisions to retire existing plant.

The model contains a list of potential new-build projects according to their size, cost and earliest possible year of operation. Total investment in a particular technology is limited by the technology’s maximum annual and cumulative build constraints. If the constraint is binding, the projects with the highest expected returns are built.

Technology costs (capex and opex) can be varied over time and if required set endogenously within the model dependent on levels of deployment, which may affect rates of learning and position on the supply curves.

For each year, the levelised cost of energy (LCOE) of potential new-build projects are compared against their expected revenues (given assumed load factors, future price expectations, capacity payments and support levels) and where costs are less than expected revenues, projects are moved first to a planning stage, and subsequently, if still economic, to a committed development phase.

Additionally, retirement decisions for existing plant are also made on the basis of near term profitability expectations.

A 5-year forward-looking view for investing in a new plant is assumed and a 1-year forward-looking view for plant retirement decisions.

Where applicable, the model can include full representation of Contracts for Difference (CfDs) and a universal capacity mechanism.
Investment modelling – Non perfect foresight

- The model has a 5 year forward view of commodity prices and demand supply (1).

- Rolling through each year, the model estimates power prices and dispatch for the forward view horizon. The resulting expected gross margin is compared to the expected levelised costs (2).

- On that basis the model decides whether a project should enter the planning stage (3) and then rolls forward to the next year (4). During planning the project can still be cancelled. Once the planning period is over the model will decide whether to move to the construction phase at which point the project is committed.
Generator decisions: new build and retirement

- **Generator build decisions:** For new plant the levelised non-fuel cost includes capital costs and annual fixed costs. The gross margin is calculated as the expected margin from power revenues, capacity payments and financial support less fuel and carbon costs and non-fuel variable costs. There are two trigger points which a project must pass to progress to construction. If a project is “in the money” it enters planning. If it continues to be in the money at the end of the planning period, the project is committed to the construction phase, and will become operational after a defined number of years.

- **Generator retirement decisions:** The logic for closure decisions of existing generators is analogous to that for new investments. The key difference, however, is that the capital already invested is ignored as this is considered to be a sunk cost. As a result, total annual fixed costs are compared against the expected gross margin and, when these are higher for a pre-defined number of years, the plant retires.
The model allowed policy intervention to correct deviation from the policy objective.

**Carbon Price Scenario baseline**

- **Under delivery**
  - Increased carbon price to €350 per tonne to deploy offshore wind
    - High electricity demand; No new nuclear; High electricity demand (low efficiency)
    - Low CCS; High/low electricity demand + low CCS

- **Over delivery**
  - Reduced or maintained carbon price
    - Low electricity demand; High CCS

**Technology Support Scenario baseline**

- **Under delivery**
  - Increase renewable deployment rate
    - High electricity demand; high CCS; no new nuclear
  - Subsidise CCS gas
    - Low offshore wind

- **Over delivery**
  - Reduce offshore wind deployment rate
    - Low electricity demand
## Capital costs assumptions

### Capital costs (£/kW, real 2011)

<table>
<thead>
<tr>
<th>Years</th>
<th>Nuclear</th>
<th>CCGT</th>
<th>Gas CCS</th>
<th>Coal &amp; Lignite</th>
<th>Onshore Wind CCS</th>
<th>Biomass</th>
<th>Solar PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>3582</td>
<td>703</td>
<td>1335</td>
<td>2837</td>
<td>912</td>
<td>2005</td>
<td>3316</td>
</tr>
<tr>
<td>2015</td>
<td>3451</td>
<td>692</td>
<td>1273</td>
<td>2700</td>
<td>912</td>
<td>1943</td>
<td>2824</td>
</tr>
<tr>
<td>2020</td>
<td>3287</td>
<td>678</td>
<td>1196</td>
<td>2528</td>
<td>911</td>
<td>1866</td>
<td>2209</td>
</tr>
<tr>
<td>2025</td>
<td>3236</td>
<td>653</td>
<td>1058</td>
<td>2219</td>
<td>903</td>
<td>1850</td>
<td>1791</td>
</tr>
<tr>
<td>2030</td>
<td>3184</td>
<td>629</td>
<td>920</td>
<td>1910</td>
<td>895</td>
<td>1833</td>
<td>1372</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years</th>
<th>Offshore Wind (Low)</th>
<th>Offshore Wind (Base)</th>
<th>Offshore Wind (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2142</td>
<td>2535</td>
<td>2964</td>
</tr>
<tr>
<td>2015</td>
<td>1933</td>
<td>2288</td>
<td>2675</td>
</tr>
<tr>
<td>2020</td>
<td>1672</td>
<td>1979</td>
<td>2314</td>
</tr>
<tr>
<td>2025</td>
<td>1602</td>
<td>1896</td>
<td>2217</td>
</tr>
<tr>
<td>2030</td>
<td>1532</td>
<td>1813</td>
<td>2120</td>
</tr>
</tbody>
</table>

- All capital costs except offshore wind are based on the Energy Roadmap 2050
- Offshore wind capital costs (Base/High/Low) are based on the study by ARUP for DECC
- The costs evolve over time reflecting learning curves and economies of scale. In particular solar and CCS are not yet mature technologies and can therefore follow steep learning curves.
The chart on the right shows the evolving Long Run Marginal Cost (LRMC) of various technologies, split into their various components.
## Other cost assumptions

