Technical Annex 1: Progress decarbonising the power sector

The intention of this technical annex is to provide reference and additional detail alongside the main report – the sections correspond to those in the main report, and charts and tables from that report are not reproduced here.

1. Power Sector Emissions

This section provides additional detail on drivers of power sector emissions reduction in recent years, specifically the growing contribution of low-carbon technologies to overall UK generation as well as trends in demand.

Table A1.1 Share of UK electricity generation by technology

Technology	2013 - TWh (% of generation)	2014 - TWh (% of generation)
Coal	124 (39%)	95 (32%)
Gas	81 (26%)	87 (29%)
Oil	1 (<1%)	<1 (<1%)
Nuclear	58 (20%)	58 (19%)
Onshore wind	17 (5%)	18 (6%)
Offshore wind	11 (3%)	13 (4%)
Biomass	17 (5%)	20 (7%)
Solar	1 (<1%)	3 (1%)
Hydro	5 (1%)	6 (2%)
Total UK generation	**318**	**298**
Imports	*14*	*21*

Source: DECC (2015) *Energy Trends Table 5.1.* Available at: www.gov.uk
Note: Total UK generation is conventional generation from 'Major Power Producers' plus renewable generation from 'All generating companies' in DECC's *Energy Trends Table 5.1.* An adjustment is made to estimate solar power that is exported to the electricity grid (rather than being consumed on site).
Imports are additional to total UK generation.
Numbers may not sum due to rounding.

Table A1.2 Electricity demand and weather-adjusted electricity demand (2007-2014)								
TWh	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Electricity demand	342	342	322	329	318	318	317	304
Temperature adjusted demand	344	343	323	326	321	318	317	307
Adjustment	*3*	*1*	*1*	*-3*	*3*	*0*	*-0*	*3*

Source: DECC (2015) *Energy Trends.* Available at: www.gov.uk
Note: Temperature adjusted demand applies to the residential sector only.

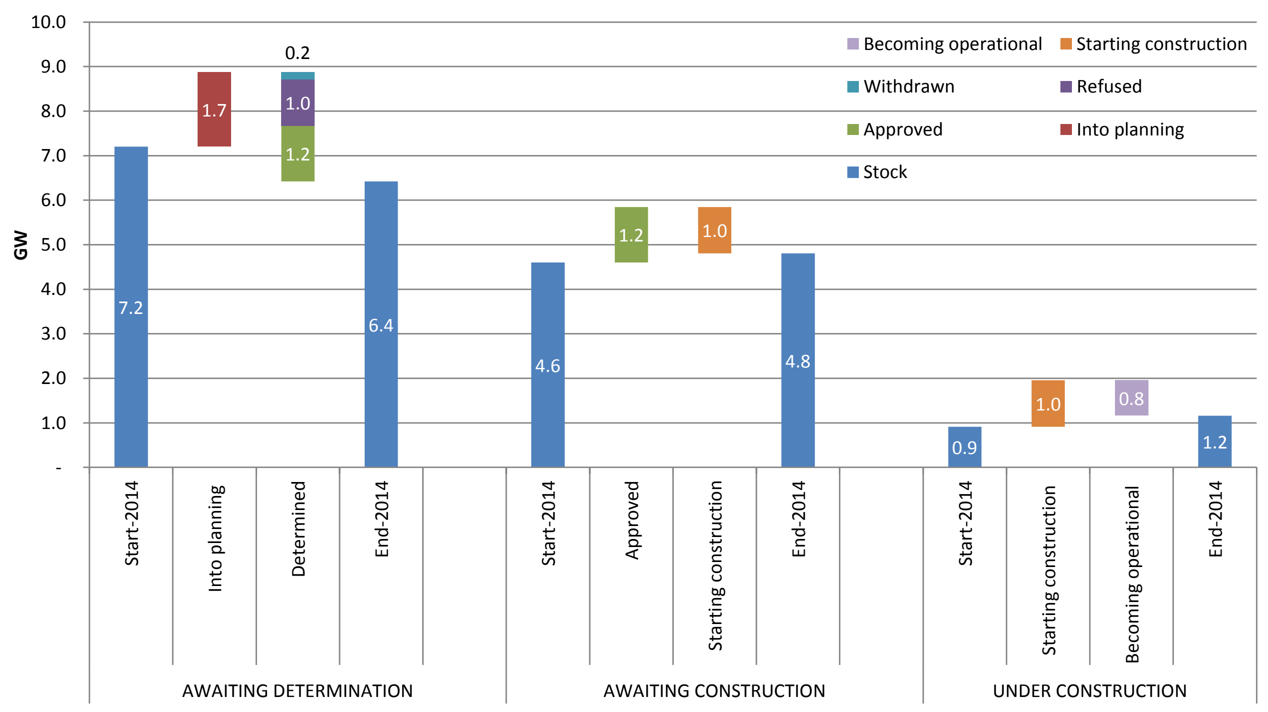
2. Performance against the Committee's progress indicators

