The Impact of Government Interventions on Investment in the GB Electricity Market

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Main Report

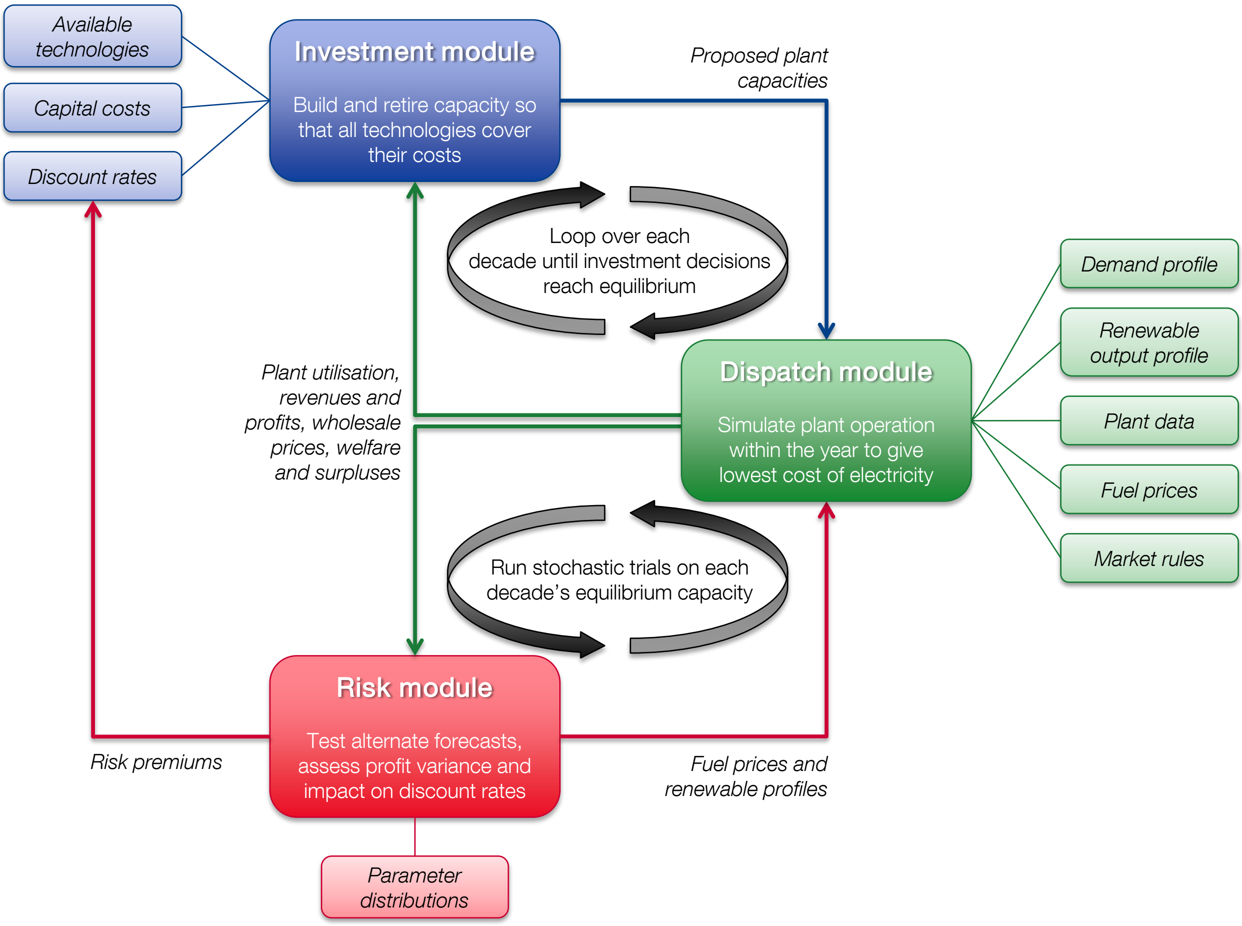
Technical Annexes

Executive Summary

The UK government has asked the European Commission for State Aid Approval to sign a 35-year Contract for Difference (CfD) with the proposed nuclear power station at Hinkley Point. This report models the impact of that contract, and of alternative policies suggested to us by the Commission, on the electricity market in Great Britain. It was commissioned by DG Competition to assist in their decision-making.

Our report is based on a model of the wholesale electricity market in Great Britain in which generators invest in power stations that they expect to be profitable over their working lifetimes. The profits of a station commissioned in the 2020s, such as Hinkley Point C, depend on the capacity that it will be competing with throughout its life, and hence on investment decisions made over the next 50 years or so. In turn, the investment decisions of the 2060s depend on predictions for the last years of this century. We therefore model the industry at regular intervals up to 2100 to ensure that we capture all the factors that could affect the investment case for Hinkley Point C.

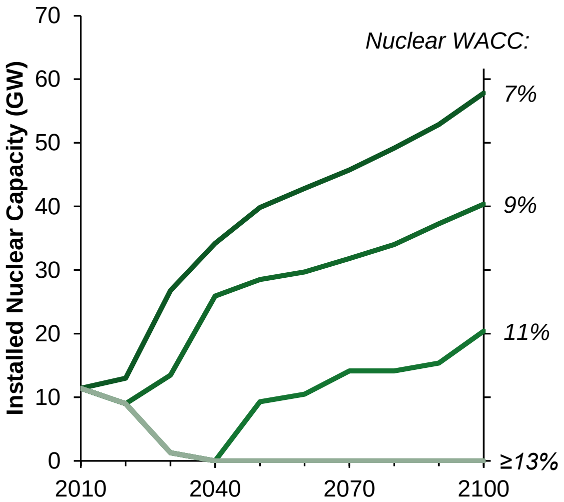
Our model includes a dispatch module that calculates electricity wholesale prices, and hence generators' profits, on the basis of the marginal costs of the stations available in each decade, given predicted fuel prices and the level of electricity demand. In our investment module, generators will add capacity as long as it is profitable to do so, in terms of covering the station's average levelised cost of electricity (including a return on investment equal to its weighted average cost of capital (WACC)) both in the decade in which the investment is made and over the station's entire lifetime. The model is dynamic, in that we check that subsequent investment decisions do not make earlier choices unprofitable. A third module checks the impact of varying fuel prices on the profits made by a given mix of power stations, as one of the key risks that investors face. The model structure is shown in the figure below.

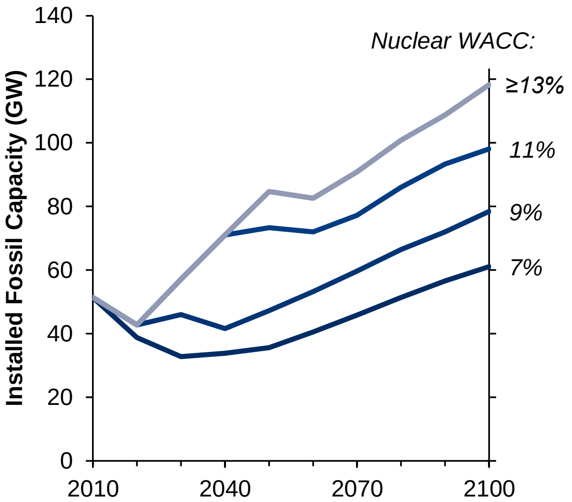


The model's predictions will depend on its input data, particularly for fuel prices and station investment costs. We have mainly taken figures from a range of public domain sources, full details of which are given in Annex B of this report. Where predictions are needed several decades into the future, we have extrapolated from these sources. Commission staff specified the WACC values that they wished us to use for nuclear stations and the policy scenarios that we are testing. The core scenarios tested are as follows:

1. ***No Aid, 13%*** – the market without government interventions, and a nuclear WACC of 13%;
2. ***CfD35, 10%*** – the Contracts for Difference policy proposed by the UK government. Up to 15 GW of nuclear stations are paid the difference between the strike price specified in their contract (£89.50 per MWh) and the annual average wholesale price during their first 35 years of operation. The nuclear WACC with this contract is 10%;
3. ***FiP35, 10%*** – this policy replaces the CfD with a Feed-in Premium. Up to 15 GW of nuclear stations sell power at the market price, and also receive a fixed premium for their first 35 years of operation. This premium is calculated to deliver the same level of support as the CfD, and assumes the same nuclear WACC of 10%;
4. ***CfDall, 10%*** – this gives every generator built in the 2020s (fossil or nuclear) a CfD for 35 years, or its expected lifetime if lower. The technology-specific strike prices are set at the same level relative to each technology's expected cost, and together deliver the same total volume of support as the CfD for nuclear. Each technology has the same WACC as in scenario 2;
5. ***CfD60, 9%*** – this gives up to 15 GW of nuclear stations a 60-year CfD split into two phases. The first is as proposed by the UK government (a strike price of £89.50 per MWh for 35 years); while the second pays a lower strike price of £44.75 per MWh for the final 25 years of each station's life. This reflects the lower ongoing costs of a station after its capital costs have been paid back to investors, while still providing a sufficient margin to remunerate any capital spending needed. With more revenue certainty, the WACC falls to 9%.
6. ***Guarantee, 11%*** – this scenario models the impact of the government providing only a credit guarantee, which reduces the cost of capital for nuclear stations by 2% compared to scenario 1, but does not involve direct intervention in the electricity wholesale market.

We first simulated the decisions that investors would make in a market without any government interventions, for a range of nuclear WACCs. With a WACC of 13% or more, nuclear investment (in the left-hand panel below) will never be attractive to private-sector investors, and decarbonisation is achieved through renewable power and carbon capture and storage (CCS). With lower WACCs for nuclear stations, investment starts in time to commission new stations in the 2050s (11%), 2030s (9%) or 2020s (7%). Investment in fossil stations (right-hand panel below) follows an inverse pattern. We also find that the lower the WACC for nuclear stations, the lower the level of wholesale electricity prices.





We have modelled the impact of government support for up to 15 GW of nuclear capacity built over the 2020s, even though this application is for a single station of 3.2 GW. We assume that if Hinkley Point C receives support, other stations will follow, and modelling a larger tranche of investment makes it easier to identify the effects on the market. The key results for each policy case are presented in the table below:

	SCENARIOS:		1: No Aid 13%	2: CfD35 10%	3: FiP35 10%	4: CfDall, 10%	5: CfD60, 9%	6: Guarantee 11%
INVESTMENTS	New nuclear capacity installed by end of decade (GW)	2020s	0	15	9.9	0	15	0
		2030s	0	15	9.9	0	15	0
		2040s	0	15	12.1	0	15	1
	New fossil capacity installed by end of decade (GW)	2020s	4	0	0	15	0	3.9
		2030s	41.1	27.1	32.2	41.9	27.1	41
		2040s	71.1	52	54.9	68.8	52	71
PRICES	Average wholesale price during decade (£/MWh)	2020s	£66.67	£51.33	£56.75	£57.97	£51.33	£66.76
		2030s	£88.15	£76.76	£80.38	£82.58	£76.76	£88.24
		2040s	£96.52	£88.05	£90.00	£92.64	£88.05	£95.22
	Average price including levelised subsidy (£/MWh)	2020s	£66.67	£64.44	£64.04	£68.13	£64.44	£66.76
		2030s	£88.15	£80.49	£86.59	£89.71	£80.49	£88.24
		2040s	£96.52	£88.43	£95.49	£94.37	£88.43	£95.22
PROFITS	Annual profits of existing stations in the 2020s (£bn)	Nuclear	£2.9	£2.0	£2.3	£2.4	£2.0	£2.9
		Fossil	£0.6	-£1.5	-£1.4	-£1.5	-£1.5	£0.6
	Annual profits of supported nuclear stations (£bn)	2020s	–	£0.1	£0.0	–	£0.9	–
		2030s	–	£0.1	£1.6	–	£0.9	–
		2040s	–	£0.1	£2.2	–	£0.9	–
WELFARE	NPV of support over duration (£bn)		£0.0	£3.5	£3.5	£3.5	£2.3	£0.0
	NPV of welfare: 2020s to 2050s (£bn)		£30.0	£28.6	£29.7	£30.1	£30.2	£29.9
	Cumulative carbon emissions: 2020s to 2050s (GT)		2.8	2.1	2.3	2.8	2.1	2.8

Main findings:

- The CfD policies are most effective at stimulating early nuclear investment, although a Feed-in Premium also delivers some new build stations in the 2020s.
- Nuclear generators see rising profits under a Feed-in Premium scheme, since market prices are expected to rise over time; under a CfD, their profits are fixed until the expiry of the CfD.
- The support given to generators with a 60-year CfD is lower than for the proposed 35-year CfD, as the strike price offered in the last 25 years is below the expected market price of electricity (though still above the costs of a written-down nuclear station), leading to savings for electricity consumers.
- The proposed 35-year CfD reduces welfare compared to the market without intervention.

Other key conclusions:

- Scenarios with nuclear investment in the 2020s see no new fossil-fuelled plants built that decade, given the large expansion in renewable capacity (which is taken as given in this report).
- Nuclear investment reduces wholesale prices in the 2020s and beyond, although the cost of the support payments means that the impact on consumers' bills is less significant.
- Existing stations earn significantly less money in the 2020s if there is significant investment in new capacity (either nuclear or fossil). In particular, existing fossil stations move from being profitable with no aid (or a guarantee) to making substantial losses with any of the modelled CfD or FiP policies, which might lead to stations retiring early (although this is not explicitly modelled).
- Carbon emissions from the 2020s to the 2050s are lowest if there is significant early nuclear investment.
- Economic welfare (the sum of consumer benefits from changes in electricity prices and company profits) appears to increase as the cost of capital for nuclear stations falls, but these figures ignore the cost of providing any financial guarantees that help to reduce the WACC.

In addition to modelling the central scenarios presented above, we perform two sensitivity analyses surrounding the future trajectory of fuel prices and the WACC for nuclear stations (in particular how much this is reduced by government policies which provide revenue certainty).

Sensitivity to WACC and fuel prices:

- The proposed CfD delivers investment in nuclear stations if their WACC is 10% or below.
- The CfD makes it profitable to build these stations earlier than they would have been in the market; however, by the end of the 2040s the industry realigns with where it would have been without any intervention (for the same level of nuclear WACC).
- For every percentage point reduction in the WACC for nuclear stations, we expect wholesale prices to fall by around £7.50/MWh in the long term, and an extra 6–8 GW of nuclear capacity to become profitable, crowding out investment in 6–8 GW of fossil capacity.
- Nuclear stations face great uncertainty in revenues and profits, as the wholesale price of electricity is linked to fossil fuel prices. With a 10% WACC, the annual profit of a 3.2 GW station in the 2030s would vary between £350m and –£400m per year depending on fuel prices during the decade.
- A CfD for nuclear generators at the expected price of electricity provides a hedge against gas prices for both nuclear generators and consumers and can therefore costlessly reduce risk. Given all of our input assumptions, the proposed strike price is set at an appropriate level to deliver new nuclear capacity without significant super-normal profits.
- A CfD at more than the expected price of electricity retains the risk benefit but also has a transfer from electricity consumers to the nuclear generator. A 1% reduction in the WACC for nuclear stations would result in a transfer of £850m per year from consumers to generators for each 3.2 GW station built.

1 Introduction

The UK government has asked the European Commission for State Aid Approval to sign a 35-year Contract for Difference (CfD) with the proposed nuclear power station at Hinkley Point. This report models the impact of that contract, and of alternative policies suggested to us by the Commission, on the electricity market in Great Britain. It was commissioned by DG Competition to assist in their decision-making.

In this section, we describe our approach to the task; Section 2 gives a brief description of our model, and our most important results are set out in Section 3. Technical Annex A documents the model in greater detail, and Annex B justifies our input data. An extended set of results covering all scenario runs is presented in Annex C.

Our report is based on a model of the wholesale electricity market in Great Britain in which generators invest in those power stations that they expect to be profitable over their working lifetimes. The profits of a station commissioned in the 2020s, such as Hinkley Point C, depend on the capacity that it will be competing with throughout its life, and hence on investment decisions made over the next 50 years or so. In turn, the investment decisions of the 2060s depend on predictions for the last years of this century. We therefore model the industry at regular intervals up to 2100 to ensure that we capture all the factors that could affect the investment case for Hinkley Point C.

Any economic model makes predictions based on a given set of input data. If some of the input data are changed, the model's predictions will usually change as well. In our case, the key data include the initial cost of building power stations, the price of the fuels that they will burn, the charge for carbon emissions and the cost of capital that investors need to receive. We run our model for a range of scenarios with different values of these key variables, and different government policies. The input data are taken from published sources; the policies tested are those suggested to us by the Commission.

It is important to note that the UK government has a legally binding target for greenhouse gas emissions in 2050. The government could achieve this target, either through specific interventions in the electricity market of the kind that we model, or by raising the price of carbon until generators find investment in low-carbon generators sufficiently profitable. In all the scenarios that we model (whether with specific policy interventions or not), we allow the price of carbon to increase through the 2030s and beyond until it reaches a level where emissions from the power sector in 2050 are 90% below those of 1990.

We model investment decisions using several different values for the cost of capital that investors in nuclear stations would require. Some of the policy interventions we model would reduce the risks faced by nuclear generators, and it is therefore likely that this would feed through into their cost of capital. While we have not been asked to predict how great a reduction would occur, the impact of some policies are best assessed by comparing the model results for a "no specific intervention" case with those from a case with both the policy intervention and a lower cost of capital (e.g. no intervention at 11.5% compared against CfD at 9.5%).

The UK government's application is for State Aid to a single power station, Hinkley Point C. If we were to model the effects of one investment, even for a station of 3.2 GW capacity, its impact on the wider market would be limited. We have taken the view, however, that the application for Hinkley Point C is a test case and that if it is approved, the Commission would in due course approve similar contracts for the other nuclear stations currently being planned. These total around 15 GW of capacity, which is enough to have a sizeable impact on the market as a whole. We have therefore modelled policy interventions which support up to 15 GW of nuclear power, if they prove attractive enough to call forth this level of investment.

Our model is designed to make comparisons between different government interventions in the UK electricity market. It is not a crystal ball to predict the future, not least because key input variables such as the future price of fuels are not predictable. Our modelling decisions (for example, that electricity prices are always equal to marginal cost) will affect the results presented here. If we had assumed that generators would charge a mark-up, the model would have produced higher wholesale prices. The key point for the purpose of making a comparison, however, is that those prices would be higher in *all* the cases presented here. When making comparisons between government interventions, this means that a policy we show to reduce wholesale prices would have had the same effect in the alternative model. We recommend that the reader should view this report as an exploration of the impact of government interventions in the GB electricity market, and concentrate on how our results change across cases, rather than on the absolute level of those outputs.

2 Overview of Modelling

This section describes the power market model used for analysing long-term investment decisions in the British electricity industry. It is designed to find the equilibrium level of capacity in the market from 2010 through to 2100, given assumptions about the level and hourly pattern of demand, fuel prices and other costs of generation, and the market rules that are in force.

2.1 Model Structure

The model used is programmed into an Excel spreadsheet that provides a flexible means of considering a range of policies and scenarios. It builds upon our previous work[1] and consists of three core modules:

- A ***dispatch module***, which simulates the operation of a fleet of power stations over the course of a year;
- An ***investment module***, which finds the most profitable mix of investment decisions (capacity additions and retirements) between years;
- A ***risk sensitivity module***, which tests the operational and financial stability of a proposed mix of plants under different conditions.

Together, these modules forecast the optimal mix of generating capacity to build in GB over the time-frame of 2010 to 2100, how to dispatch this capacity at least cost to meet the hourly demand for electricity, and how sensitive the results are to the input assumptions. The mix of power stations is defined to be 'optimal' if each technology earns enough revenue to cover its capital costs, but not earn super-normal profits above this (known as long-run equilibrium).

The interactions between these modules are illustrated in the figure overleaf, along with the main data inputs.