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hurdle Rate</th>
<th>Variable Operating &amp; Maintenance (€/MWh)</th>
<th>Fixed costs (% of capital costs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>8.2%</td>
<td>1.40</td>
<td>3.0%</td>
</tr>
<tr>
<td>Coal</td>
<td>9.0%</td>
<td>2.50</td>
<td>3.0%</td>
</tr>
<tr>
<td>Lignite</td>
<td>9.0%</td>
<td>3.50</td>
<td>3.0%</td>
</tr>
<tr>
<td>Gas CCS</td>
<td>12.0%</td>
<td>3.50</td>
<td>3.0%</td>
</tr>
<tr>
<td>Coal CCS</td>
<td>12.0%</td>
<td>5.50</td>
<td>3.0%</td>
</tr>
<tr>
<td>Lignite CCS</td>
<td>12.0%</td>
<td>5.50</td>
<td>3.0%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>11.5%</td>
<td>5.00</td>
<td>2.0%</td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>9.0%</td>
<td>0.40</td>
<td>4.0%</td>
</tr>
<tr>
<td>Offshore Wind</td>
<td>11.0%</td>
<td>0.40</td>
<td>5.5%</td>
</tr>
</tbody>
</table>
Baseline commodity prices

- The Base commodity prices are based on the 450 scenario from the IEA World Energy Outlook 2011.

- Where applicable, the lignite fuel price is assumed to be 1.7 €/GJ (real 2011) throughout the modelling horizon.
Gas price shocks were introduced overnight with no foresight for beginning or ending of the event.

- Baseline gas price is based on the 450 scenario from the IEA World Energy Outlook 2011.
- High and low gas price shocks are 75% higher or lower than the baseline price.
- Gas price shocks introduced overnight in early 2020s and lasts for 4-5 years.
Electricity demand: baseline and sensitivity assumptions

**HIGH DEMAND**
- Overall electricity demand is **483 TWh**. This was due to a combination of failing to deliver electrical efficiency and higher demand from other sectors.
  - In this scenario, only half of the electrical efficiency assumed under the DECC UEP Central scenario is delivered. The difference between the DECC UEP Central scenario and Baseline Scenario was taken as the level of energy efficiency savings from climate change policies.
  - 54 TWh additional demand due to electrification in transport (30 TWh from Electric Vehicles) and heat (24 TWh from Heat Pumps) by 2030 is assumed, based on the higher end of the Committee on Climate Change 4th carbon budget projections.

**BASELINE DEMAND**
- Overall electricity demand is **434 TWh**. This is based on DECC UEP Central Scenario and 39 TWh additional demand due to electrification in heat (24 TWh from heat pumps) and transport (15 TWh from EV) is assumed, based on the lower end of CCC’s 4th carbon budget projections.

**LOW DEMAND**
- Overall electricity demand is **395 TWh**. This is based on DECC UEP Central Scenario which includes delivery of electrical efficiency and no additional demand from other sectors.

Sources: DECC 2011 Updated Energy and Emissions Projections 2011; CCC 2010 4th Carbon Budget: Reducing emissions through the 2020s
Investment decisions were taken with the expectation of base electricity demand, but were then subject to higher or lower electricity demand.

- Investment decisions were made with the expectation of a base demand.
- Every five years, investors readjusted their expectations in line with a base demand (red) trajectory (green and purple dotted lines); however, the demand remained higher or lower than their expectations (yellow and blue lines). For example:
  - In the High Demand case, the expectation in 2015 follows the green dashed line, although outturn demand follows the yellow line.
  - In 2019 expectations still follow the downward path (smaller green dashed line).
  - In 2020 expectations are reset but again follow the downward gradient (as illustrated by the green dashed lines).
- This 5 year cycle continues throughout the modelling horizon.
Technology deployment assumptions and maximum levels

- **High Deployment**: 50% higher than the baseline deployment (~30 GW by 2030)
- **Baseline**: Around 21 GW of combined CCS capacity across both fuels (gas and coal). CCS initially gets deployed only in the Carbon Price Baseline scenario.
- **Low deployment**: CCS technology fails a year into construction of the first commercial plant and there is no subsequent CCS deployment.

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**CCS**

- **Baseline**: Around 21 GW of combined CCS capacity across both fuels (gas and coal). CCS initially gets deployed only in the Carbon Price Baseline scenario.
- **Low deployment**: CCS technology fails a year into construction of the first commercial plant and there is no subsequent CCS deployment.

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**Nuclear**

- **Baseline**: We assume 12.8 GW of nuclear new build capacity by 2030 in both baseline scenario.
- **No new nuclear sensitivity** assumes this new capacity does not get built

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**Offshore wind**

- 35, 41 and 52 GW maximum installed capacity in the Low/Base/High cases respectively based on ARUP study.
- The Low case (35 GW) refers to a maximum realisation of 60% of R3 offshore potential, the Base case to 80% and the High case to complete R3 realisation with some additional R4 projects.

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**Onshore wind**

- 17 GW maximum installed capacity by 2030 based on ARUP’s Base scenario