This section provides additional detail on progress and delivery risks for deploying onshore and offshore wind, as well as detail on the costs and potential of marine technologies (wave and tidal).

Onshore wind

Figure A1.1 illustrates onshore wind capacity moving through the planning pipeline during 2014.

Figure A1.1: Onshore wind capacity moving through planning and construction (2014)

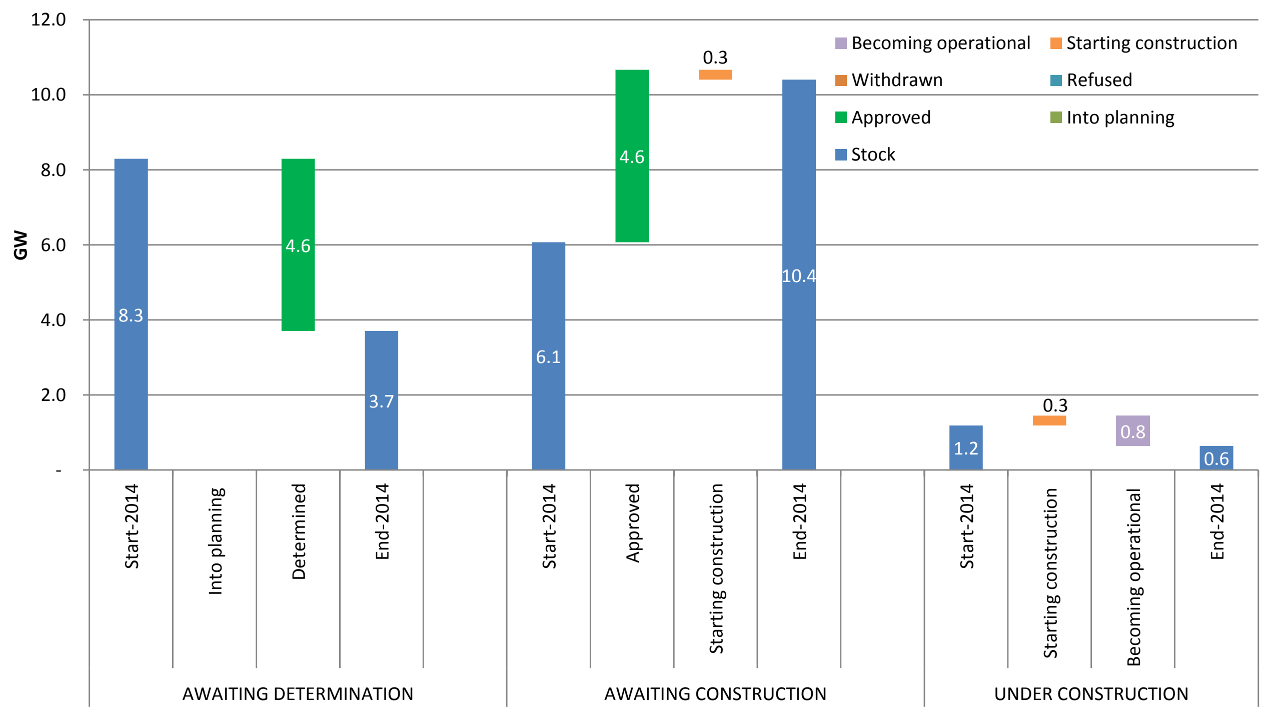


Source: DECC (March 2015) *Renewable Energy Planning Database*. Available at: www.gov.uk
Notes: Numbers may not sum due to rounding. As of 2015 the Renewable Energy Planning Database no longer contains projects below 1 MW in size; calculations of capacity moving through the planning pipeline may be slightly different to those published in previous years.

Offshore wind

Figure A1.2 illustrates offshore wind capacity moving through the planning pipeline during 2014.