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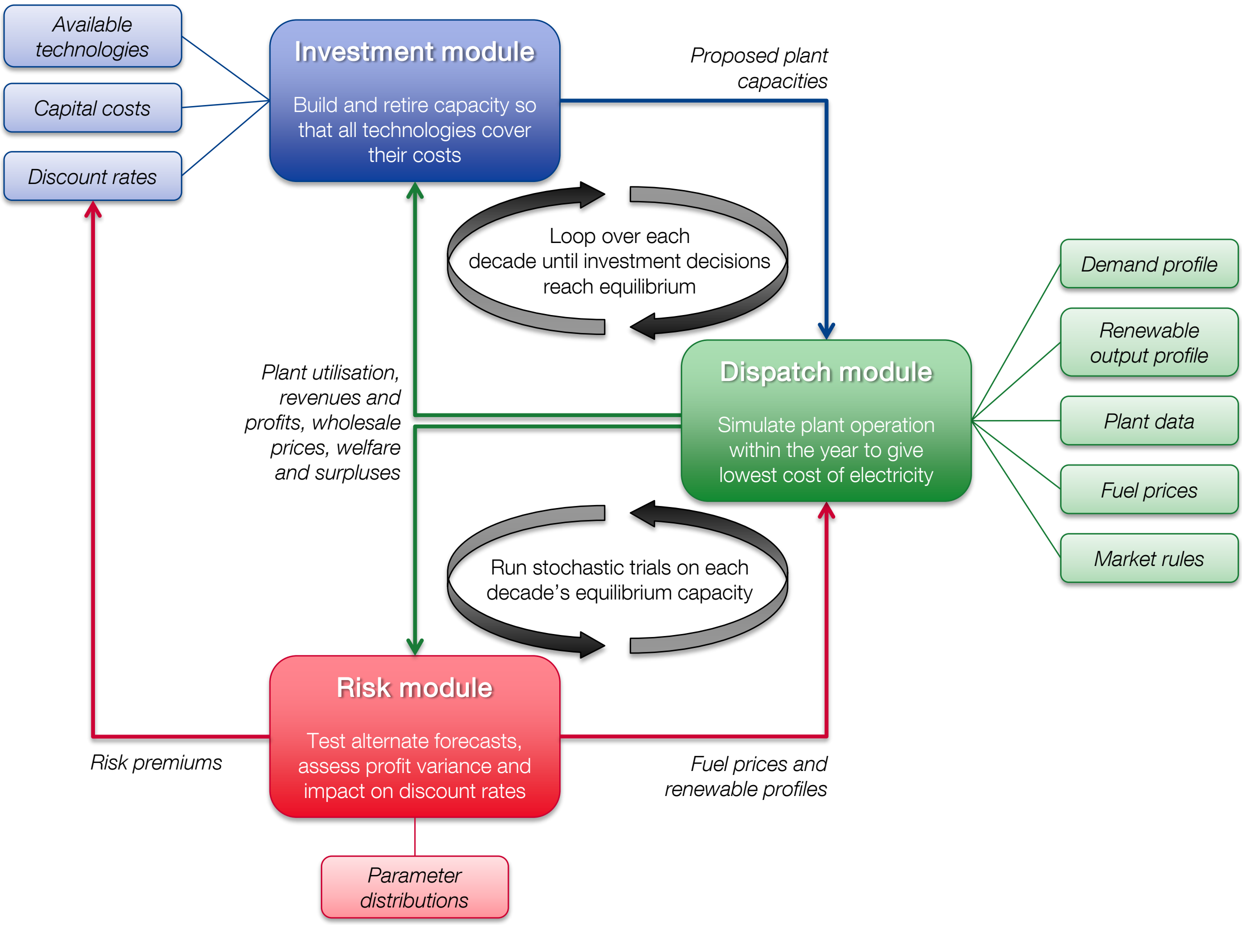
[1] Previous versions of this model have been used in Green, R.J. (2008) "Carbon Tax or Carbon Permits: The Impact on Generators' Risks," *Energy Journal*, vol. 29, no. 3, pp. 67-89; Green, R.J. and N. Vasilakos (2010) "Market Behaviour with Large Amounts of Intermittent Generation" *Energy Policy*, vol. 38, no. 7, pp. 3211-3220; Green, R.J., H.Hu and N. Vasilakos (2011) "Turning the Wind into Hydrogen: The long-run impact on electricity prices and generating capacity" *Energy Policy*, vol. 39, no. 7, pp. 3992-8; Green, R. and I. Staffell (2012) *How Large Should a Portfolio of Wind Farms Be?* IAEE European Conference, Venice; Staffell, I and R.J. Green (2012) *Is there merit in the Merit Order Stack?* 2012 BIEE Conference



The model first loops between the investment and dispatch modules (top right). Beginning with the 2010s, the dispatch module simulates the incumbent mix of generation capacity operating over the course of a year, deciding when to run each plant in order to meet demand at the lowest cost. This provides the hourly wholesale price of electricity through the year, from which the annual revenue and profit of each technology is calculated. The investment module takes these profits and proposes a set of investments to make in that decade, which are then tested in the dispatch module, giving rise to new electricity prices and station profits. Stations that have reached the end of their technical lifetime are retired. An equilibrium is found when no more potential capacity meets the criteria for investment, which are that it is expected to break even (after providing a return on investment equal to its cost of capital) both in its first decade of operation and over its lifetime. The resulting capacity mix is then taken forward to the next decade, and this loop repeats. The initial investment decisions for each decade are then revisited in turn, and adjusted in the light of prices and profits that were projected for later decades, so that each investment covers its costs over its lifetime. This cycle is repeated until all decisions are consistent. This modelling process is dynamic, in that the investment decisions made in one decade will go on to influence plant operation and investment decisions in subsequent decades.

Once the optimal set of decisions for the whole period (2010 to 2100) has been found, the model loops between the risk and dispatch modules (bottom right). The optimal plant mix for each decade is re-run in the dispatch module numerous times with varied input parameters (primarily fuel price forecasts, patterns of renewable output, and learning rates for capital cost reduction). The risk module assesses the resulting variation in profits, and thus the robustness of the investment decision. Ultimately, this can be used to alter the discount rates applied to each technology and vintage by factoring the variance in profit into the technology's risk premium, which can then be fed back into the first loop.

The model is run in 10-year steps, and for each decade it is given exogenous assumptions (ones that are fixed outside the model) on:

- the level and underlying pattern of demand over a typical year;
- the capacity and pattern of output from wind and solar;
- prices of coal, oil, gas and carbon;
- construction cost, cost of capital, fixed and variable operating costs for each generating technology;
- net operating efficiency, carbon intensity, and minimum fleet output for each generating technology.

The model considers six commercial and near-commercial technologies, each of which has fifteen vintages (from 1960s through to 2100s) with different cost and performance parameters:

- Nuclear
- Coal
- Coal with CCS (carbon capture and storage)
- Gas CCGT (combined cycle gas turbine)
- CCGT with CCS
- Gas OCGT (open cycle gas turbine)

Four renewable and storage technologies are incorporated in the model, but are treated exogenously. Their installed capacity is based on existing forecasts rather than optimised within the model, and their resulting output is netted from the gross demand for each decade. Hourly output patterns for wind and solar are synthesised from historic weather and satellite data; while river hydro, pumped storage and other forms of electricity storage are assumed to provide load balancing, producing output when net demand (gross demand minus wind and solar) is highest, and recharging when it is lowest, subject to constraints on the available storage capacity.

2.2 Key Inputs and Assumptions

The data and assumptions provided to the model are listed in full in Technical Annex B. The key inputs to the model are:

- Station construction costs and the efficiency with which they convert fuel to power
- Fuel prices
- Carbon prices
- The cost of capital for investors in power stations

We have attempted to stay as close to modelling work by the UK Department of Energy and Climate Change (DECC) where possible, and so the majority of our inputs are taken from three documents: DECC's Electricity Generation Costs,[2] Parsons Brinckerhoff's 2012 and 2013 updates to DECC's cost model,[3] and DECC's Fossil Fuel Price Projections.[4] The central-case values from these reports were used throughout, except for the capital cost of nuclear, for which we used the low sensitivity value given by DECC[2] so as to be consistent with the widely reported cost of £16 billion for Hinkley Point C (£5,000/kW).

The data and forecasts given in the DECC reports cover a time-frame up to 2020 or 2030, whereas our modelling stretches forwards to 2100. We therefore extend these forecasts using other literature or our best judgement.

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[2] DECC, 2013. Electricity Generation Costs. http://tinyurl.com/oyjpvhr

[3] Parsons Brinckerhoff, 2013. Electricity Generation Cost Model – 2013 Update of Non-Renewable Technologies. http://tinyurl.com/ne927dx (2012 update available from http://tinyurl.com/pmlq45t)

[4] DECC, 2013. Fossil Fuel Price Projections. http://tinyurl.com/n8844f6

The weighted average cost of capital (WACC) for investors in power stations is generally regarded as varying between technology types, and is likely to be affected by some of the policy interventions that we study. We therefore use a range of figures, and indicate in Section 3 which combinations seem most plausible to us. Our central economic assumptions are listed in the table below, and we also test a range of values for each as part of a sensitivity study.

Technology	Capital Cost (£/kW)*		Cost reduction per decade	Central WACC†
	Overnight	Investment		
Nuclear	£3,810	£4,953	7.5% in 2020s 2.5% thereafter	13% with no aid 10% with policy
Coal	£1,625	£1,950	1.25%	7.7%
Gas CCGT	£610	£702	1.25%	7.7%
Gas OCGT	£310	£341	1.25%	7.7%
Coal CCS	£2,325	£3,023	7.5% in 2020s 2.5% thereafter	12.6%
Gas CCGT CCS	£1,330	£1,663		12.9%

* *Overnight cost excludes interest during construction (IDC), investment cost includes it.*

† *WACC is given in post-tax nominal terms.*

We also make assumptions on the level and pattern of electricity demand, on the volume of intermittent renewable (wind and solar) capacity built and on their outputs. These assumptions determine the absolute amount of investment required in each of our scenarios, but will have little impact on how a particular policy changes the attractiveness of nuclear stations relative to other plant types. We therefore use the same assumptions in all scenarios.

2.3 Methods of Assessment

For each representative year, the model calculates the following items:

- Wholesale electricity prices, which will be received by other generators;[5]
- Revenues and profits for each type and vintage of power station (including existing and supported power stations);
- Investment in each kind of available technology, and thus the installed capacity mix each decade;
- Operating hours for each technology and the resulting generation mix (annual energy output by type);
- Total carbon emissions from the power sector;
- The total subsidy paid to supported generators, and the levelised support (in £/MWh) that is passed on to consumers;
- Consumer surplus, combining price and quantity changes relative to a reference level to estimate benefits to consumers after taking account of the cost of subsidies to nuclear power and other thermal power stations;
- Overall economic welfare (consumer surplus plus generator profits).

By design, generators considering investment in the 2020s or later will earn zero economic profits,[6] as the model finds the equilibrium capacity to build. This means that we cannot use these generators' profits as a measure of any distortion to competition. The distortion (if present) would instead be measured by the change in investment, and by the change in the profits earned by generators that already exist today.

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[5] Prices are calculated from the marginal cost of generating power, or the price needed to ration demand to the level of available capacity during a given hour.

[6] As in, their revenues exactly cover their costs, discounted at their weighted average cost of capital.

3 Results

Our results are split into four sections:

- 3.1 considers what the market may deliver without government intervention, testing a range of WACCs for nuclear stations;
- 3.2 compares the proposed CfD and other policies against the no aid case;
- 3.3 explores the influence that the policy's reduction on the cost of capital for nuclear has;
- 3.4 quantifies the risk that different technologies face due to uncertain fuel prices.

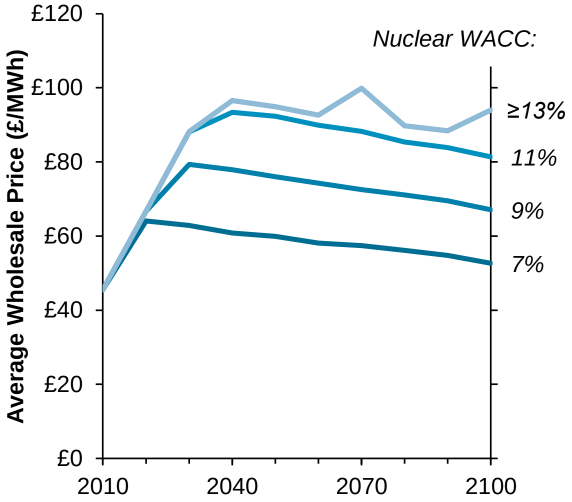
Each of these sections presents a summary of the results, highlighting the key messages and discussing the findings. The full case-by-case results are presented in Annex C.

In each model run, we use the central fuel prices and a carbon price sufficient to reduce the electricity sector's carbon emissions in 2050 by 90% of their 1990 level.

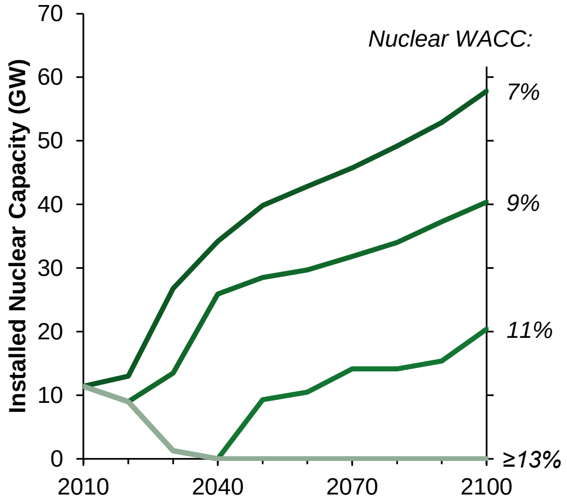
3.1 What Might the Market Deliver?

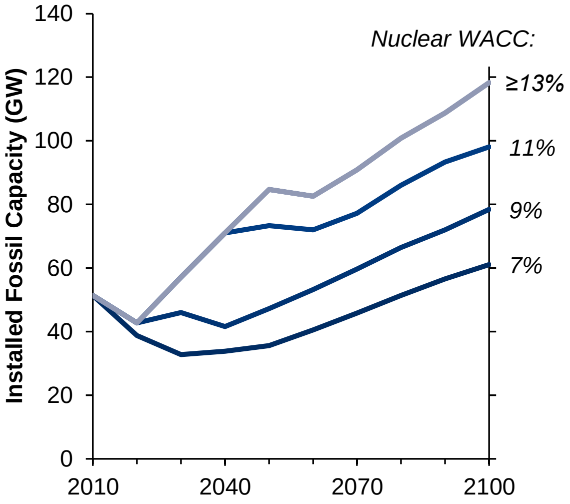
We begin by exploring what the marking might deliver with no government intervention, testing different WACCs for nuclear stations ranging from 7% up to 15%. WACCs of 11%, 13% and 15% are considered to be part of the ***No Aid*** scenario (without any government intervention at all), with 13% being the central case. The lower WACCs are considered as part of our ***Guarantee*** scenario, and could result from the government providing a credit guarantee to nuclear stations, but not offering any other support.

The evolution of wholesale prices over the century depends strongly on the WACC for nuclear stations. In all cases it rises initially, predominantly due to the rising carbon price, but also rising fossil fuel prices and a tightening of the capacity margin as existing stations reach the end of their lives. Once new nuclear capacity is built wholesale prices begin to gradually decline, and the lower the cost of building this capacity, the lower the eventual wholesale price.



With a WACC of 13% or more, nuclear investment (in the left-hand panel below) will never be attractive to private-sector investors, and decarbonisation is achieved through renewable power and carbon capture and storage (CCS). With lower WACCs for nuclear stations, investment starts in time to commission new stations in the 2050s (11%), 2030s (9%) or 2020s (7%). Investment in fossil stations (right-hand panel below) follows an inverse pattern. We also find that the lower the WACC for nuclear stations, the lower the level of wholesale electricity prices.





The table below highlights the impact of the WACC for nuclear on investments, electricity prices, profits and welfare. Our central case with a WACC of 13% is highlighted.

- Investments in new capacity are shown for the coming three decades, both for nuclear and fossil technologies (with and without CCS).
- The wholesale prices in each decade will relate to both what competing generators will earn and what consumers will pay, as there are no additional subsidy payments from providing CfDs.
- The profits of existing stations operating in the 2020s are considered, but they are not reported beyond this as most of this capacity reaches the end of its technical lifetime, and any remaining fossil plant is inclined to shut down due to the rising carbon price.
- The net present value of welfare is calculated with a social rate of 3.5%, as are the cumulative emissions of CO_2.

	NUCLEAR WACC:		7%	9%	11%	13%	15%
INVESTMENTS	New nuclear capacity installed by end of decade (GW)	2020s	4	0	0	0	0
		2030s	25.5	12.2	0	0	0
		2040s	34	26	0	0	0
	New fossil capacity installed by end of decade (GW)	2020s	0	4	4	4	4
		2030s	16.7	30	41.1	41.1	41.1
		2040s	34	42	71	71	71
PRICES	Average wholesale price during decade (£/MWh)	2020s	£64.07	£66.67	£66.67	£66.67	£66.67
		2030s	£62.87	£79.33	£88.05	£88.15	£88.15
		2040s	£60.81	£77.92	£93.34	£96.52	£96.52
PROFITS	Annual profits of existing stations in the 2020s (£bn)	Nuclear	£2.8	£2.9	£2.9	£2.9	£2.9
		Fossil	£0.1	£0.6	£0.6	£0.6	£0.6
WELFARE	NPV of welfare: 2020s to 2050s (£bn)		£35.5	£32.1	£30.3	£30.0	£30.0
	Cumulative carbon emissions: 2020s to 2050s (GT)		2.0	2.5	2.8	2.8	2.8

The key messages about the free market, given our particular set of assumptions, are:

- Nuclear will only be competitive in the first half of the century with a WACC below 11% (given an investment cost of around £5,000/kW, declining to around £4,250/kW by the 2050s);
- A credit guarantee would have to reduce the cost of capital for nuclear to 10% to produce investment in the 2040s, or 9% to produce investment in the 2030s;
- Building nuclear stations reduces the amount of fossil capacity that will be profitable, although even with nuclear WACCs as low as 7%, there is still need for significant CCGT as well as OCGT capacity;
- Wholesale electricity prices are set to increase sharply in the near-term due to rising carbon prices;
- Building nuclear stations reduces wholesale electricity prices and breaks this upwards trajectory – and with the lower cost of capital values for nuclear, the eventual price of electricity is reduced;
- Total welfare is highest with the lowest cost of capital for nuclear because the industry's costs are lowest (by design of assumption).

3.2 Comparison of Policies: Central Cases

We first present results for six scenarios, each using our central assumptions for WACC. The core scenarios tested are as follows:

1. ***No Aid, 13%*** – the market without government interventions, and a nuclear WACC of 13%;
2. ***CfD35, 10%*** – the Contracts for Difference policy proposed by the UK government. Up to 15 GW of nuclear stations are paid the difference between the strike price specified in their contract (£89.50 per MWh) and the annual average wholesale price during their first 35 years of operation. The nuclear WACC with this contract is 10%;
3. ***FiP35, 10%*** – this policy replaces the CfD with a Feed-in Premium. Up to 15 GW of nuclear stations sell power at the market price, and also receive a fixed premium for their first 35 years of operation. This premium is calculated to deliver the same level of support as the CfD, and assumes the same nuclear WACC of 10%;
4. ***CfDall, 10%*** – this gives every generator built in the 2020s (fossil or nuclear) a CfD for 35 years, or its expected lifetime if lower. The technology-specific strike prices are set at the same level relative to each technology's expected cost, and together deliver the same total volume of support as the CfD for nuclear. Each technology has the same WACC as in scenario 2;
5. ***CfD60, 9%*** – this gives up to 15 GW of nuclear stations a 60-year CfD split into two phases. The first is as proposed by the UK government (a strike price of £89.50 per MWh for 35 years); while the second pays a lower strike price of £44.75 per MWh for the final 25 years of each station's life. This reflects the lower ongoing costs of a station after its capital costs have been paid back to investors, while still providing a sufficient margin to remunerate any capital spending needed. With more revenue certainty, the WACC falls to 9%.
6. ***Guarantee, 11%*** – this scenario models the impact of the government providing only a credit guarantee, which reduces the cost of capital for nuclear stations by 2% compared to scenario 1, but does not involve direct intervention in the electricity wholesale market.