Figure A1.2: Offshore wind capacity moving through planning and construction (2014)



Source: DECC (March 2015) *Renewable Energy Planning Database*. Available at: www.gov.uk
Notes: Numbers may not sum due to rounding. As of 2015 the Renewable Energy Planning Database no longer contains projects below 1 MW in size; calculations of capacity moving through the planning pipeline may be slightly different to those published in previous years.

Table A1.3 Planning approval rates for onshore and offshore wind

Technology	2007-2013 Average	2014
Onshore wind	67%	55%
England	56%	46%
Wales	63%	28%
Scotland	60%	45%
Northern Ireland	89%	65%
Offshore wind	96%	100%

Source: CCC calculations based on DECC (2015) *Renewable Energy Planning Database.* Available at: www.gov.uk
Note: As of 2015 the Renewable Energy Planning Database no longer contains projects below 1 MW in size; calculations of average planning approval rates may be slightly different to those published in previous years.

Marine energy

Table A1.4 Overview of Marine energy					
Technology	**Load Factor (%)**	**Installed Capacity (MW)**	**Capacity in pipeline (MW)**	**Current Cost Estimates (£/MWh)**	**Future Cost Estimates (£/MWh)***
Tidal lagoons	22%	0	3620	£130-170/MWh	£110/MWh
Tidal Stream	31%	6	170	£200-300/MWh	£70-100/MWh
Wave power	31%	26	80	£350-400/MWh	£120/MWh

Source: DECC (2015) *Renewable Energy Planning* Database. Available at: www.gov.uk; Pöyry (2014) *Levelised cost of power from tidal lagoons.* Available at: www.tidallagoonpower.com; ETI (2015) *Insights into wave and tidal energy.* Available at: www.eti.co.uk
Note: Load factor for tidal lagoon is a project, (not actual) volume weighted average load factor from Pöyry (2014).
*Future cost estimates for wave and tidal stream from ETI (2015) are for 2030, and volume weighted average levelised cost for the first three tidal lagoons, based on Pöyry (2014).

Table A1.4 presents an overview of load factors, capacity and costs for tidal stream, wave power and tidal lagoon technologies. Both wave and tidal stream technologies remain high cost early stage technologies, although early signs suggest that tidal stream technologies may be better placed than wave technology towards 2030. The Government is currently in negotiations around a contract for a tidal lagoon in Swansea bay.

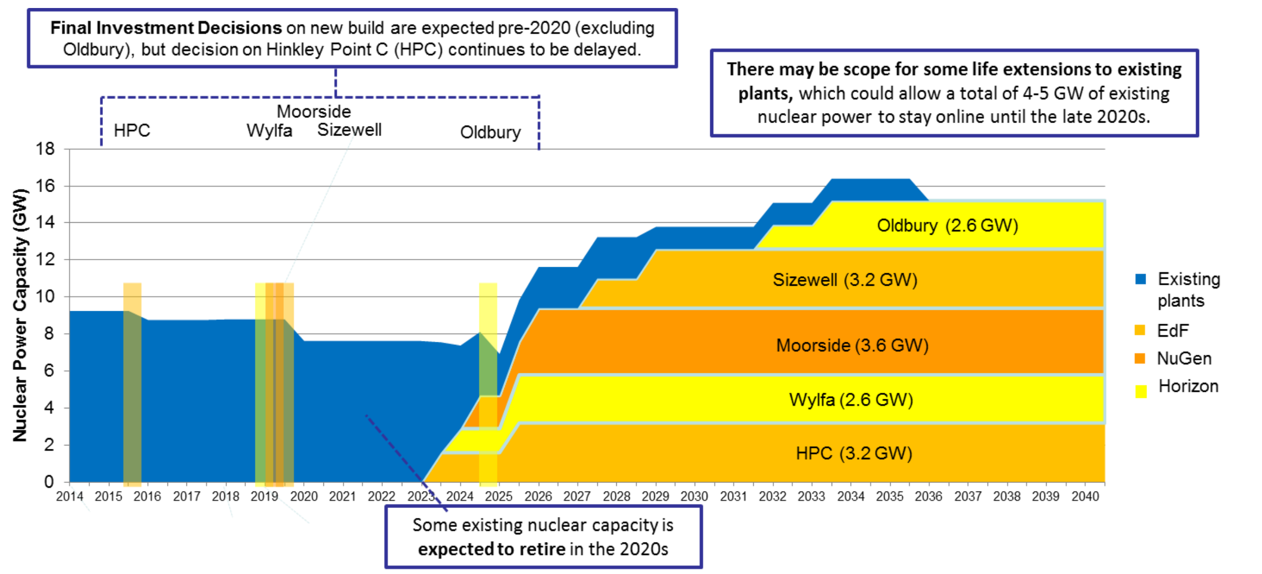
- **Tidal Lagoons**
  - In the 2015 Budget the Chancellor announced the opening of negotiations into the world's first tidal lagoon project at Swansea Bay.
  - The benefits of Tidal Range are predictable output that is not correlated with other renewables, very long lifetimes (e.g. over 100 years) and the potential that future projects could be paired to provide a source of baseload low-carbon generation (i.e. individual projects with different generation profiles).
  - The challenges are around costs, capital requirement and possibly environmental impacts. Some estimates suggest these projects could have levelised costs averaging £110/MWh, although the first two projects are likely to be more expensive (e.g. £130-170/MWh). It is important that these proposals proceed with careful assessment of the potential environment impacts. Previous tidal range proposals in the UK, such as the Severn barrage, have been halted for such concerns.
  - There may be a role for tidal lagoon power in providing predictable low-carbon electricity in the UK if projects can be delivered at acceptable costs, allowing for any benefits from pairing projects to provide a stable electricity supply. We will continue to monitor progress with project proposals and expected costs.
- **Tidal Stream**
  - Deployment of tidal stream technologies could make a contribution to power sector decarbonisation towards 2030 and beyond. Early commercial arrays totalling 6 MW (generating less than 3 GWh in 2014) are deployed in UK waters (with another 6 MW under construction, and 96 MW awaiting construction). The industry is largely harmonised around the horizontal axis turbine technology, which a recent ETI study suggests could cost between £100-200/MWh by 2020, and between £70-100/MWh by 2030.
  - We will monitor the costs of this technology in order to develop our understanding around the contribution tidal stream technologies can make towards power sector decarbonisation.
- **Wave**
  - Wave power has significant potential in UK waters, but currently remains a high cost early stage

technology with costs of around £350-400/MWh, and limited scope for cost reductions in the near term. Wave energy projects of 26 MW capacity are currently deployed in UK waters, across 4 different technology types, with 80 MW awaiting construction. Unlike tidal stream technologies, where technologies being demonstrated typically represent similar technology types, the wave industry is yet to focus on a single technology type to take forward. This can be expected to limit the potential of wave deployment to 2030.

Nuclear power

Figure A1.3 presents an overview of existing and new build nuclear power in the UK between 2014 and 2040 based on publically available information from both the Office of Nuclear Regulation (ONR) and developer websites.

Figure A1.3: Potential timing of new nuclear projects currently under development in the UK (2014-2040)



Source: ONR (2015) *Generic Design Assessment Timeline.* Available at: www.onr.org.uk; Developer websites.

3. Supporting infrastructure for low-carbon generation

Table A1.5 provides an overview of the six key 'Stage 1' assets as identified by the Electricity Networks Strategy Group (ENSG) in 2009[1]. These assets are consistent with an updated assessment of required electricity transmission investment undertaken for the Committee in 2014[2].

In North Wales, the first part of the Stage 1 transmission upgrade was completed in 2014; upgrade completion dates for the three remaining parts of these upgrades were pushed back due to revised generation connection dates of renewables, and the connection date of Horizon's Wylfa nuclear power station. The West coast 'bootstrap' ('Scotland Stage 1') is on track to be completed by 2017. Completion dates for other stage 1 assets have been pushed back towards 2020 and beyond, primarily due to changes in when generation assets are expected to come online.

[1] ENSG (2009) *Our Electricity Transmission Network: A Vision for 2020*. Available at: webarchive.nationalarchives.gov.uk