In each case, the cost of capital we use applies in all decades, although we assume that stations built in the 2030s and beyond receive only the wholesale market price. We test for the impact of different WACCs and different fuel prices in subsequent sections.

The key results for each case are presented in the following table. Our two main cases (the market with no aid, and the government's proposed policy) are highlighted.

	SCENARIOS:		1: No Aid 13%	2: CfD35 10%	3: FiP35 10%	4: CfDall 10%	5: CfD60 9%	6: Guarantee 11%
INVESTMENTS	New nuclear capacity installed by end of decade (GW)	2020s	0	15	9.9	0	15	0
		2030s	0	15	9.9	0	15	0
		2040s	0	15	12.1	0	15	1
	New fossil capacity installed by end of decade (GW)	2020s	4	0	0	15	0	3.9
		2030s	41.1	27.1	32.2	41.9	27.1	41
		2040s	71.1	52	54.9	68.8	52	71
PRICES	Average wholesale price during decade (£/MWh)	2020s	£66.67	£51.33	£56.75	£57.97	£51.33	£66.76
		2030s	£88.15	£76.76	£80.38	£82.58	£76.76	£88.24
		2040s	£96.52	£88.05	£90.00	£92.64	£88.05	£95.22
	Average price including levelised subsidy (£/MWh)	2020s	£66.67	£64.44	£64.04	£68.13	£64.44	£66.76
		2030s	£88.15	£80.49	£86.59	£89.71	£80.49	£88.24
		2040s	£96.52	£88.43	£95.49	£94.37	£88.43	£95.22
PROFITS	Annual profits of existing stations in the 2020s (£bn)	Nuclear	£2.9	£2.0	£2.3	£2.4	£2.0	£2.9
		Fossil	£0.6	-£1.5	-£1.4	-£1.5	-£1.5	£0.6
	Annual profits of supported nuclear stations (£bn)	2020s	–	£0.1	£0.0	–	£0.9	–
		2030s	–	£0.1	£1.6	–	£0.9	–
		2040s	–	£0.1	£2.2	–	£0.9	–
WELFARE	NPV of support over duration (£bn)		£0.0	£3.5	£3.5	£3.5	£2.3	£0.0
	NPV of welfare: 2020s to 2050s (£bn)		£30.0	£28.6	£29.7	£30.1	£30.2	£29.9
	Cumulative carbon emissions: 2020s to 2050s (GT)		2.8	2.1	2.3	2.8	2.1	2.8

Main findings:

- The CfD policies are most effective at stimulating early nuclear investment, although a Feed-in Premium also delivers some new build stations in the 2020s.
- Nuclear generators see rising profits under a Feed-in Premium scheme, since market prices are expected to rise over time; under a CfD, their profits are fixed until the expiry of the CfD.
- The support given to generators with a 60-year CfD is lower than for the proposed 35-year CfD, as the strike price offered in the last 25 years is below the expected market price of electricity (though still above the costs of a written-down nuclear station), leading to savings for electricity consumers.
- The proposed 35-year CfD reduces welfare compared to the market without intervention.

Other key conclusions:

- Scenarios with nuclear investment in the 2020s see no new fossil-fuelled plants built that decade, given the large expansion in renewable capacity (which is taken as given in this report).
- Nuclear investment reduces wholesale prices in the 2020s and beyond, although the cost of the support payments means that the impact on consumers' bills is less significant.
- Existing stations earn significantly less money in the 2020s if there is significant investment in new capacity (either nuclear or fossil). In particular, existing fossil stations move from being profitable with no aid (or a guarantee) to making substantial losses with any of the modelled CfD or FiP policies, which might lead to stations retiring early (although this is not explicitly modelled).
- Carbon emissions from the 2020s to the 2050s are lowest if there is significant early nuclear investment.
- Economic welfare (the sum of consumer benefits from changes in electricity prices and company profits) appears to increase as the cost of capital for nuclear stations falls, but these figures ignore the cost of providing any financial guarantees that help to reduce the WACC.

A contract for difference, as proposed by the UK government, is the most effective mechanism for supporting the construction of nuclear power stations in the 2020s. The total amount of nuclear capacity built by the 2050s, however, does not appear to depend on the policy adopted, but only on the cost of capital.[7] The cost of capital is a key variable for the analysis, as can be seen by comparing the first and last columns of the table. With no other policy support, a lower cost of capital is sufficient to bring forth much more nuclear investment by the middle of the century, lower wholesale prices, and a higher level of economic welfare. Carbon emissions are lower, despite a lower carbon price.

Our model does not ask why the cost of capital is lower in some cases than in others. If the reduction is due to a government guarantee which might be called upon, then the cost of providing this guarantee (linked to the expected payments that might be made) should also be subtracted from our measure of welfare. We have not attempted to estimate the cost of such a guarantee, but note that 15 GW of nuclear investment involves construction costs of around £75 billion. The second source of a lower cost of capital, however, is a reduction in market risk linked to the selling price of power. A nuclear station with a CfD is much less exposed to the price of fossil fuels (which feed into the wholesale electricity price) than a station without, which should reduce its cost of capital. At the same time, however, the consumers who are the ultimate counter-party to the CfD will also reduce their exposure to fossil fuel prices. In other words, the CfD offers a simultaneous hedge against fossil fuel price risk to both buyers and sellers of low-carbon electricity and can reduce the cost of capital to nuclear stations without imposing an offsetting liability on a counter-party – quite the reverse.

The level of welfare[8] in cases 4 to 6 is very similar to the no aid level (case 1). It is highest (by a very small amount) in case 5, as the longer duration of the CfD is assumed to further reduce the cost of capital for nuclear stations, and hence the cost of power. If part of this lower cost of capital were due to a government guarantee that was expensive to provide, it is likely that this might reverse the conclusion. Welfare is reduced by the other two policies that deliver nuclear investment, cases 2 and 3, for nuclear stations with a 10% WACC appear expensive, given the carbon prices in the early decades. The Feed-in Premium has higher welfare than the 35-year CfD because it delivers less nuclear capacity in the 2020s.

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[7] The difference between 25.8 GW and 26.1 GW (the range of expected capacities in the second row of the table) is approximately 1% and should be ignored.

[8] We measure welfare as generators' profits after return on capital (super-normal profits), plus the impact on consumers of changes in power prices and the resulting change in quantity of electricity consumed (due to price-responsive demand). Generators' profits are reduced by the need to buy emissions permits, and the cost of this acts as a proxy for the social damage caused by carbon emissions. We do not model other externalities of electricity generation.

By construction, the support payments are identical for the three 35-year policies, but they are about one-third lower with a two-stage, 60-year, CfD. This has very little impact on overall welfare as conventionally measured by economists, however, because it is effectively a transfer from the nuclear stations to consumers. The reduction in consumer prices in the 2060s and 2070s will lead to slightly higher electricity demands which will increase welfare, but only by amounts which, once discounted, are very small. Discounting also mutes the impact of the 60-year CfD on the average price including support payments.

The cases with CfDs for nuclear stations give the lowest wholesale prices; once support payments are included, the Feed-in Premium and the CfD for all stations actually increase the price of electricity, relative to a market without direct intervention but the same nuclear cost of capital (case 6). The impact on other generators is based on the wholesale price, however, and they lose the most money (in the 2020s) from the nuclear-only CfDs proposed by the UK government.

3.3 Sensitivity to WACC Reduction

The reduction in the cost of capital for nuclear stations that will result from government offering them a CfD is not certain. We therefore test a range of WACC reductions considering three sensitivity studies, each surrounding a CfD for 35 years which delivers a specific WACC for nuclear stations:

- the policy proposed by the UK government (with a 10% WACC);
- a CfD which delivers a WACC of 8%;
- a CfD which delivers a WACC of 12% (i.e. one with no attached credit guarantee).

In each case we alter the cost of capital for nuclear stations, adjust the carbon price to ensure that emissions targets are met, and hold all other assumptions constant – including the strike price offered by the CfD.

Nuclear stations with a capital cost (including interest during construction) of around £5,000 per kW would become profitable with a CfD offering £89.50 per MWh if their WACC lies below 10.2%. The impact on stations' profit and the cost of providing support at different WACCs is highlighted below:

	WACC of supported nuclear				
	8%	**9%**	**10%**	**11%**	**12%**
NPV of supported nuclear profits (£bn)	£4.5	£2.1	£0.2	-£1.3	-£2.6
NPV of providing support (£bn)	£4.5	£3.8	£3.5	£0.0	£0.0

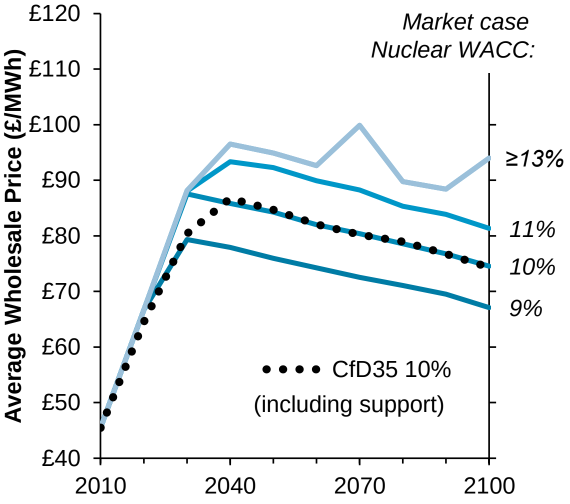
For every percentage point reduction in the WACC for nuclear stations, we expect wholesale prices to fall by around £7.50/MWh in the long term, and an extra 6–8 GW of nuclear capacity to become profitable, crowding out investment in 6–8 GW of fossil capacity. The cost of support is zero for a WACC above 10% since nuclear investment becomes unprofitable at a strike price of £89.50/MWh and so would not take place.

There is a strong relationship between the WACC for nuclear and the average wholesale electricity price. The annual average wholesale price is determined by the average cost of the type of station providing the marginal unit of baseload capacity which runs all year, and this will be nuclear stations if their WACC is 10% or less. If the wholesale price was any higher than this average cost, the marginal baseload capacity would make super-normal profits, which would lead to more investment in it and a reduction in the wholesale price.

3.3.1 Further Analysis: CfD35 at 10%

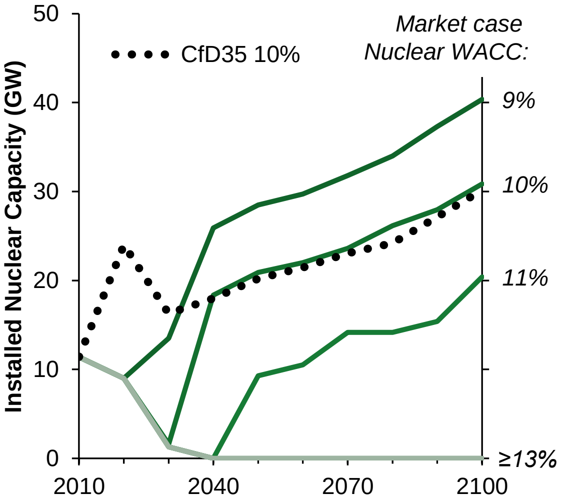
First, we consider the CfD as proposed by the government: 35-year contracts for difference which gives a 10% WACC for nuclear. The figures below compare this policy to what the market would deliver without intervention, for different levels of WACC for nuclear.

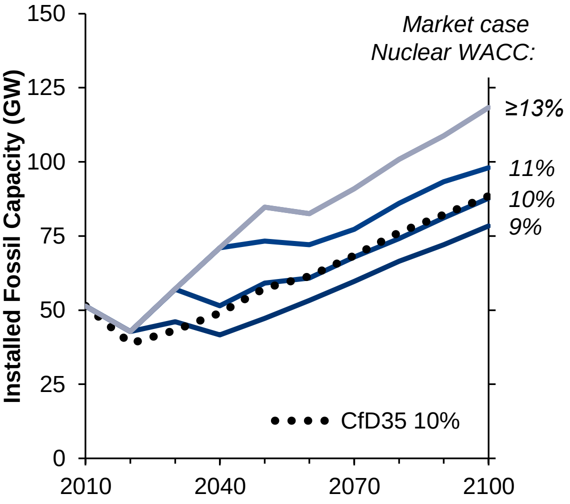
The price of electricity with a CfD (including the levelised cost of support) follows a very similar trajectory to the no aid case with a 10% WACC. In the 2020s and 2030s, the CfD slightly depresses prices, but from the 2040s onwards it is almost indistinguishable.



Similarly, a CfD would introduce distortions to the amount of nuclear and fossil capacity that get installed over the next two decades, but these distortions are short-lived, and so by the 2040s the CfD delivers the same installed mix of capacity that the market would at the same nuclear WACC.

The change in nuclear investment is more pronounced than for fossil stations, as 15 GW of capacity is built with a CfD in the 2020s which would otherwise not be built until the 2040s; raising the total installed capacity from a low of 1.6 GW in the 2030s to 16.6 GW. The change in fossil capacity is of similar magnitude: 14 GW less would be operating in the 2030s with the CfD; however, the relative change is much smaller (43 GW instead of 57 GW). The spike in nuclear capacity in the 2020s comes from new stations arriving at about the time that existing Advanced Gas-cooled Reactor (AGR) stations are due to retire; in practice, there might be no overlap.

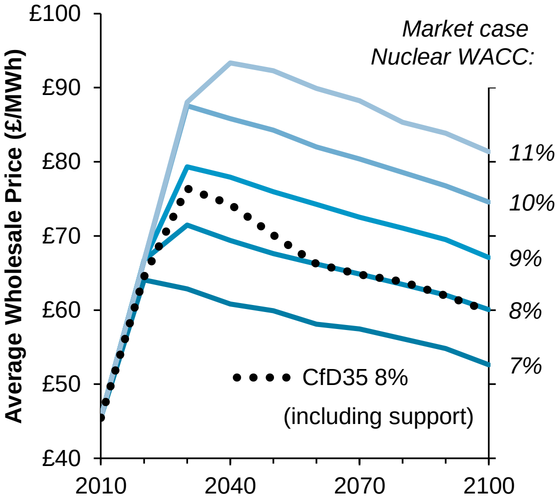




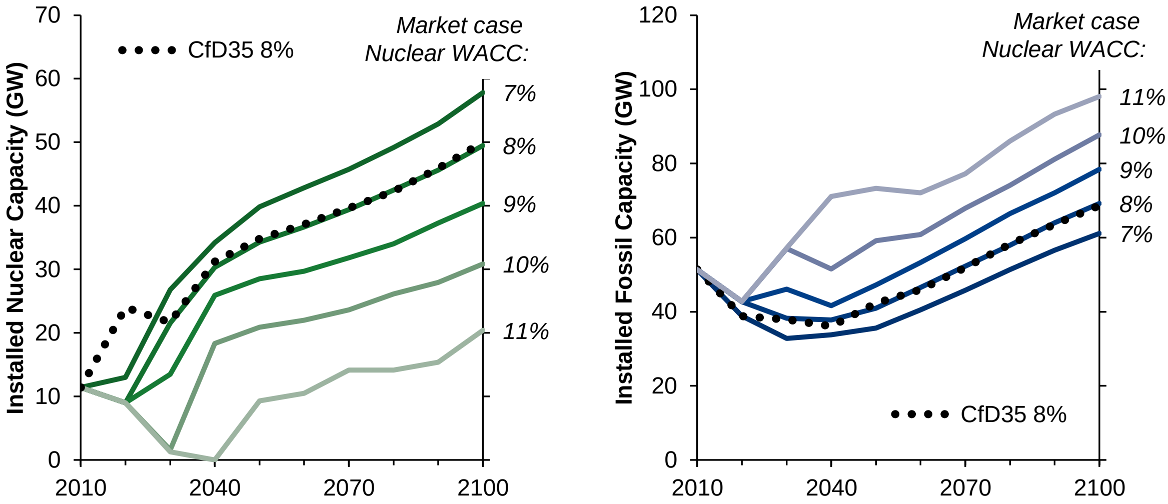
3.3.2 Sensitivity Analysis: CfD35, 8%

We consider a second sensitivity around a CfD which reduces the cost of capital further to 8%, and find that the conclusions from the previous test are for the most part repeated.

A CfD for nuclear stations with a WACC of 8% and a strike price of £89.50 involves a larger transfer of money from consumers to the nuclear stations.[9] The lower cost of capital means wholesale prices are around £16/MWh lower in the later decades than with a 10% WACC, and the strike price in the 2020s could be reduced without affecting investment. This is seen in the figure below as a hump in the wholesale prices with the CFD, relative to prices with no aid and an 8% WACC. Once the CfD expires, wholesale prices return to the same levels as the market would deliver.



With a WACC of 8%, the impact of the CfD on investment is similar, but less pronounced, than with 10% as in the previous section. The CfD brings 15 GW of nuclear investment forwards by a decade, and pushes back 4 GW of fossil investment by a decade. After the 2030s, the CfD makes no changes in the installed capacity, other than by lowering the WACC for nuclear.



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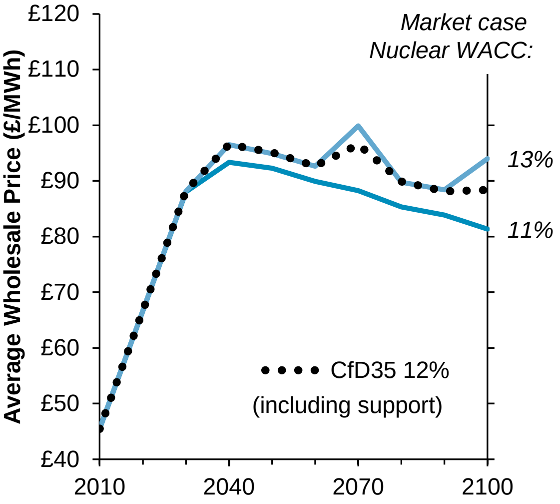
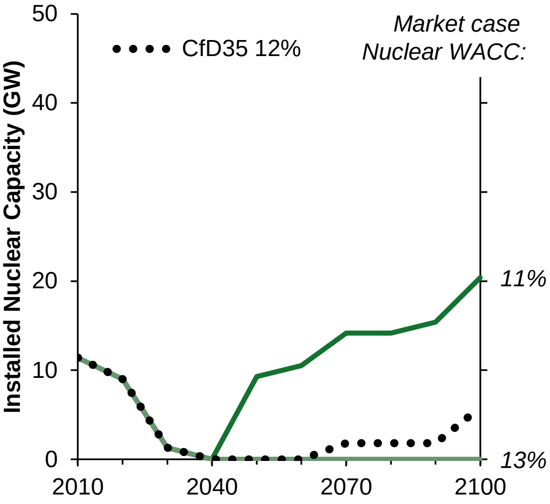
[9] The NPV of support is £4.5 billion with an 8% WACC, compared to £3.5 billion at 10%.

3.3.3 Sensitivity Analysis: CfD35, 12%

Our third sensitivity surrounds a CfD that is only able to reduce the cost of capital for nuclear down to 12%, for example if government offered a CfD without a credit guarantee. This scenario is almost indistinguishable from the no aid case with a WACC of 13%. No nuclear is built under this support, as wholesale prices in later decades rise to above the strike price (£90–96/MWh), meaning the CfD as proposed would transfer revenue away from already loss-making stations.

No nuclear is built in the near-term, so emissions reductions are achieved with a high carbon price of £250/T which encourages CCGT with CCS to be built. With the WACC lowered to 12%, a small amount of nuclear is built late into the century, 1.8 GW in the 2070s, and a further 4 GW in the 2100s. This is insufficient to have a substantial impact on wholesale prices, which remain above £90/MWh.





3.4 Sensitivity to Fuel Prices

Next, we run sensitivity analyses involving our high and low predictions of fuel prices, adjusting the carbon price so that the 2050 emissions target is still achieved. For each set of fuel prices, we consider the two main scenarios from the previous section; no government intervention and a nuclear cost of capital equal to 13%, and the UK government's proposed CfD with a 10% cost of capital. Our cases are therefore:

7. ***No Aid, 13%, low fuel*** – the market without government interventions, and a nuclear WACC of 13%, together with low fuel prices;
8. ***CfD35, 10%, low fuel*** – this is the policy proposed by the UK government, together with low fuel prices;
9. ***No Aid, 13%, high fuel*** – the market without government interventions, and a nuclear WACC of 13%, together with high fuel prices;
10. ***CfD35, 10%, high fuel*** – this is the policy proposed by the UK government, together with high fuel prices;

The key results are given in the following table:

	SCENARIOS:		1: No Aid, 13%	2: CfD35, 10%	7: No Aid, 13% Low Fuel	8: CfD35, 10% Low Fuel	9: No Aid, 13% High Fuel	10: CfD35, 10% High Fuel
INVESTMENTS	New nuclear capacity installed by end of decade (GW)	2020s	0	15	0	15	0	15
		2030s	0	15	0	15	0	20.1
		2040s	0	15	0	15	10.1	30.7
	New fossil capacity installed by end of decade (GW)	2020s	4	0	4.4	0	3.5	0
		2030s	41.1	27.1	41.5	27.5	40.9	21.7
		2040s	71.1	52	71.5	52.6	59.7	36.2
PRICES	Average wholesale price during decade (£/MWh)	2020s	£66.67	£51.33	£48.16	£34.05	£84.47	£66.35
		2030s	£88.15	£76.76	£67.07	£59.03	£106.97	£87.64
		2040s	£96.52	£88.05	£75.98	£67.64	£111.56	£85.93
	Average price including levelised subsidy (£/MWh)	2020s	£66.67	£64.44	£48.16	£53.03	£84.47	£74.33
		2030s	£88.15	£80.49	£67.07	£67.92	£106.97	£88.18
		2040s	£96.52	£88.43	£75.98	£73.29	£111.56	£86.82
PROFITS	Annual profits of existing stations in the 2020s (£bn)	Nuclear	£2.9	£2.0	£1.9	£1.1	£3.9	£2.8
		Fossil	£0.6	-£1.5	£0.6	-£1.6	£1.0	-£1.3
	Annual profits of supported nuclear stations (£bn)	2020s	–	£0.1	–	£0.2	–	£0.1
		2030s	–	£0.1	–	£0.2	–	£0.1
		2040s	–	£0.1	–	£0.2	–	£0.1
WELFARE	NPV of support over duration (£bn)		–	£3.5	–	£6.4	–	£1.9
	NPV of welfare: 2020s to 2050s (£bn)		£30.0	£28.6	£38.3	£33.5	£22.7	£25.0
	Cumulative carbon emissions: 2020s to 2050s (GT)		2.8	2.1	2.8	2.0	2.9	2.0

These results are much as we might expect. Less nuclear capacity would be built in a world with (correctly anticipated) low fuel prices than in one with high fuel prices. Since wholesale prices are linked to fossil fuel prices, whereas the strike price in the CfD is fixed across scenarios, the amount of government support required is much greater with low fuel prices. With high prices, the 35-year nuclear CfD raises welfare, compared to a market with a higher cost of capital. With low or central fuel prices, the nuclear CfD reduces welfare. A CfD with a strike price equal to the expected price of power can raise welfare by cutting the cost of capital for nuclear investors without harming consumers, but in the cases with low or central fuel prices, this is offset by the fact that nuclear costs would still be much higher than those of the alternatives.

The impact of nuclear support on cumulative emissions is greatest in the case with high fuel prices. The final carbon price varies much less in response to fuel prices in the cases with a CfD than when the carbon price alone is used to decarbonise generation. The impact on existing generators' profits in the 2020s does not appear to depend on fuel prices to a large extent (although the level of those profits does, particularly for existing nuclear stations).

3.5 Risk Profiles

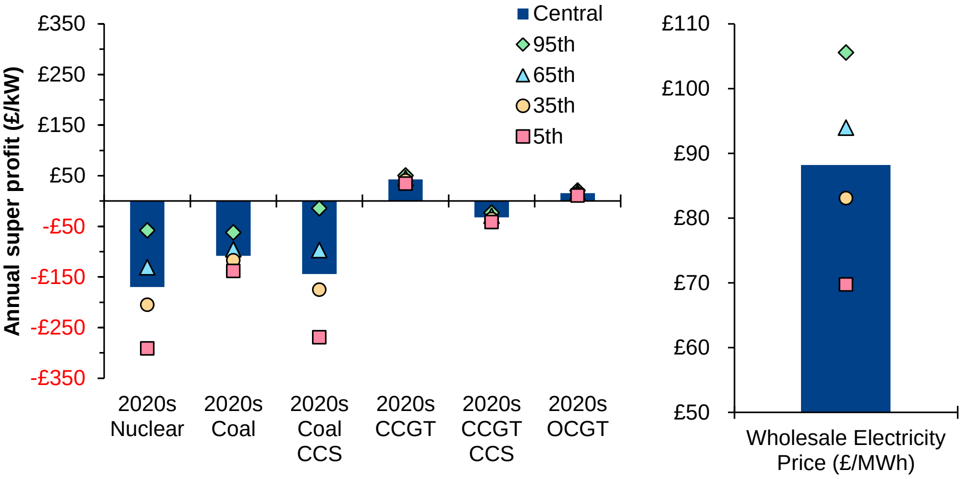
To assess the risks facing different generators, we have run Monte Carlo simulations with varying fuel prices for the two key cases, the market with no intervention and the UK government's proposed CfD. For each case, we ran the model with the central fuel prices to fix the capacity of each type of power station. We then allowed the fuel prices to vary and recorded the profits made by each type of plant that might be built in the 2020s during the 2030s.

In the charts presented below, the bars show results for the central set of assumptions (expected profits after capital costs to the left, and average electricity price to the right), while the points show the dispersion of profits and prices when fuel prices are varied, capturing the 5th, 35th, 65th and 95th percentiles.

3.5.1 No Aid, 13% WACC

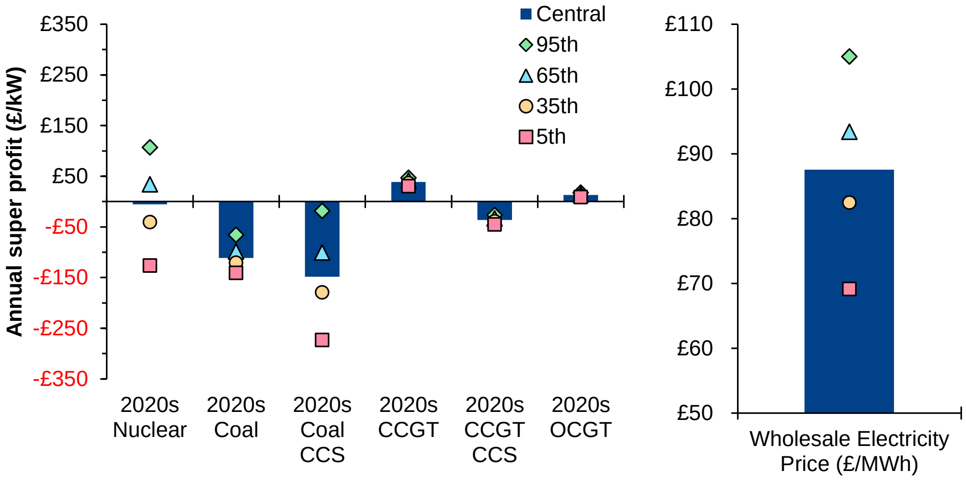
Note that our model allows us to simulate the profits that would be made by the first plant of a given type, even if that plant is in fact unprofitable and does not appear in our equilibrium capacity mix. This is in fact the case for four types of capacity in the market without intervention (case 1) – no company would want to build coal stations (with or without CCS) or nuclear plant. CCGT stations with CCS are also unprofitable, but unabated gas stations – whether combined or open cycle – are expected to make money in this decade. The level of capacity has been expanded to the point where the stations expect to just cover their overall costs – including their return on capital – over their technical lifetime; supernormal profits in the 2030s are needed to offset lower returns later on.

It is immediately clear that the three gas-fired station types face little variation in their profits – this is because the wholesale electricity price, which also varies significantly, does so in step with the price of gas and hence these generators' costs. Coal and nuclear stations, by contrast, face a varying selling price that is not highly correlated with their costs, and so have very uncertain profits.



3.5.2 No Aid, 10% WACC

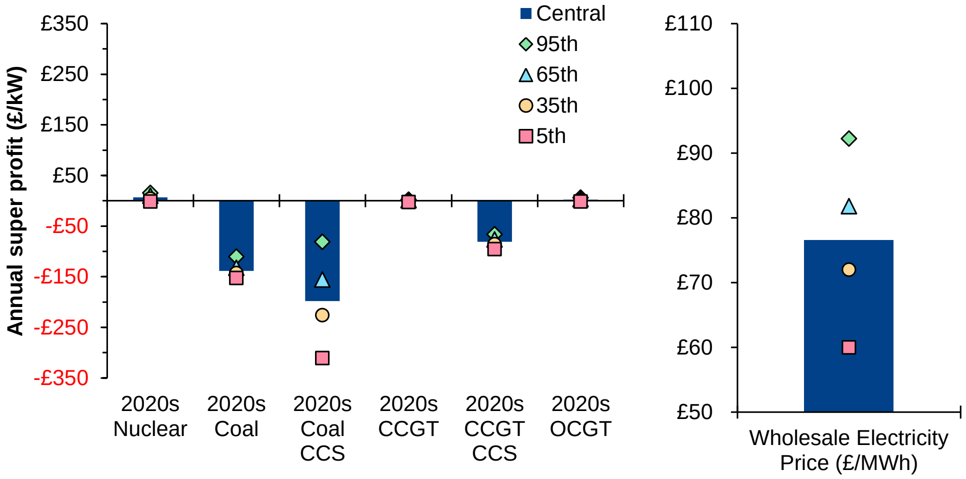
To help separate the effects of the contracts for difference from the effects of the reduction in nuclear WACC, we run a risk assessment on the market with a WACC of 10%, but no other support for nuclear stations. The lower cost of capital increases the profits that 2020s nuclear stations would earn (if they were built) to just below zero (hence none are built). Nuclear profits show a wide range of plus or minus £120/kW around this central value as fuel prices vary. The profits of other stations are unaffected, as no nuclear capacity is built, and so electricity prices and their operating hours are no different than in the market with 13% WACC.



3.5.3 CfD35, 10% WACC

When we consider the impact of a CfD (case 2), however, the nuclear stations face much less risk – variations in the market price of power are almost exactly offset by variations in the premium they receive under their contract. The average profit of nuclear stations becomes slightly positive, averaging £7/kW, with a range of –£2 to £15/kW as their hours of operation, and hence total output and revenues, are slightly uncertain.

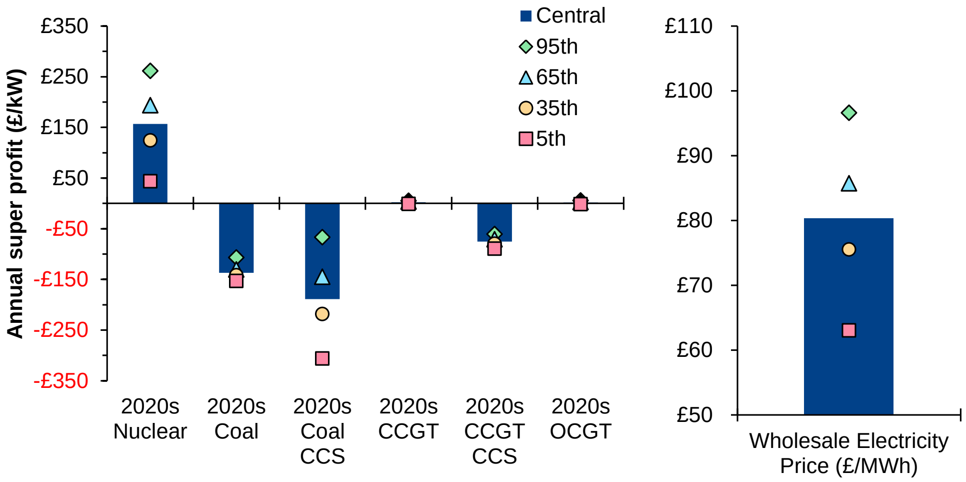
2020s gas-fired stations earn less, with profits centred around zero as nuclear stations are depressing the price of power in this decade, but their profits are still almost independent of fuel prices. Wholesale prices are £12/MWh lower on average, and their variability with respect to fuel prices is slightly reduced (the range from 5th to 95th percentile falls from £36 to £32/MWh). By reducing the variation of electricity prices, the CfD also reduces the range in revenues that other generation technologies could expect with respect to fuel prices, and so reduces profit risk for coal and coal with CCS.



We note that the same results apply to the CfD for 60 years (case 5), as this scenario is identical to CfD35 in the 2030s.

3.5.4 FiP35, 10% WACC

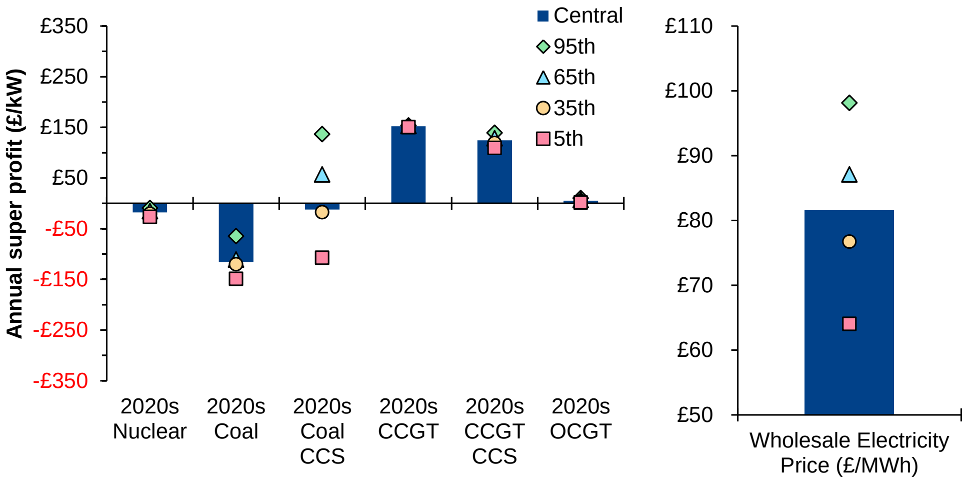
In this scenario, nuclear stations earn the wholesale price plus a fixed premium in the 2030s, and the rising market price makes them very profitable, on average. They are no longer hedged against the price of gas and other fossil fuels, however, and this is shown in the variability of their profits. Gas-fired stations are effectively hedged as the price of gas has the same impact on their costs and on their revenues, while coal remains unprofitable and unbuilt.



3.5.5 CfDall, 10% WACC

The CfDall scenario offers each technology a strike price which is indexed to its own fuel cost, and so risk therefore stays low for gas and nuclear. Coal, and particularly coal with CCS see significant variation in the number of hours they can operate for as coal and gas prices change, and so would still face considerable risk if they were built.

The central profits earned by nuclear stations are slightly negative and so these do not get built. Conversely, CCGT and CCGT with CCS could earn substantial super-normal profits. Only unabated CCGT gets built in the central scenario, as it consistently provides higher returns, and so crowds out CCGT with CCS.



Annex A Model Operation

The modelling work for this report was produced using an electricity market model consisting of:

- a short-run merit order stack with price responsive demand, to simulate the operation of power stations within a year and prices on the wholesale market;
- a long-run equilibrium investment planning model, to find the most profitable mix of stations to build each year;
- a Monte Carlo risk sensitivity model, to test the impact of varied fuel prices on plant revenues and profitability.

A.1 Method for Simulating Short-Run Dispatch of Power Stations

The dispatch module takes a profile for the electricity demand over the course of a year, a set of installed power stations and their costs, and simulates how these stations would run in order to meet demand at the lowest cost.

The dispatch model solves the so-called 'merit order stack' for the given year. This means that the cheapest plants (in terms of their variable costs) run throughout the year, so long as demand is high enough to use their full capacity. The second-cheapest plants run for most of the year, and so on until plants with high variable costs are only used at the times when demand is highest. The model calculates a price equal to the marginal cost of the most expensive plant in operation, or the price needed to ration demand to the level of the available capacity. From this, it calculates the profits that each plant would expect to make over the year. The model therefore emulates the price-setting mechanism used in the UK, with the simplification that dynamic operating constraints are neglected (such as transmission congestion or plant operating limits). The model also implements curtailment payments for wind farms which are forced to not generate during times of insufficient demand.

Demand is modelled to be price-responsive, meaning that consumers reduce their demand with increasing wholesale price, modelling the effect of demand side management within heavy industry. The actual pattern of demand is therefore determined endogenously by the model, simultaneously with the level of prices.

A.2 Method for Optimising Long-Run Investment Decisions

The investment module proposes a set of plant investments and retirements to make in each decade, which are tested in the dispatch module. Plants retire at the end of their technical lifetime. Capacity is added if it is expected to earn revenues in excess of all of its costs (capital, fixed and variable operating costs) over its future lifetime. Retiring capacity will tend to raise wholesale prices and make the remaining stations more profitable; adding capacity will reduce wholesale prices, making further investment less attractive. The module finds an equilibrium in which no more potential capacity looks profitable enough to be added. The resulting capacity mix is then taken forward to the next decade.

Investment decisions depend upon the prospect of profits from future decades, which will depend upon the capacity mix in those decades and hence upon future investment decisions. In the model's first run, each technology's future profits are inferred from those in the current decade (e.g. when deciding on investments to make in 2020, the model extrapolates profits over the plant's lifetime based on those estimated for 2020). As the model then runs forward through the decades, these assumed profits are replaced by the actual profits earned in that decade, based on the capacity that actually gets installed.

By the end of the process, it is likely that some investment decisions made in earlier decades will have proven sub-optimal, given the subsequent path of prices and profits. The model therefore returns to the 2010s and reconsiders its investment decisions for each decade in turn, given what has now been predicted about the future. The changed investment decisions lead to a new set of prices and profits, and so the model returns to the start again until the investment decisions converge. By this point, the model only invests in stations which recover their capital costs over their lifetime, simulating rational investor behaviour with perfect foresight.

The model considers investments up to the 2100s decade, and thus plants which may operate until 2160. In every run, the prices and profits from the final modelled decade (2100) are assumed to remain constant throughout the remaining years of each plant's life. This is a simplifying assumption to avoid having to model many more decades of decisions in the far future. It may have a significant impact on investment decisions made in the 2080s, but they are in turn unlikely to have an important effect on the decisions being made now, which are of most concern to us.

A.3 Method for Assessing Result Sensitivity and Investment Risk

With the equilibrium capacity mix determined for a given scenario, we perform a sensitivity analysis, re-running the short-run operations model with varied inputs for fuel prices, wind patterns and so on, to estimate the level of risk of the chosen investment options, and the distribution of profits that each type could expect to make with uncertainty in the future.