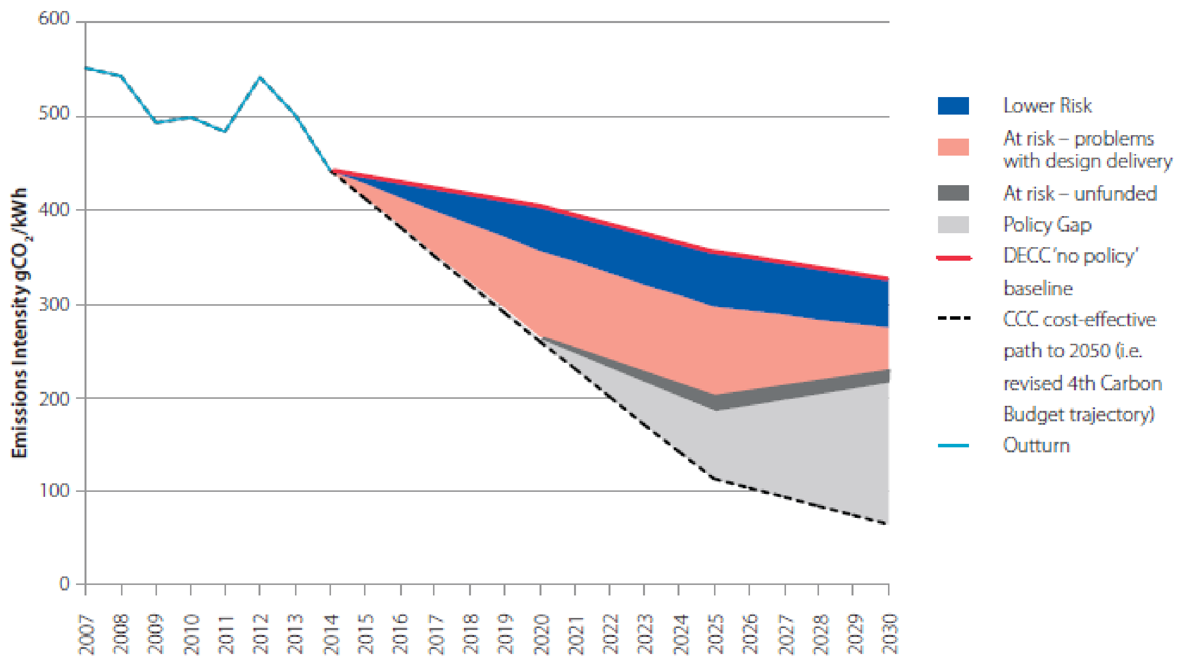
[2] Imperial College and Element Energy (2014). *Infrastructure in a low-carbon energy system to 2030: Transmission and distribution.* Available at: www.theccc.org.uk.

Table A1.5 Detail of transmission progress on each investment and reasons for delays		
Transmission Asset	**Project status and expected delivery date**	**Reason for delay**
Scotland Stage 1	2017	Delays with cable manufacturer.
Wales Stage 1 (Central)	2019	Planning delays and land access issues.
South East	2022-2031	Delivery date revised in line with 2014 Future Energy Scenarios*
English East Coast Stage 1	2025+	Not required until neighbouring substation reconfiguration has been reviewed.
South West	2022	Revised connection date for Hinkley Point C.
Wales Stage 1 (North)	i – completed; ii – 2021-2027; iii – 2024; iv – n/a	i- completed; ii- FES; iii-new generator program agreed; iv-not necessarily until Wylfa confirmed.

Source: DECC/Ofgem (2015) *Transmission Owner major projects: status update March 2015.* Available at: www.gov.uk
Notes: *Future Energy Scenarios (FES) are developed by National Grid, presenting different future electricity generation scenarios in order to inform transmission needs. In 2014 delivery dates for many ‘Stage 1’ assets were delayed, in line with changing Future Energy Scenarios trajectories. More information at: www2.nationalgrid.com.

4. Forward look and policy gap

Figure A1.4: Assessment of current and planned policies: power sector



Source: DECC (2014) *Updated Emissions Projections*; CCC analysis.

Table A1.6 Risk assessment of power sector policies

Policy	Comment
Lower risk policies	
Renewables Obligation, FiTs, FIDER and the first CfD allocation round.	Policies target the right technologies and have been effective in the past. Support is broadly matched to technology costs and funding is sufficient.
Policies with design/delivery problems	
CCS demonstration	Targets the right CCS applications; continuing risks to delivery of technology and reaching final investment decisions; £1 billion funding has been allocated.
Fuel switching	Some existing coal plant will close under the Large Combustion Plant Directive (LCPD) & the Industrial Emissions Directive (IED), however other plant may stay open for some time due to weakness of EU ETS and low coal prices. No new unabated coal plant due to the Emissions Performance Standard (EPS). Capacity mechanism is an incentive for new gas plant.
CfDs to 2020	Programme is in place and first auction has taken place, however lack of support beyond 2020 may increase uncertainty for bidders pre-2020. Support broadly appropriate.
Unfunded policies	
Nuclear – first 2 reactors at Hinkley	Agreement on terms for proposed first contract, state aid approval granted, level of agreed strike price appropriate, contract terms have been agreed, however contract is not signed and funding has not yet been allocated.
Missing policies	
Power sector deployment beyond 2020	Moving the power sector from 200 gCO_2/kWh in 2020 to 50-100 gCO_2/kWh by 2030.