Once a sequence of investment decisions and capacity levels has been obtained, we simulate the risks faced by generators, running the model for a variety of different short-term fuel prices without changing the capacity mix. This shows which kinds of investment face the greatest market risks (and hence highest costs of capital); it also shows the impact of government interventions on those risks. This part of the work follows the methodology previously used to study the impact of carbon pricing on the risks faced by nuclear and other generators.[10]

A.4 Simplifications and Limitations

Some technical and economic features of the electricity market are ignored by the model for the sake of simplicity and transparency:

- ***Market power*** – we assume that all market prices are equal to the generator's marginal cost, or the rationing price needed to reduce demand to the available capacity. Any oligopolistic behaviour on the part of the major generation companies is ignored;
- ***Uniform investors*** – we do not differentiate between vertically integrated utilities and merchant investors;
- The evolution of ***transmission charges*** – it is assumed that the regional mix of power stations remains the same (with wind predominantly in Scotland, nuclear predominantly in the south), so that average transmission system charges by generating type stay the same;
- ***Wind curtailment*** specifically due to congested transmission down the north-south corridor is neglected – curtailment is only required if the must-run (minimum) output from the nuclear fleet exceeds demand net of wind and solar;

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[10] Green, R.J. (2008) "Carbon Tax or Carbon Permits: The Impact on Generators' Risks," *Energy Journal*, vol. 29, no. 3, pp. 67-89

- ***Dynamic constraints*** on power station operation: namely the costs of start-up, shut-down, and changing between output levels – previous work has shown that these are not overly significant[11];
- Details of the ***real-time balancing*** mechanism, frequency response and other power quality markets.
- We do not model the ***interconnectors*** to France, The Netherlands and Ireland. These act to raise or lower the effective demand for electricity within GB when exporting or importing power. The balance between exporting and importing depends on behaviour in the other markets, which, at present, is beyond the scope of this project;
- We do not explicitly model ***plant retirements***, but assume that all stations close at the end of their technical lifetimes;
- We exclude the impact of the government's proposed ***capacity mechanism***, as its impact on nuclear stations would be limited.

The model only considers six types of thermal generating technology, and all capacity of a given technology and vintage is uniform (having no variation in costs, efficiency, contracts for fuel purchase, etc.). Other generating technologies which are further from market, such as fuel cells, marine or fusion power are not included as they are unlikely to make a significant contribution over the early decades most important for understanding the impact of CfDs.

The maximum available generation from solar and wind generators is determined by the weather and their installed capacities which is decided exogenously. At times when their generation is greater than the demand for power minus the must-run capacity of nuclear stations, some of their output will be curtailed. Run of river and pumped storage hydro stations are modelled exogenously. Other forms of energy storage, such as compressed air, thermal storage and batteries are not explicitly modelled, but can be treated as additional pumped storage with different round-trip efficiencies, and ratios of peak power to stored energy.

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[11] I. Staffell and R. Green. 2012. *Is there still merit in the merit order stack?* BIEE 9th Academic Conference, Oxford.

Annex B Economic and Technical Assumptions

The model requires seven broad categories of data:

1. A current snapshot of the electricity system to be modelled
2. Fuel and carbon price projections
3. Plant technical and cost parameters
4. Financial assumptions
5. Installed capacity for renewables, hydro and storage
6. Projections for the level and pattern of national demand
7. Projections for the installed capacity of renewables, hydro and storage, and their patterns of output

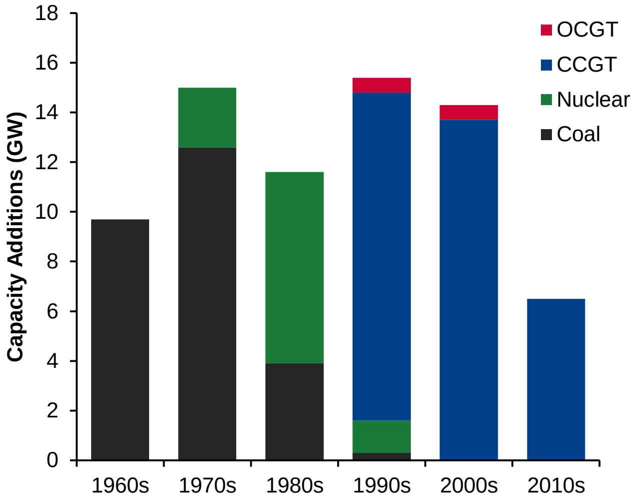
We attempt to follow the input assumptions used by the UK Department of Energy and Climate Change (DECC) wherever possible. In most cases, DECC's projections are only available to 2020 or 2030, and so we use other sources and our own judgement to determine input parameters for the decades beyond the 2030s.

A key aspect of DECC's modelling work is that it assumes compliance with the UK Government's carbon intensity targets – achieving an 80% reduction in national emissions by 2050. The Committee on Climate Change have recommended that this is achieved via a significant decarbonisation of the electricity sector by 2030, almost zero emissions in the sector by 2050[12]. We increase the price of carbon by 1 per cent a year from 2030, and find that the base case of market-driven investment roughly meets this target.

B.1 Snapshot of the GB Electricity System

The model is calibrated with the current installed generating capacity in Britain, separated into broad plant type and vintages (by decade from the 1960s) using data from Platts and Elexon.[13]

The generating capacity that has been built in each decade is summarised in the figure below, giving the current total of 72.5 GW of centrally-dispatched thermal capacity. The GB system also has approximately 4 GW of hydro (including pumped storage), 3.5 GW of interconnectors, 7 GW of capacity owned by companies that generate power alongside their main business, mainly for their own needs (auto-generators) and 9 GW of wind capacity, giving a total 96 GW gross capacity.[14]



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[12] HM Government, 2011. The Carbon Plan: Delivering our low carbon future. http://tinyurl.com/9wm8d7g

[13] Platts, 2012. World Electric Power Plants database. http://tinyurl.com/qcsbky2
Elexon, 2013. Balancing Mechanism Reporting System. http://bmreports.com/

[14] DECC, 2013. Digest of United Kingdom Energy Statistics. http://tinyurl.com/pf9vrqv

B.2 Fuel and Carbon Price Projections

The model requires a time-series of prices for each fuel (coal, gas, and uranium) and for carbon emissions forwards to 2100.

B.2.1 Fossil Fuel Prices

Fossil fuel prices are based on DECC's fossil fuel price projections which run to 2030.[4] We consider their low, central and high price scenarios, where the central scenario sees coal rising 30% and gas 20% by 2020 in real terms (to £8 and £20 per MWh of LHV input respectively), then remaining flat thereafter.

We consider three scenarios for real fuel prices after 2020 (when the DECC series level off), which are based on historic trends in oil prices:

- ***Low:*** fuel prices fall by 0.1% per year;
- ***Central:*** fuel prices stay constant;
- ***High:*** fuel prices rise by 0.1% per year.

Gas prices are assumed to vary between seasons, based on historic trends in UK prices (6% above annual average in winter, 6% below in summer).

B.2.2 Carbon Price Projections

The central carbon price follows DECC's projections to 2030 with the UK's Carbon Price Floor (CPF)[15]. Their carbon price rises from £7.20 in 2010 to £32.67 in 2020 and £76.23 per tonne in 2030. The carbon price averages £52.27/T during the 2020s, and over this period it rises linearly at a rate of £4.35/T each year.

Beyond 2030, we assume the carbon price continues rising at this rate until reaching an upper limit, after which it remains constant in real terms. Rather than picking arbitrary upper limits for the low, central and high scenarios, we determine the upper limit for each individual model run so that 2050 CO_2 emissions from the GB power sector do not exceed a threshold level.

To keep our model consist with the UK's target of 80% emissions reductions by 2050 we assume that power sector emissions must fall to 90% below their 1990s levels by 2050, as other sectors are expected to be more difficult to decarbonise. We therefore find the upper limit for carbon price which gets emissions from the model to equal 20.3 MT per year in 2050.

In some scenarios, particularly with high costs of capital for nuclear investments, the carbon price must rise higher than £160/T by 2050 in order to meet the 90% carbon reduction target. In these cases, we assume the carbon price rises at a constant rate from 2030 to 2050 in order to reach the required value.

These scenarios give the following price trajectories over our study period. The central scenario for each fuel is shown as the solid line, while the high and low cases are the dashed or dotted lines. The carbon price scenarios are illustrative, in practice the upper limits were determined for each case individually.

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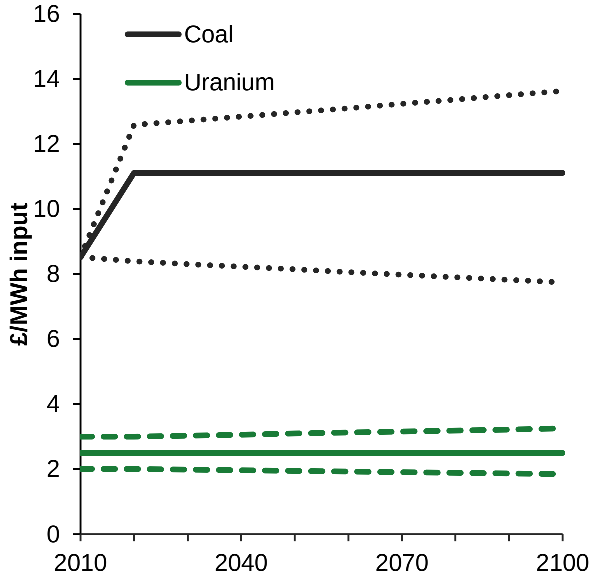
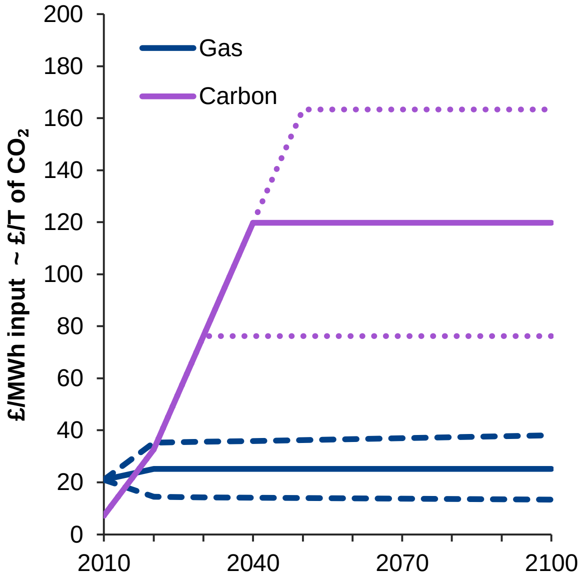
[15] DECC, 2013. Updated short-term traded carbon values used for modelling purposes. http://tinyurl.com/myawyh5





B.2.3 Nuclear Fuel and Waste Disposal

The cost of uranium is specified in the same manner as for fossil fuels, with a central value of £2.50 per MWh of available fissile energy, giving £7 per MWh of electricity produced at current plant efficiency. This cost is assumed to remain constant in real terms over the period 2010 to 2100 in the central case, and falls or rises by 0.1% per year in the low and high cases respectively.

This cost is taken from DECC,[2] and consists of £5/MWh for front-end fuel fabrication and £2/MWh for back-end decommissioning, waste reprocessing and disposal costs. The decommissioning and waste disposal costs for nuclear stations come from DECC,[16] on the assumption that an end-of-life fund of £1.5bn can be accrued at 2.2% discount rate with levelised costs of £0.28/MWh for waste and £1.62/MWh for decommissioning. These costs are added to the cost of fuel, which gives the same result as if they were added to variable O&M costs.

B.3 Power Station Parameters

The model requires the following information about each generator technology:

- Capital cost (£/kW – and does it include interest during construction)
- Change in capital cost over time (either as learning rates, or a time-series of values)
- Fixed operations & maintenance (O&M) costs (£/kW per year)
- Variable O&M costs (£/MWh – excluding fuel and carbon)
- Net thermal efficiency (%)
- Technical lifetime (years)

B.3.1 Plant Economic Parameters

Present-day capital costs were taken from DECC where available, and Parsons Brinckerhoff for unabated coal plant.[2,3] These figures were reviewed against Mott MacDonald[17] and EnergiNet[18] – a similar study from Danish authorities – and found to be consistent.

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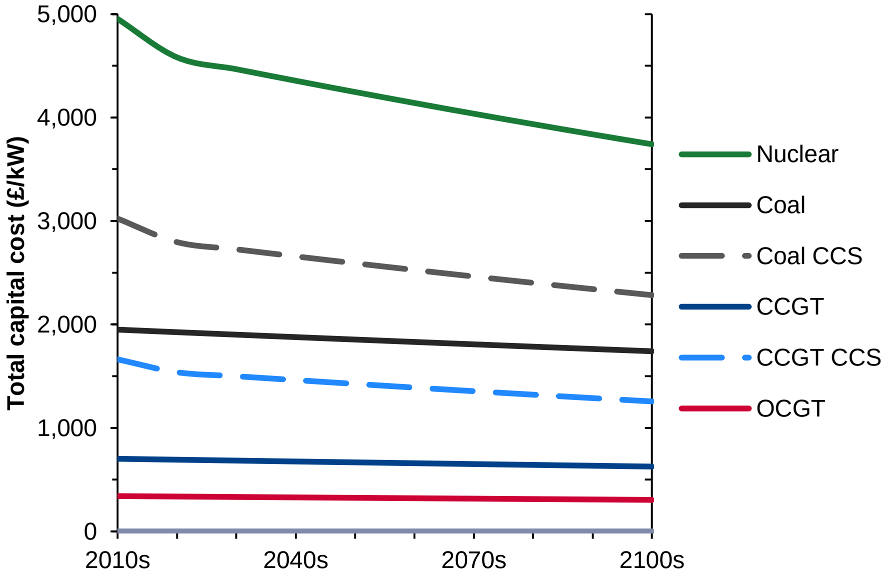
[16] DECC, 2010. Consultation on a Methodology to Determine a Fixed Unit Price for Waste Disposal and Updated Cost Estimates for Nuclear Decommissioning, Waste Management and Waste Disposal. http://tinyurl.com/oj3rlm4

[17] Mott MacDonald, 2010. UK Electricity Generation Costs Update. http://tinyurl.com/q28xny8

The capital costs given in these reports include pre-development and engineering, procurement and construction (EPC), but exclude interest during construction (IDC). The impact of IDC (the ratio of investment to overnight cost) was taken from the average of recent projects for each technology type as reported by the IEA.[19] These IDC inflators ranged from 30% for nuclear (due to long lead-times) to 10% for OCGT. A figure of around £5,000 per kW has been widely reported for the Hinkley Point C plant (£16 billion for a 3.2 GW station) and we use this as our starting point for nuclear costs in the UK.

The future trajectory for capital costs was taken from EnergiNet, which gives projections to 2050. Their projections were based on learning rates and projections for global deployment (similar to the Forward Pricing Model used in PB's reports). The reductions in real cost were 1.25% per decade for conventional fossil stations, and 2.5% per decade for plant with CCS after an initial fall of 7.5% in the first decade after deployment. No information was given on future nuclear costs, so these were assumed to fall in line with CCS plant, due to the immaturity of the EPR design.

The figure below shows our assumptions for capital costs (including IDC) and how they change over time.



O&M costs were taken from DECC,[2] except for coal which came from Parsons Brinckerhoff.[3] These studies assumed that almost all O&M costs were fixed, and so independent of annual output levels, in contrast to studies such as Mott MacDonald,[17] EnergiNet[18] and actual values reported by the IEA.[19] We therefore used the ratio of fixed (£ per kW of capacity per year) and variable (£/MWh generated) O&M costs from Mott MacDonald, scaling their totals to equal those from DECC.[2] This means that more O&M costs were transferred through into the year-round price of electricity, and plants covered their remaining fixed costs with less need to resort to demand rationing at the peaks, reflecting current price patterns.

Fixed costs include operations and maintenance (O&M) and insurance, but not use of system charges (we exclude payments for connection to the transmission system). The costs associated with nuclear decommissioning and waste disposal are attributed to fuel costs, rather than O&M costs for reactors.

In line with Parsons Brinckerhoff[3] and EnergiNet[18], we add £20 per tonne of CO_2 captured from CCS-equipped plant to cover transport and storage costs, which equates to around £0.75/MWh from CCGT-CCS and £2/MWh from coal-CCS.

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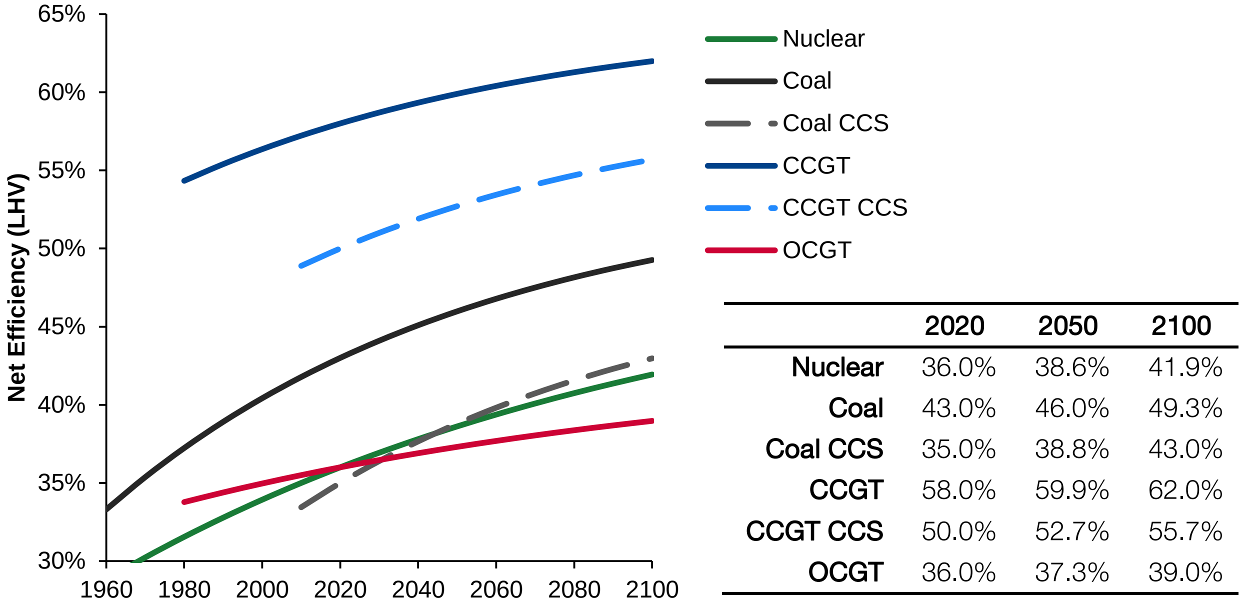
[18] EnergiNet, 2012. Technology Data for Energy Plants. http://tinyurl.com/ptqhhf3

[19] International Energy Agency, 2010. Projected Costs of Generating Electricity. http://tinyurl.com/ould2es
Projects in South Korea and China were excluded, due to their access to beneficial finance terms.

B.3.2 Plant Technical Parameters

Present-day plant efficiencies are taken from Parsons Brinckerhoff[3] and are given net of plant self-consumption against LHV. CCS is assumed to incur an efficiency penalty of 8% for both coal and CCGT plants (in absolute terms) in the 2020s, falling to 6% by the 2100s.[20]

The improvement in efficiency over the coming decades is based on projections of 2050 plant efficiency being 3–4 percentage points higher than today,[18] and the maximum efficiency considered possible at present, from moving to higher operating temperatures (e.g. ultra-super-critical coal, and super high-temperature gas turbines).[21] Plant efficiencies are assumed to edge closer to their ultimate limits by a fixed percentage each decade, giving diminishing returns over time, as shown in the figure below.



	2020	2050	2100
Nuclear	36.0%	38.6%	41.9%
Coal	43.0%	46.0%	49.3%
Coal CCS	35.0%	38.8%	43.0%
CCGT	58.0%	59.9%	62.0%
CCGT CCS	50.0%	52.7%	55.7%
OCGT	36.0%	37.3%	39.0%

The national fleet availability to generate electricity is assumed to be 80% in winter and 70% in summer; the remaining capacity is providing reserve or unavailable because of maintenance. The resulting peak outputs as a proportion of installed capacity match historic trends in the GB system.

Plant lifetimes are based on Parsons Brinckerhoff,[3] and are assumed to remain constant at 60 years for new nuclear (40 for existing), 40 years for coal, and 30 years for all other technologies. While more recent reports to DECC assume that lifetimes are 5 years lower for all fossil plants, these are likely to be cautious accounting lives over which the costs must be recovered, rather than the operational lives that will be achieved in practice.

It is assumed that the nuclear fleet is not designed to change its output in response to fluctuations in demand and wind farm output due to technical constraints, and so the nuclear fleet must operate at a minimum of 90% load factor (net of availability).

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[20] IEA, 2006. Energy Technology Essentials: CO_2 Capture & Storage. http://tinyurl.com/ob7qg3d

[21] JRC, 2012. Study on the state of play of energy efficiency of heat and electricity production technologies. http://tinyurl.com/of7b542

B.4 Financial Assumptions

We use the weighted average cost of capital (WACC) values specified to us by the Commission for nuclear stations under different policy scenarios. For other technologies, we use the so-called hurdle rates specified by DECC.[2] The values used for different technologies and policy scenarios are outlined below:

Nuclear Stations (built in the 2020s)		WACC	
		Post-tax Nominal	Pre-tax Real
No Aid	(central)	13%	14.0%
	(low)	11%	11.5%
	(high)	15%	16.4%
Guarantee only	(high)	11%	11.5%
	(low)	9%	9.1%
35 year support	(central)	10%	10.3%
	(low)	8%	7.8%
	(lower)	6%	5.4%
	(floor)	4%	2.9%
60 year support	(central)	9%	9.1%
	(low)	8%	7.8%

Other Stations (all decades)	WACC	
	Post-tax Nominal	Pre-tax Real
Coal	7.7%	7.5%
Coal CCS	12.6%	13.5%
CCGT	7.7%	7.5%
CCGT CCS	12.9%	13.8%
OCGT	7.7%	7.5%

The Commission provided WACC values for nuclear stations in post-tax nominal terms, whereas DECC specify WACC values in pre-tax real terms. Our model uses pre-tax real terms throughout, so the Commissions values were converted to pre-tax real using the following equation, with an assumed inflation rate of 2% and a 20% corporate tax rate:[2]

$$PreTaxReal = \frac{1 + \frac{PostTaxNominal}{1 - Tax}}{1 + Inflation} - 1$$

A pre-tax rate of return needs to be higher than the post-tax equivalent, and a real return will be lower than its nominal equivalent. With the values we are testing, these two corrections roughly cancel out. For the lowest post-tax rates, relatively little tax is taken (in absolute terms) and so the pre-tax rates are particularly low; high post-tax rates involve higher tax payments and thus much higher pre-tax rates. For renewable technologies (wind and solar PV), the equivalent tax rate is estimated by KPMG to be 12%.[22] We assume the same WACC rates apply for each technology throughout the duration of a scenario. All results are reported in terms of the post-tax nominal rate of return.

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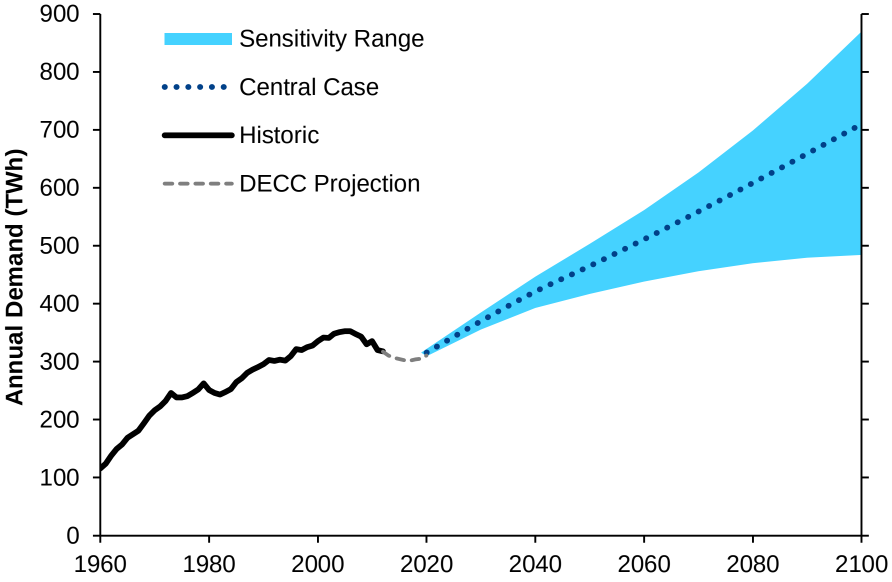
[22] Formulae for pre- and post-tax WACCs (and the intermediate "Vanilla WACC" which ignores tax effects) are set out on page 11 of KPMG, 2013. Electricity Market Reform: Review of effective tax rates for renewable technologies. http://tinyurl.com/oddu9h6.

B.5 Demand for Electricity

B.5.1 Growth in Demand

We take historic metered demand data from National Grid,[23] which covers the supply from major power producers (the companies which generate power as their main business). DECC provide long-term forecasts of annual UK electricity demand to 2030.[24] We reduce each year's forecast by 2.7% to exclude Northern Ireland, and then by a further 33 TWh to remove power which is supplied by auto-producers and other small sources. We exclude this element of supply, as these small producers are assumed to be unaffected by the market. These modified DECC forecasts align well with the National Grid historic data from 2009–12 (where the two series overlap).

A combination of the global economic recession and improving energy efficiency mean that demand is expected to continue its recent downwards trend during the rest of the 2010s. DECC's central forecast sees –0.3% annualised growth between 2010 and 2020, then +1.6% annualised growth from 2020 to 2030. In the longer term, we assume demand growth settles on 1.0% per year, based on historic trends from 1971–2010.[23]



B.5.2 Hourly Pattern of Demand

For the hourly pattern of demand, we take 18 years of historic demand (1994–2011) and the corresponding spot prices. We need both price and quantity to anchor the price-responsive demand curves used in the model. Demand is assumed to fall as the wholesale price increases, with a decrease of 10 MW per £/MWh of price increase. This time series of 157,776 hours is reduced down to two load-duration curves for winter and summer, each of which consists of 150 time slices of varying length. The extremes of each season's curve are represented in high detail (times of peak and minimum demand), while the middle of the load-duration curve is simplified, to preserve the important features of the demand profile.

The shape of the gross demand profile is not assumed to change over time, and historic patterns are scaled up linearly. Future work could include modelling the increasing impact of electrification: electric vehicle charging and heat pump ownership; however, this is unlikely to have a major impact on the key questions for this study.

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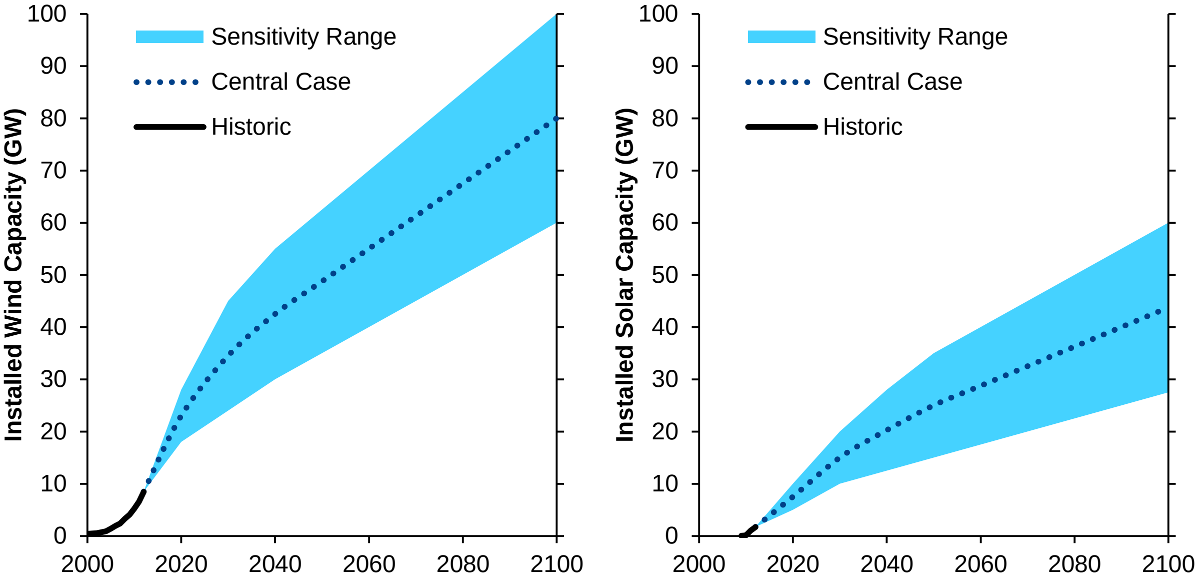
[23] National Grid, 2013. Half-hourly metered demand data. http://tinyurl.com/nljrsb3
National Grid, 2006. E&W Daily Demand Data (data file no longer available online).
[24] DECC, 2012. Updated Energy and Emissions Projections. Annex E. http://tinyurl.com/plufe69

B.6 Renewables, Hydro and Storage

B.6.1 Installed Capacity

The future installed capacities for renewables, hydro and storage are exogenous variables input into the model, rather than decisions made within the model in the light of assumed levels of government support and market revenues. For wind and solar, these were based on projections by Arup which went forwards to 2030.[25] We assumed that capacity increases linearly after 2030, and chose a reasonably wide range to represent uncertainty for the sensitivity study. The historic and forecast capacities are shown in the figure below.



We assume that the quantity of run-of-river hydro remains the same as today, at 1.4 GW producing 5 TWh per year. The quantity of storage is assumed to increase from 2.8 GW in 2010 to 6 GW by 2050, and 10 GW by 2100, following central scenarios from Strbac (2012)[26] and the DECC 2050 Pathways Analysis.[27] Future storage is modelled with the same parameters as current pumped hydro storage, with a 77% round-trip efficiency and a storage capacity of 3.6 GWh per GW capacity, which is discharged on a daily cycle.

The gradual increase in storage helps to mitigate some of the variability introduced by increasing generation from wind farms; however it is not sufficient to prevent times of negative net demand, where wind supply exceeds demand. This occurs from 2040 onwards with the central case for renewables capacity, increasing from 15 hours of negative demand in 2040 to 85 in 2100. Over this period, there are 600–800 hours where net demand is below 15 GW, and so nuclear plant (if any are installed) would likely have to pay wind curtailment payments.

B.6.2 Patterns of Output

The hourly pattern of output from wind and solar are simulated using historic weather patterns from 1994–2011 (the same years as our demand data), so that the relationships between weather, renewables output and electricity consumption are preserved. We use historic reanalysis data from NASA, which is in turn based

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[25] Arup, 2011. Review of the generation costs and deployment potential of renewable electricity technologies in the UK. http://tinyurl.com/pykuaqk

[26] Strbac *et al*, 2012. *Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future.*

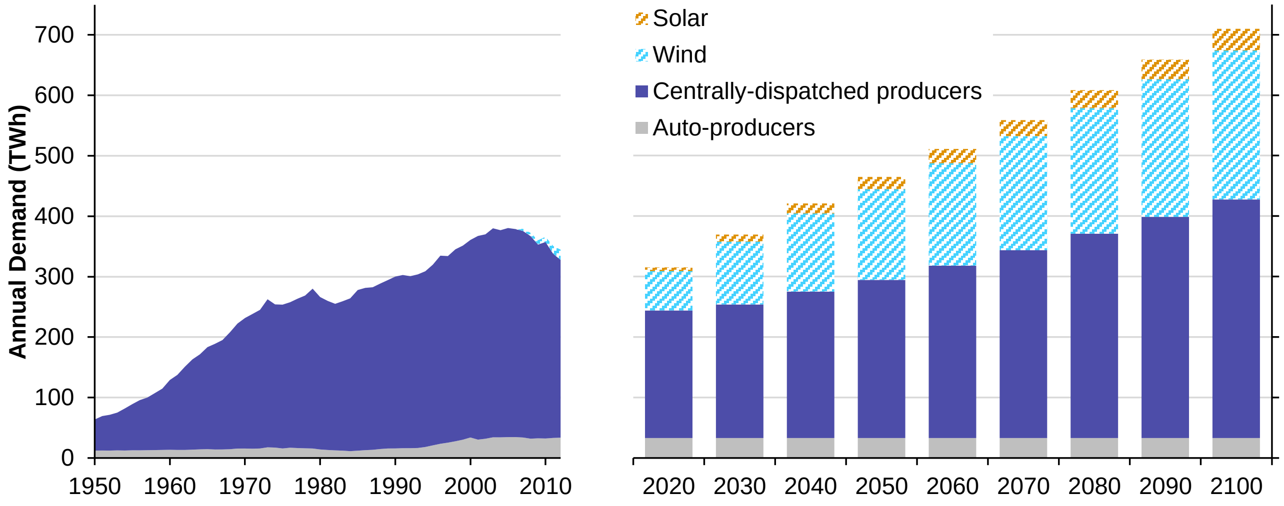
[27] http://2050-calculator-tool.decc.gov.uk

on weather station and satellite data, giving measurements of temperature, wind speed and solar irradiance with complete spatial coverage over the UK and North Sea.

We simulate the aggregate output of the UK's fleet of onshore wind farms, and the proposed Round 2 and 3 offshore wind farms, using the 'virtual wind farm' model developed by the authors.[28] For solar PV outputs, we simulate 1,000 PV panels with the approximate geographic distribution of the current installed fleet, using the 'virtual solar panel' model being developed at Imperial College London.[29]

The overall impact of the demand and renewable supply assumptions is shown in the figure below. The annual demand that needs to be met by main power producers (those that we simulate) in each decade is shown by the blue areas. Due to decreasing demand and rapidly expanding renewables, this is expected to be lower in the 2020s than at any time since 1970. With the central rates for growth in demand and renewables, the annual supply from centrally dispatched power stations eventually rises above 2005 levels by 2100, while the total gross demand becomes double that value.

In the central scenario, power stations supply 395 TWh in 2100. At the extremes of the sensitivity cases, they supply 555 TWh (high demand, low renewables) or 169 TWh (low demand, high renewables).



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[28] Staffell, I. and Green, R., 2014. *How Does Wind Farm Performance Decline with Age?* Renewable Energy, in press. http://dx.doi.org/10.1016/j.renene.2013.10.041

[29] Currently under development by Stefan Pfenninger and Iain Staffell.

Annex C Extended Results

This annex presents our results for each scenario in a standard format. It is split into three sections, corresponding to different parts of section 3:

C.1: the market results with no intervention for different WACCs;
C.2: the comparison of policies;
C.3: the fuel price sensitivity;

Each scenario is presented on a single page. The top left-hand section contains a brief description of the scenario and its input data. The top right of the page gives the amount of investment in nuclear plant and in fossil stations in each decade from the 2020s to the 2050s – changes in investment will be a primary measure of whether the policy is affecting the electricity market. The next item gives the amount of public support received by generators (of all kinds) from a CfD or Feed-in Premium, discounted at a public sector discount rate of 3.5%. Economic welfare consists of consumer surplus and generators' profits – our calculation of consumer surplus takes account of the support payments made to generators. The average wholesale price (time-weighted in each year, and discounted over time) is given before and after adding the cost of support payments, and is another variable that would be affected by any market distortion.

The profits of new-build generators would not be affected by a market distortion, since the model endogenously chooses investment levels to ensure that all new-build fossil-fuelled stations break even. This does not apply to the profits of existing power stations, however, and so we also report the total annual profits of existing nuclear and fossil-fuelled stations during the 2020s. We also calculate the lifetime profits of a nuclear station built in the 2020s. In some cases (such as the first one we present, ***No Aid, 13%***) these would be negative and so no stations are actually built; in some cases (with low WACCs and government support) these are very positive. These values imply that a lower strike price would be capable of calling forth the investment; in our modelling, we do not adjust the strike price but set a limit on the amount of capacity that the government is willing to support; otherwise, the model would find it profitable to invest in an unlimited number of stations.

We also report the carbon emissions in key decades, as a check that the policy is meeting the UK government's climate commitments, together with the maximum carbon price required to achieve these. To recap, the price initially rises at the same rate in every scenario until it reaches the level needed to limit 2050 emissions, and those levels differ across scenarios.

At the bottom of each results page we present a selection of graphs. The first graph (top left) reports the time-weighted wholesale electricity price in each decade as a solid line; and in cases with policy support, the cost of these is added (or subtracted) from the wholesale price in a dotted line.

The graph below measures the annual spending within the electricity sector in each decade. The figures for capital investment are (almost) inevitably lumpier that the stream of payments for fuel and carbon permits, often showing cycles of investment over the decades as large amounts of old capacity are retired. The black line shows the total net expenditure, which may rise above capital + fuel + carbon when policy measures require payments to generators, or may fall below these levels in cases where generators return money to the government.

The top-right graphs show the installed capacity by fuel type, in two blocks. The continuous areas to the left give the historical context from 1950, in which a coal-dominated mix saw nuclear and then gas capacity added; while the bars to the right give our predictions for each decade from 2010 onwards. The bottom-right graphs show the generation by fuel type, again giving both the historical context and the model's predictions.

C.1 Free Market

Seven scenarios were tested with no direct interventions into the electricity market, with the cost of capital for nuclear stations ranging from 7% to 15% post-tax nominal. These were used within the ***No Aid*** and ***Guarantee*** scenarios, or as part of the sensitivity analysis around WACC reductions.

C.1.1: 13% WACC
C.1.2: 11% WACC
C.1.3: 10% WACC
C.1.4: 9% WACC
C.1.5: 8% WACC
C.1.6: 7% WACC

The scenario for 15% WACC is not shown, as it gave identical results to the scenario for 13% WACC.

C.1.1 13% WACC

This is our central case for a market without any government intervention.

The relatively high cost of capital makes the capital-intensive nuclear stations unattractive; so no stations are built at all in this century. A 3.2 GW nuclear station built in the 2020s would expect to lose £6.2 billion over its lifetime.

Existing nuclear and fossil stations expect to return a profit during the 2020s, as very little additional capacity is built, leading to higher wholesale prices.

Decarbonisation is achieved through building CCGT stations with CCS, and a high carbon price (reaching a maximum of £250/tonne of CO₂) is needed to promote this.