5. Levy Control Framework expenditure

Our calculations around the level of support required for low-carbon generation are based on reaching a decarbonisation target of 50-100 gCO_2/kWh in 2030. For example, a 50 gCO2/kWh scenario could include around 6 GW CCS, 24 GW of each of onshore and offshore wind, as well as 17 GW of nuclear. We assume that 100 gCO_2/kWh would be delivered at a similar cost - given that a higher carbon intensity outcome would reflect either that the costs of low-carbon technologies are higher, or because cheaper low-carbon technologies face deployment constraints.

Direct support for low-carbon generation is provided through Feed-In-Tariffs (FITs) for small-scale low-carbon generation, the Renewables Obligation (RO) up to 2016/17 and Contracts for Difference (CfDs) from 2014/15. The cost of this support is recovered through energy bills, limited by the Levy Control Framework (LCF).

In a central case, we estimate the funding required to directly support low-carbon generation to be around £7.2 bn in 2020 and £8.6 bn in 2025 (see Table A1.7) and falling thereafter, in order to meet carbon budgets:

- **FITs:** We assume projected spend in the 2020s to remain in line with DECC's projected level for 2020 of £1.2 bn[3]. We make an adjustment to reflect the difference between actual and projected FiTs spend in 2013/14, of around £100m per annum.
- **RO:** We assume that the RO peaks at £3.6 bn per annum in 2016, in line with DECC's projections in its *Annual Energy Statement 2014*. In the 2020s and beyond, as older projects that were installed under the RO come to the end of their 20 year lifetime, the total spend under the RO falls.
- **CfDs:** We assume all projects beyond 2016 opt for the CfD (rather than the RO) at costs in line with DECC's published strike prices, and the recent CfD allocation round. Beyond 2020, we assume strike prices in line with recent work produced for the Committee on offshore wind and CCS[4], auction results for solar PV and onshore wind[5], DECC's administrative strike price for biomass conversion[6], and the strike prices of Hinkley Point C and Sizewell B for new nuclear power[7].

As we have set out in previous reports, the LCF as currently calculated is likely to overstate the additional cost of low-carbon generation to consumers in the longer term. We therefore continue to recommend calculating the support for low-carbon generation against the alternative of providing electricity through a new unabated gas plant facing a carbon price. We present analysis on the estimated cost of direct support for low-carbon generation according to both methods in tables A1.7 and A1.8 below.

[3] DECC (2014) *Annual Energy Statement.* Available at: www.gov.uk
[4] BVG Associates (2015) *Approaches to cost-reduction in offshore wind*. Available at: www.theccc.org.uk; Pöyry (2015). *Potential CCS Cost Reduction Mechanisms*; Available at: www.theccc.org.uk
[5] DECC (2015). *Contracts for Difference (CFD) Allocation Round One Outcome.* Available at: www.gov.uk
[6] DECC (2013). *EMR Delivery Plan.* Available at: www.gov.uk
[7] DECC (2013). *Hinkley Point C.* Available at: www.gov.uk

Table A1.7 Levy Control Framework Expenditure to meet Carbon Budgets

		Subsidy cost (£bn *per annum*)	
Gas prices	**Year**	**Against in-year cost of new unabated gas plant**	**Against wholesale electricity price**
Central	2020	7.2	7.4
	2025	8.6	9.9
Low	2020	7.6	7.9
	2025	11.1	12.5
High	2020	6.4	6.7
	2025	6.2	7.8

Notes:
1) All years are calendar years.
2) All money is in £2014.
3) The Levy Control Framework cap for 2020/21 is £7.8bn in the calendar year 2020.