The increase in carbon price combined with near-total reliance on high-cost gas means electricity prices almost double between the present day and the 2040s, and remain high through the rest of the century.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0	0	0
Fossil:	4	37.1	30	17.7

NPV of public support: £0.0 billion
NPV of total welfare: £36.8 billion
3.5% discount rate, measured from 2020

Average wholesale price: £84.79 / MWh
Including support: £84.79 / MWh

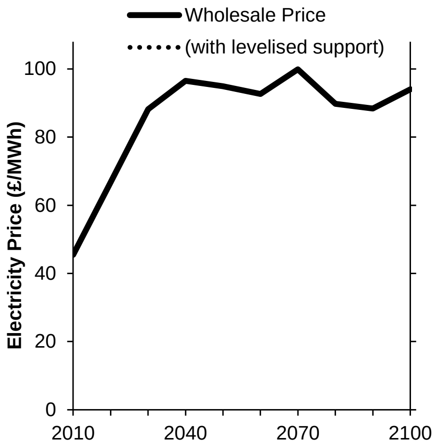
Annual profits of existing stations in the 2020s:
Nuclear: £2.9 billion
Fossil: £0.6 billion

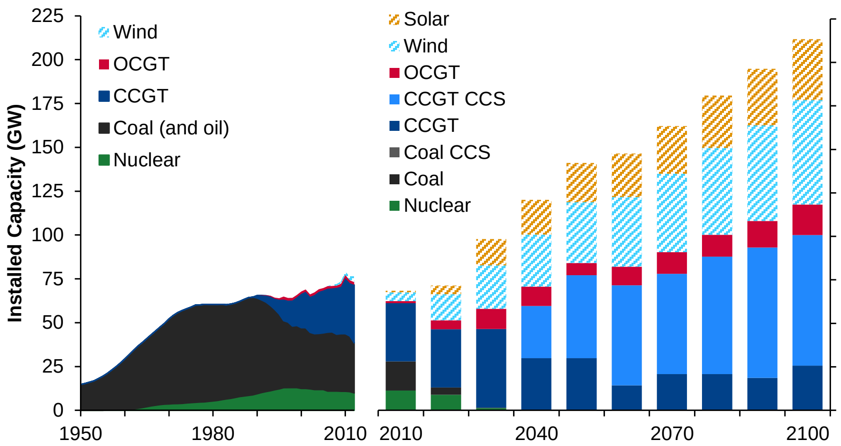
NPV of profits for 2020s nuclear: -£6.2 billion
14.0% discount rate, 3.2 GW station

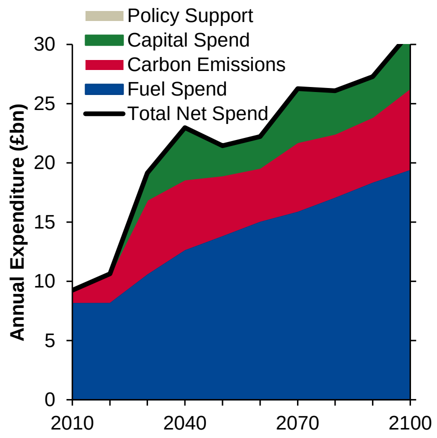
Carbon emissions (relative to 1990) in:

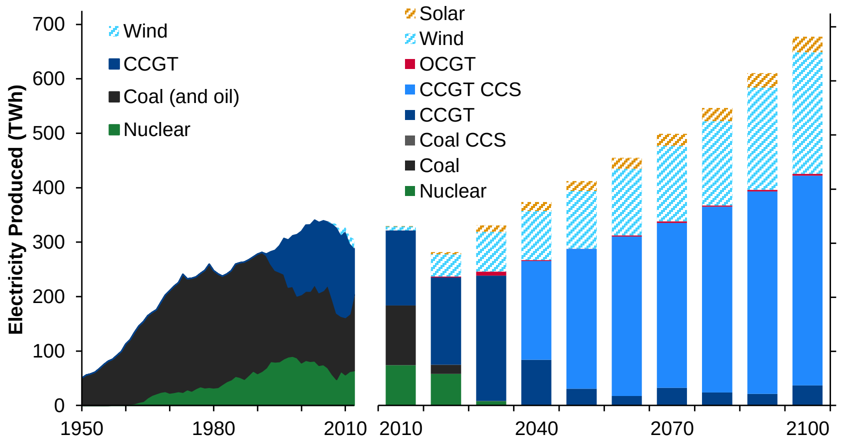
2010	2020s	2050s	2100s
-27%	-65%	-90%	-86%

Maximum carbon price: £250 / T
Cumulative emissions to 2100: 3.9 GT









C.1.2 11% WACC

With an 11% cost of capital for nuclear, this scenario is identical to the central case (C.1.1) up until the 2050s.

We still find that no stations are built in the 2020s; however, around 9 GW of capacity is able to return a profit from the 2050s onwards, once wholesale prices have risen sufficiently.

From the 2050s onwards, wholesale prices fall slightly relative to C.1.1, ending the century around £9/MWh less.

The investment in nuclear in the 2050s means a slightly lower carbon price is required to meet emissions targets, and total emissions over the century are slightly lower than in C.1.1.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0	0	9.3
Fossil:	4	37.1	30	6.2

NPV of public support: £0.0 billion
NPV of total welfare: £37.4 billion
3.5% discount rate, measured from 2020

Average wholesale price: £82.61 / MWh
Including support: £82.61 / MWh

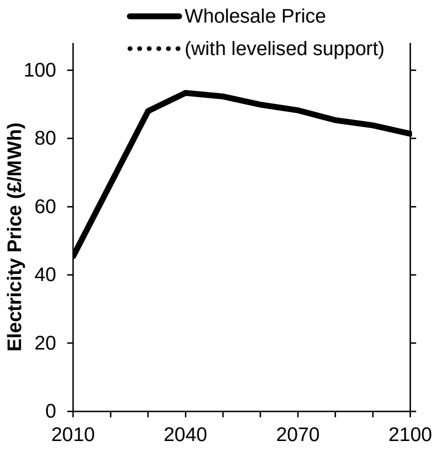
Annual profits of existing stations in the 2020s:
Nuclear: £2.9 billion
Fossil: £0.6 billion

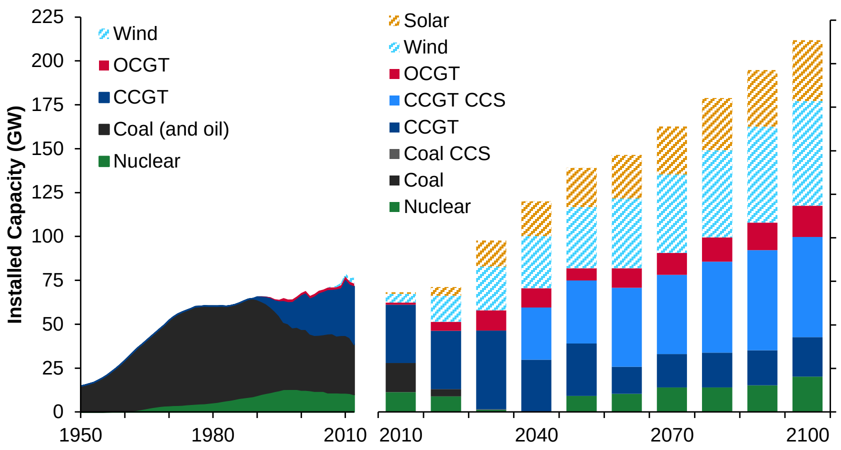
NPV of profits for 2020s nuclear: -£4.1 billion
11.5% discount rate, 3.2 GW station

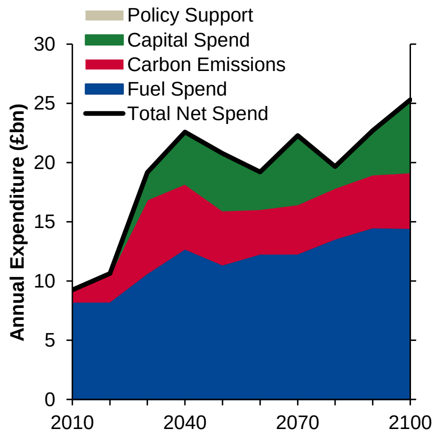
Carbon emissions (relative to 1990) in:

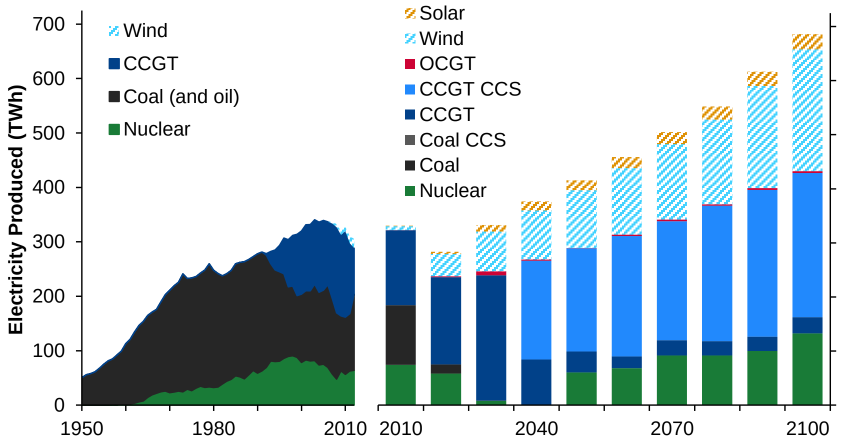
2010	2020s	2050s	2100s
-27%	-65%	-90%	-90%

Maximum carbon price: £227 / T
Cumulative emissions to 2100: 3.8 GT









C.1.3 10% WACC

With this cost of capital, no nuclear investment would be profitable in the 2020s. Results for the 2020s are identical the central no aid case (C.1.1).

A small amount would be profitable in the 2030s (too small to justify building an actual station), and much more in the 2040s, so that the installed capacity by the 2050s would be practically identical to the level with the government's proposed policy (C.2.1).

The lower nuclear cost of capital means that carbon emissions can be cut with a lower carbon price. This produces a lower average wholesale price than with no intervention (C.1.1), which is nonetheless higher than with the government's policy (C.2.1), even after its support payments are taken into account.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0.3	18.1	2.6
Fossil:	4	37	10.6	11.6

NPV of public support: £0.0 billion
NPV of total welfare: £38.6 billion
3.5% discount rate, measured from 2020

Average wholesale price: £78.85 / MWh
Including support: £78.85 / MWh

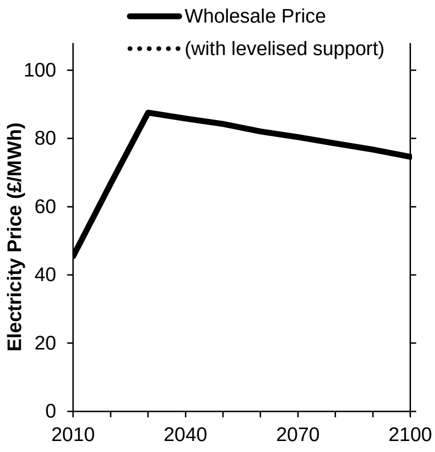
Annual profits of existing stations in the 2020s:
Nuclear: £2.9 billion
Fossil: £0.6 billion

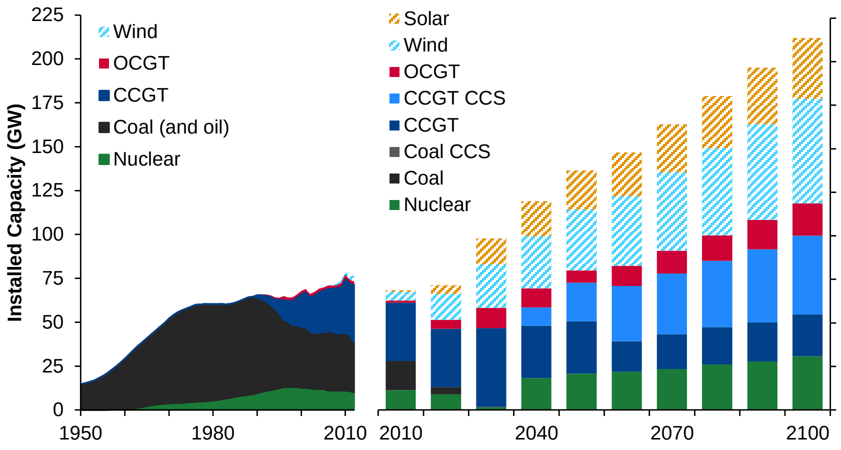
NPV of profits for 2020s nuclear: -£2.8 billion
10.3% discount rate, 3.2 GW station

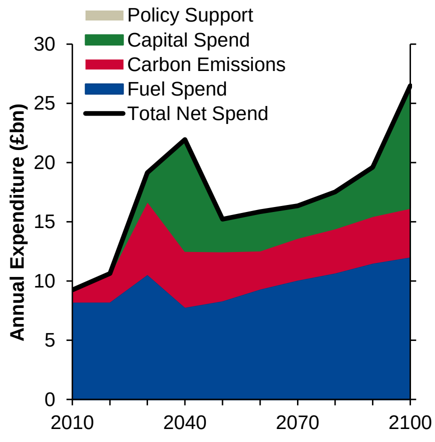
Carbon emissions (relative to 1990) in:

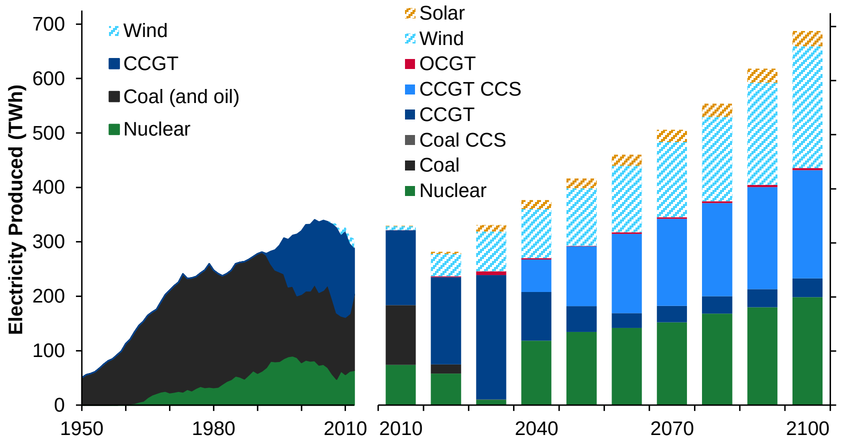
2010	2020s	2050s	2100s
-27%	-65%	-90%	-90%

Maximum carbon price: £206 / T
Cumulative emissions to 2100: 3.7 GT









C.1.4 9% WACC

With the cost of capital reduced to 9%, significant investment in nuclear takes place in both the 2030s and 2040s.

Results for the 2020s are again unchanged from the central no aid case (C.1.1).

The lower cost of generation again raises welfare, reduces wholesale prices, reduces carbon emissions, and the carbon price needed to meet emissions targets.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	12.2	13.7	2.6
Fossil:	4	26	11.7	9.6

NPV of public support: £0.0 billion
NPV of total welfare: £40.7 billion
3.5% discount rate, measured from 2020

Average wholesale price: £73.30 / MWh
Including support: £73.30 / MWh

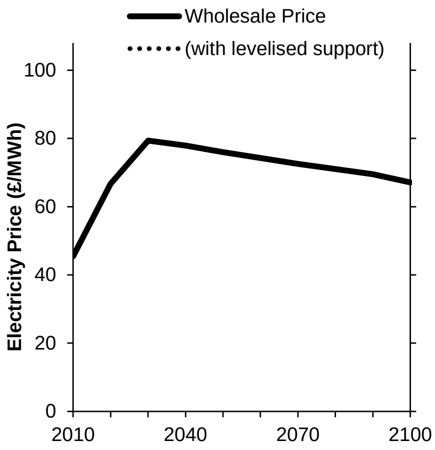
Annual profits of existing stations in the 2020s:
Nuclear: £2.9 billion
Fossil: £0.6 billion

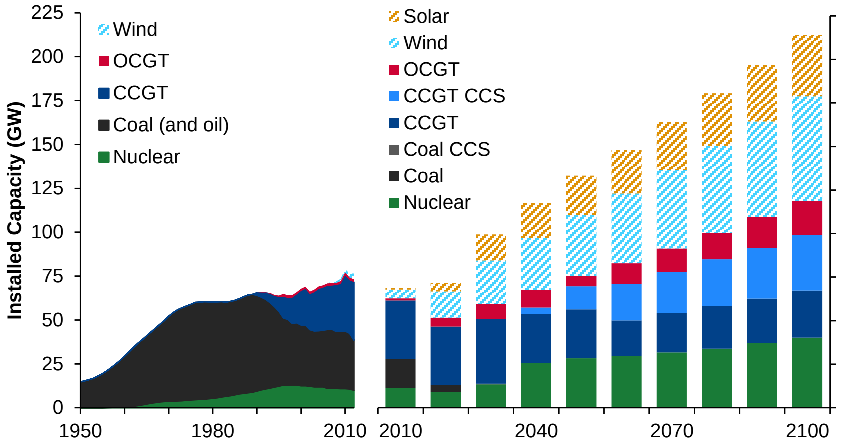
NPV of profits for 2020s nuclear: -£1.8 billion
9.1% discount rate, 3.2 GW station

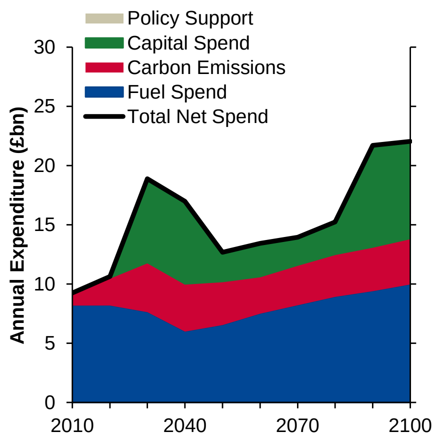
Carbon emissions (relative to 1990) in:

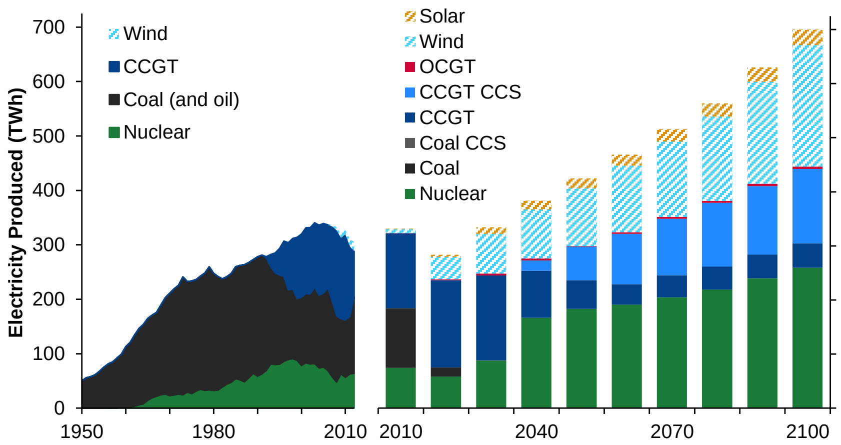
2010	2020s	2050s	2100s
-27%	-65%	-90%	-89%

Maximum carbon price: £180 / T
Cumulative emissions to 2100: 3.5 GT









C.1.5 8% WACC

With the cost of capital reduced to 8%, more investment in nuclear takes place in the 2030s, with some moving forwards from the 2040s, and a slightly higher overall capacity installed by the 2050s. Consequently, less fossil capacity is installed in the 2020s and 2030s than in C.1.4, although slightly more is in the 2040s.