Table A1.8 Wholesale electricity prices and long run marginal costs (LRMC) of new unabated gas plant (2020, 2025)

		£/MWh	
Gas prices	**Year**	**2020**	**2025**
Central	Wholesale electricity price	54.2	68.4
	LRMC gas	60.8	77.6
Low	Wholesale electricity price	42.5	48.7
	LRMC gas	49.8	59.3
High	Wholesale electricity price	73.6	84.2
	LRMC gas	80.0	96.2

Notes:
1) All years are calendar years.
2) All money is in £2014.
3) The long-run marginal cost of gas includes the price of gas, a carbon price uplift based on the Government's carbon price trajectory, 2p/therm to reflect transportation costs and an uplift of 1.2p/kWh to reflect an the costs of capital expenditure on a new unabated gas being passed through into the electricity market. For more information see p43 of the technical annex to CCC (2011) *The Renewable Energy Review.* Available at: www.theccc.gov.uk

Source: CCC estimates; DECC (2014) *Updated Emissions Projections Annex M.* Available at: www.gov.uk

Table A1.9 Capacity used in Levy Control Framework expenditure estimates

	Capacity (GW)	
Technology	**2020**	**2025**
Onshore wind	13.0	18.5
Offshore wind	11.0	17.9
Solar PV	10.2	16.2
Biomass	3.6	3.6
Carbon capture and storage	0.6	2.1
Marine energy	0.2	0.6
New nuclear power	0.0	4.5

Notes: Capacity estimates are for illustrating modelling assumptions only.
Source: CCC estimates;

6. Indicator table

Table A1.10 Power Sector Indicator Table

Power		Budget 2	Budget 3		Budget 4		2014 Outturn
Headline Indicators							
			50g	*100g*	*50g*	*100g*	
Emissions Intensity (gCO_2/kWh)		328	151	174	53	100	442
Total emissions (% change from 2007 in final year of budget period)		-57%	-78%	-75%	-91%	-80%	32%
Achievable Emissions Intensity (g/kWh)		205	103	122	53	100	263
Generation (TWh)	*Wind*	43	83	82	116	116	32
	Nuclear	58	57	57	140	118	58
	CCS	0	13	5	33	5	0
Supporting Indicators							
Transmission							
Grid reinforcement planning approval		Estimated connection dates for several 'Stage 1' transmission assets have been delayed until the 2020s, pending a review of the needs case for these assets.					Central Wales still a concern. Other assets (except Scotland Stage 1) delayed due to reassessment of needs case.

Table A1.10 Power Sector Indicator Table				
Grid reinforcement construction begins		2018: Scotland Stage 2 2019: Wales Stage 1 (North) 2019: South West"	2020s: English East Coast Stage 1; South East	Scotland Stage 1 in construction, delayed by 1 year. Wales stage 1 on track for 2019
Grid reinforcements operational	2017: Scotland Stage 1	2019: Wales Stage 1 (Central). 2021-27: Wales Stage 1 (North). 2022: South West	2022-31: South East 2023: Scotland Stage 2. 2025+: English East Coast Stage 1	One element of Wales Stage 1 (North) was installed in 2014.
Agreement on long-term charging regime	Project TransmiT confirmed and adopted in 2016.			Project TransmiT concluded in 2014, set to be implemented in 2016.
Tendering for first offshore connections under enduring OFTO regime	2014			Continuing to tender under a combination of both the transitional and enduring regimes.
Construction of first offshore connections under enduring OFTO regime begins	2015			Tender Round 3, under the enduring regime, began in February 2014.
First offshore connections under enduring OFTO regime operational	2016			First connections under enduring regime are delayed, but connections being built successfully under transitional regime.
Market				
Next steps on EMR & long-term vision for energy sector	2014: First CfDs and Capacity Market auctions			On track: auctions for low-carbon contracts and the

Table A1.10 Power Sector Indicator Table							
		2015: Ensure power sector can invest on a ten year lead time. Confirm LCF funding post-2020. Launch cost reduction strategies for CCS and offshore wind.					capacity market took place successfully. Clarity and an extension of funding post-2020 is needed.
Wind							
			50g	*100g*	*50g*	*100g*	
Generation (TWh)	*Onshore*	23	33	31	42	43	18.3
	Offshore	20	51	50	74	72.9	13.3
			High	*Low*	*High*	*Low*	
Total capacity (GW)	*Onshore*	10.1	15.4	13.0	21.4	13.0	8.3
	Offshore	6.3	16.7	13.8	32.2	20.8	4.5
Capacity entering construction (GW)	*Onshore*	0.9	1.2	0.0	1.2	0.0	1.0
	Offshore	0.8	3.4	1.4	2.9	1.4	0.3
Capacity entering planning	*Onshore*	New planning applications will be required from the end of the second budget period at the latest to maintain flow into construction					1.7
	Offshore	New planning applications will be expected in line with site leasing					0.0
Average planning period (months)		<12	<12		<12		>20

Table A1.10 Power Sector Indicator Table

Cost reduction and commercialisation strategy for offshore wind.	In place	Monitor cost reductions in line with objectives identified in commercialisation strategy		See recommended approach in Chapter 1 of 2015 Progress Report
Nuclear				
Generic Design Assessment	Westinghouse's AP1000 (NuGen) resumes GDA.	Horizon's UK-ABWR approved in 2018.		GDAs underway for both NuGen's and Horizon's reactors.
Agreement on long-term plan for waste disposal facility	National geological screening	Talking to communities, providing information and investment; designing and planning for a facility	Site investigation and investment, aiming for construction in 2030s	Government White Paper in 2014 restarts voluntary approach to communities hosting a waste disposal factility.
Entering planning	Subsequent applications at approximately 2 year intervals			N/A for 2014
Planning approval; site development and preliminary works begin	State Aid approval from the European Commission for Hinkley Point C in 2014. Subsequent application approvals, site development and preliminary works at a ~12 month intervals			State aid approval for Hinkley Point C granted from European Commission in 2014.
Construction begins		First plant in 2017, subsequent plants at approximately 12 month intervals		Delayed, construction expected 2017
Plant begins operation			First plant in 2023, with subsequent plants at approximately 12 month intervals. Site potential for 16GW by 2030	N/A for 2014

Table A1.10 Power Sector Indicator Table				
CCS				
Launch Commercialisation Program				Initiated 2012
Front-End Engineering and Design (FEED) studies for competition contenders initiated	FEED studies start in 2014			Initiated: White Rose (Drax) - December 2013; Peterhead (SSE/Shell) - February 2014
FEED studies for competition contenders completed	FEED studies complete in 2015			FEED studies for first competition completed in 2011. Second competition awaiting completion in 2015
Final Investment Decision for Demonstration projects	For both preferred bidders by the end of 2015			Funding not awarded, 2011. Final Investment Decisions for preferred bidders expected by end of 2015
Quantification of saline aquifer CO2 storage potential	No later than 2015			Storage potential estimated in 2013, under the UK Storage Appraisal Project, managed by the British Geological Survey, Energy Technologies Institute and Crown Estate
Review of technology (including cost reduction and commercialisation strategy), strategic plan for infrastructure development and decision on framework for future support.	No later than 2016*			See recommended approach in Chapter 1 of 2015 Progress Report
Planning and authorisation approval, land acquisition, and storage site	2015-2016 for first			First demo not yet commissioned, Final Investment

Table A1.10 Power Sector Indicator Table				
testing completed, construction commences	demonstrations			Decisions expected end-2015
Demonstrations operational		First plant in 2018, subsequent plant in 2019		N/a for 2014
First new full CCS plants supported via the post-demonstration mechanism		First plant operational		N/a for 2014
Grid Requirements for Decarbonisation				
Interconnection	Interconnection Regime in place by 2016. Phase 1 assets (pre-2020) entering construction. Phase 2 assets (pre-2030) entering development and planning	Potential for more than 7 GW by 2020	Additional 10 GW by 2030.	Ofgem accepting tenders and approving projects for more than 7 GW of interconnection to come online by 2020
Smart Meter Deployment (Electricity)	On track to Government's trajectory of 17m installed by 2017	Full rollout (28m) complete by 2020		Full rollout to begin in Autumn 2016, on track for completion by end of 2020
Other Drivers				
Total demand (TWh), coal and gas prices, nuclear outages *Average wind load factors, availability of offshore installation vessels, access to turbines* *Monitor technology costs.* *Nuclear supply chain, availability of skilled staff* *International progress on CCS demonstration and deployment* *Uptake of solar power, and developments in seasonal storage.* *Planning approval rates and frequency of public inquiries to decisions of Infrastructure Planning Commission*				

Table A1.10 Power Sector Indicator Table
Monitor participation of demand response and demand reduction in Capacity Market auctions and in the wider electricity market.
Notes: * The Energy Act 2010 requires a rolling review of CCS progress, to report on the appropriate regulatory and financial framework by 2018. **Source:** CCC estimates.