The lower cost of generation again raises welfare, reduces wholesale prices, reduces carbon emissions, and the carbon price needed to meet emissions targets.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	20.3	10.1	4
Fossil:	3.9	18.2	15.7	7.1

NPV of public support:	£0.0	billion
NPV of total welfare:	£43.3	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£67.74	/ MWh
Including support:	£67.74	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.9	billion
Fossil:	£0.6	billion

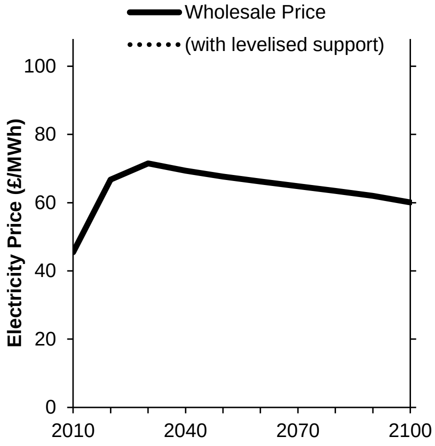
NPV of profits for 2020s nuclear:	-£0.7	billion

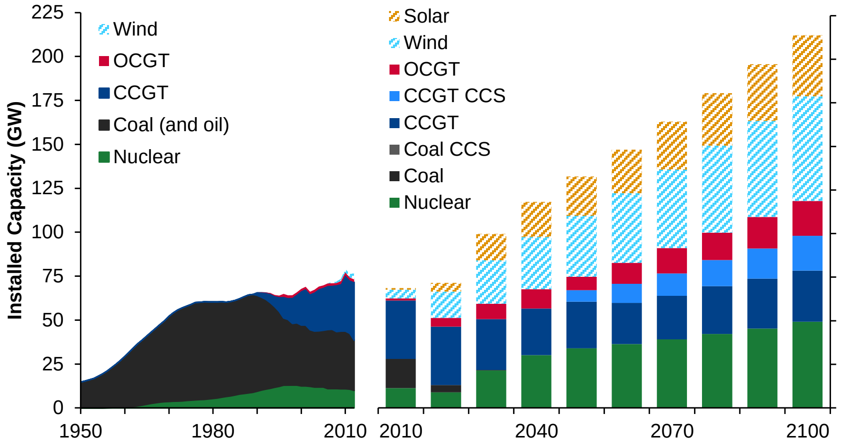
7.8% discount rate, 3.2 GW station

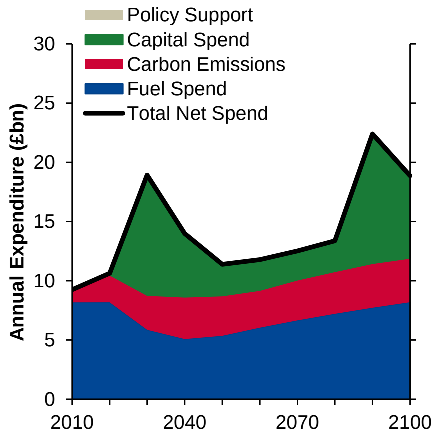
Carbon emissions (relative to 1990) in:

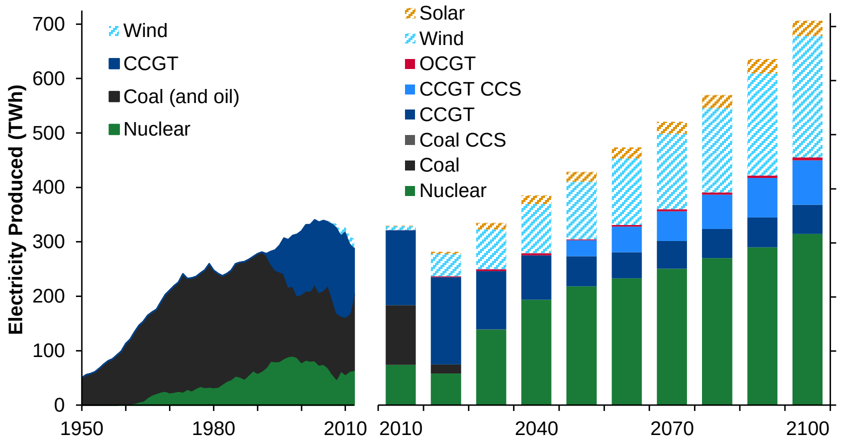
2010	2020s	2050s	2100s
-27%	-65%	-90%	-89%

Maximum carbon price:	£166	/ T
Cumulative emissions to 2100:	3.4	GT









C.1.6 7% WACC

Reducing the cost of capital for nuclear down to 7% is sufficient to make nuclear have a lower levelised cost than CCGT in the 2020s. 4 GW of nuclear is therefore built in place of the 4 GW of fossil capacity in the 2020s, leading to a slightly lower increase in wholesale prices in this decade.

Slightly more nuclear capacity is built in the 2030s and 2050s than in C.1.5, and slightly less in the 2040s; with the inverse pattern true for investment in fossil capacity.

With only 4 GW of nuclear capacity built in the 2020s, existing stations are still able to return a profit, although slightly less than when 4 GW of fossil is built (C.1.1 to C.1.5) due to the lower 2020s wholesale price.

As we assume the low cost of capital continues throughout the century, this policy eventually delivers more nuclear capacity than the policies with aid (C.2.1 onwards), despite less being built in the 2020s.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	4	21.5	8.7	5.7
Fossil:	0	16.7	17.1	1.8

NPV of public support:	£0.0	billion
NPV of total welfare:	£46.4	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£61.25	/ MWh
Including support:	£61.25	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.8	billion
Fossil:	£0.1	billion

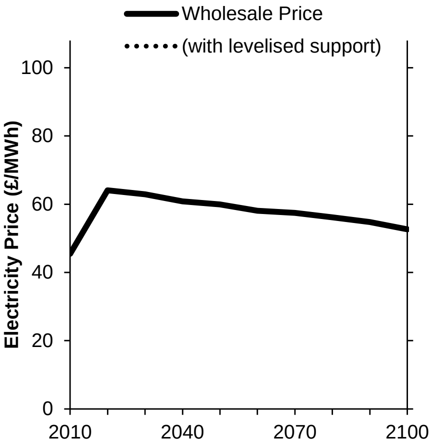
NPV of profits for 2020s nuclear:	£0.1	billion

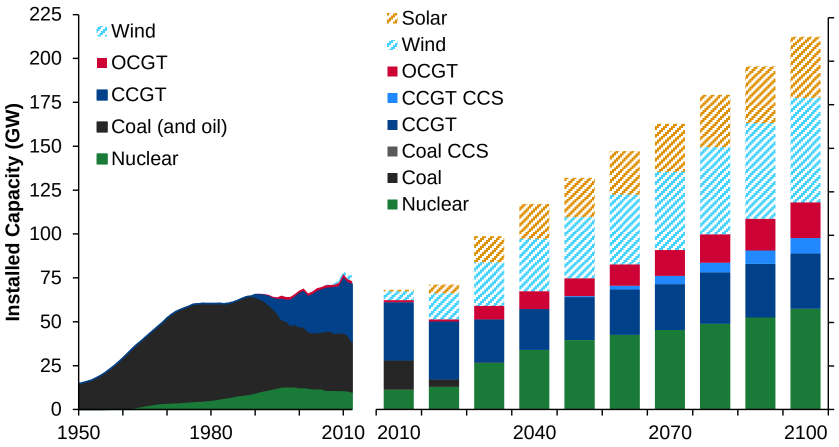
6.6% discount rate, 3.2 GW station

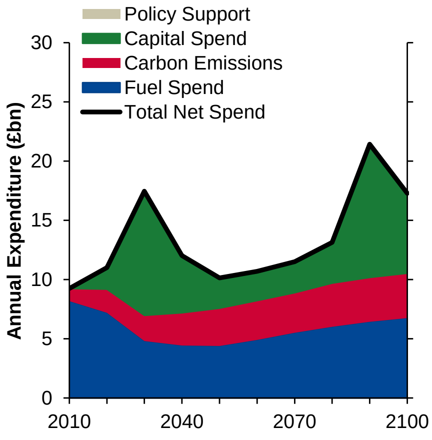
Carbon emissions (relative to 1990) in:

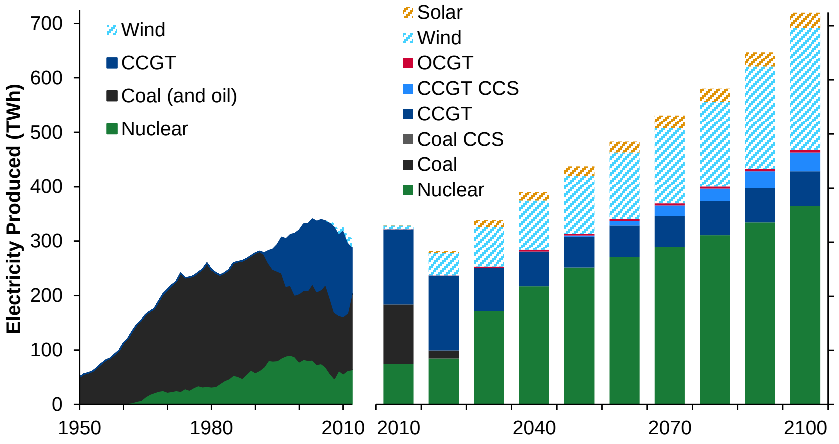
2010	2020s	2050s	2100s
-27%	-70%	-90%	-88%

Maximum carbon price:	£157	/ T
Cumulative emissions to 2100:	3.2	GT









C.2 Comparison of Policies

Four potential policies were investigated in this report:

- ***CfD35*** – a contract for differences for nuclear stations lasting 35 years;
- ***FiP35*** – a feed-in premium paid to nuclear stations for 35 years;
- ***CfDall*** – a contract for differences for all stations lasting 35 years;
- ***CfD60*** – a contract for differences for nuclear stations lasting 60 years, with a lower strike price paid inover the last 25 years of the contract.

These were tested in the model with the WACC for nuclear stations ranging from 6% to 12%. The results from every model run are presented below, although not all of them are discussed in the main report.

C.2.1: CfD35, 10% WACC
C.2.2: CfD35, 12% WACC
C.2.3: CfD35, 9% WACC
C.2.4: CfD35, 8% WACC
C.2.5: CfD35, 6% WACC

C.2.6: FiP35, 10% WACC
C.2.7: FiP35, 8% WACC
C.2.8: FiP35, 6% WACC

C.2.9: CfDall, 10% WACC

C.2.10: CfD60, 9% WACC
C.2.11: CfD60, 8% WACC
C.2.12: CfD60, 6% WACC

The CfD35 scenario was also calculated with an 11% WACC, but did not result in any supported capacity being built, as the NPV of lifetime profits for 2020s nuclear was –£1.3 billion. This scenario was therefore identical to the no aid scenario with an 11% WACC (C.1.2).

The CfD60 scenario was also calculated with a 10% WACC, but this did not result in any supported capacity being built, as the NPV of lifetime profits for 2020s nuclear was –£70 million. This scenario was therefore identical to the no aid scenario with a 10% WACC (C.1.3).

C.2.1 CfD35, 10% WACC

This is our central case for modelling the policy intervention proposed by the UK government. Up to 15 GW of nuclear stations are offered 35-year CfDs at a price of £89.50 per MWh.

This price is sufficiently attractive for the full 15 GW of nuclear plant to be built – a two-reactor station (like Hinkley Point C) earns profits of £200 million (over and above its return on capital) over its lifetime. No fossil-fuelled stations are built in the 2020s, then the 2030s see a large amount of gas-fired plant, and the succeeding decades see a mix of fossil (with and without) and nuclear stations being built.

The large amount of nuclear capacity depresses the earnings of existing plant in the 2020s. The whole-century average wholesale price is lower than in the no aid case (C.1.1), even after including the support payments to nuclear generators. The carbon price is lower than in C.1.1, and so are cumulative emissions.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	0	3	2.2
Fossil:	0	27.1	22	8.3

NPV of public support:	£3.5	billion
NPV of total welfare:	£36.2	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£71.77	/ MWh
Including support:	£76.80	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.0	billion
Fossil:	-£1.5	billion

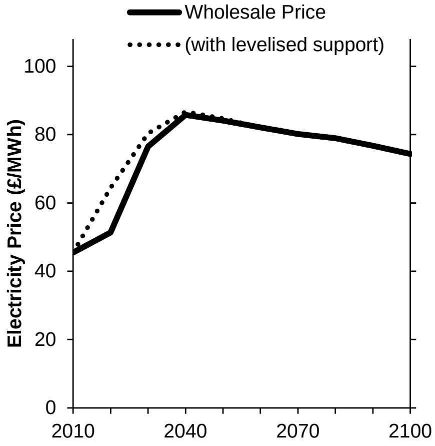
NPV of profits for 2020s nuclear:	£0.2	billion

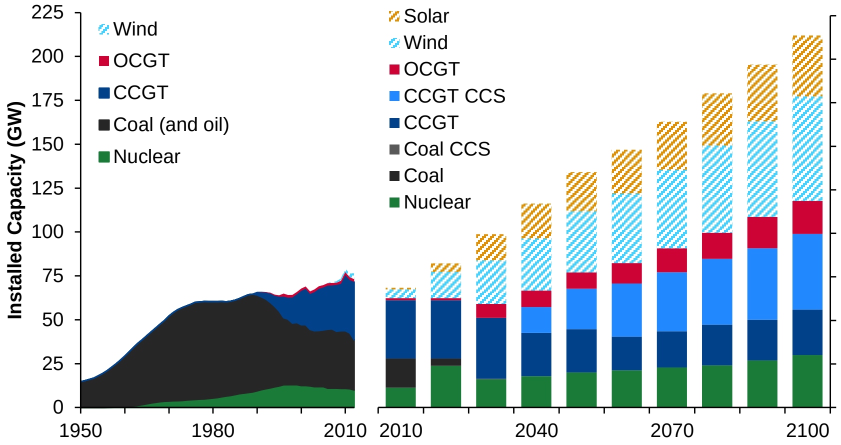
10.3% discount rate, 3.2 GW station

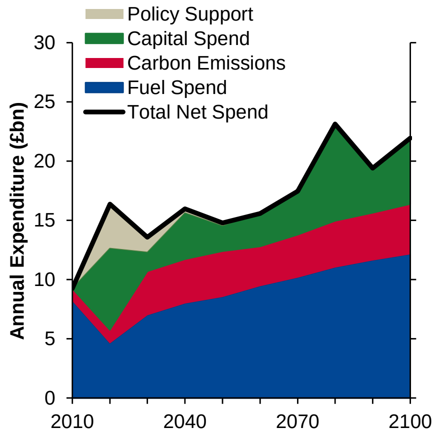
Carbon emissions (relative to 1990) in:

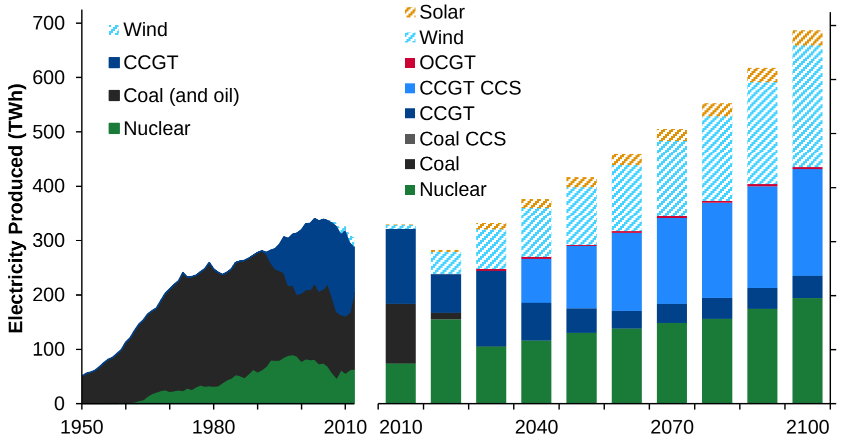
2010	2020s	2050s	2100s
-27%	-83%	-90%	-89%

Maximum carbon price:	£190	/ T
Cumulative emissions to 2100:	3.0	GT









C.2.2 CfD35, 12% WACC

If the CfD could not deliver a significant reduction in the cost of capital for nuclear stations (e.g. if it came with no guarantee), and this cost remained at 12%, no nuclear station would be built with the support, or later on during the century.

The results for this scenario are therefore the same as they would be for the free market, and lie between the no aid cases with a WACC of 13% (C.1.1) and 11% (C.1.2).

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0	0	0
Fossil:	4	37.1	30	17.6

NPV of public support:	£0.0	billion
NPV of total welfare:	£36.8	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£84.52	/ MWh
Including support:	£84.52	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.9	billion
Fossil:	£0.6	billion

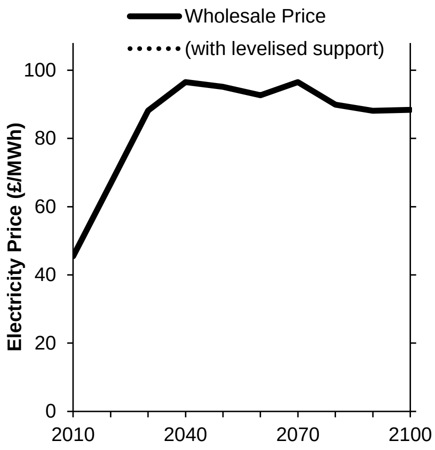
NPV of profits for 2020s nuclear:	-£2.6	billion

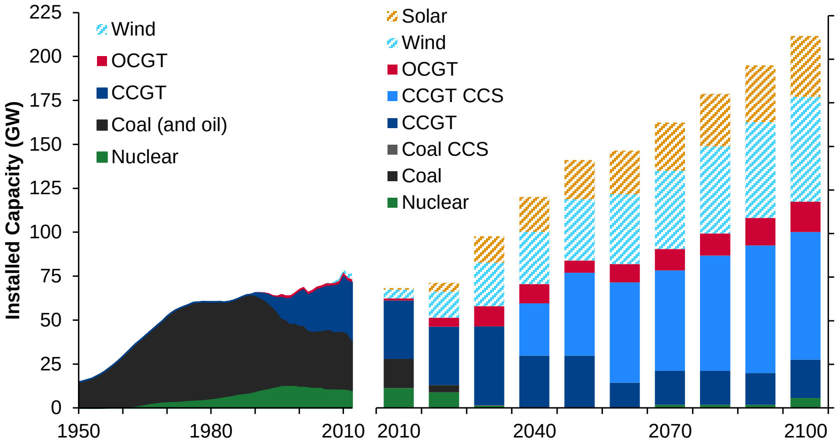
12.7% discount rate, 3.2 GW station

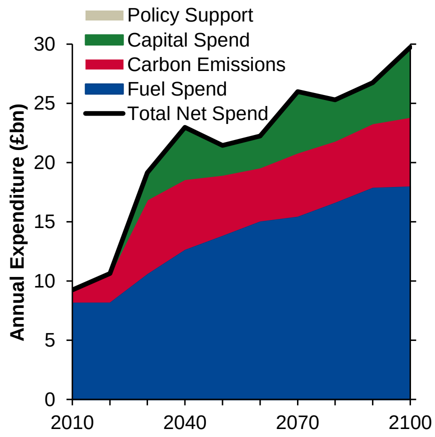
Carbon emissions (relative to 1990) in:

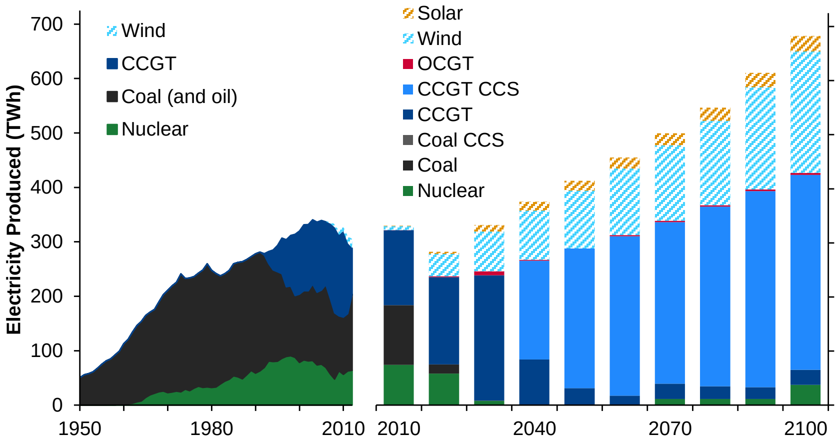
2010	2020s	2050s	2100s
-27%	-65%	-90%	-88%

Maximum carbon price:	£250	/ T
Cumulative emissions to 2100:	3.9	GT









C.2.3 CfD35, 9% WACC

A CfD which reduces the cost of capital for nuclear to 9% delivers very similar investment to our central CfD case (C.2.1) in the 2020s and 2030s. With this lower cost of capital continuing into future decades, more nuclear capacity is built than in C.2.1 after the 2040s.

The NPV of public support is slightly higher than would be required by a CfD at 10% (C.2.1), as wholesale prices are reduced after the 2040s, meaning the strike price is unchanged. Unlike the CfD with a 10% cost of capital, wholesale prices including support are higher than in the market with no aid and the same WACC (C.1.4).

Significant super-normal profits are made by supported nuclear stations due to the lower cost of capital, increasing from £0.2 to £2.1 billion compared to C.2.1.

The additional nuclear capacity installed in the 2040s means a slightly lower carbon price is required to meet emissions targets than in C.2.1, although cumulative emissions are similar.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	0	10.8	2.4
Fossil:	0	27.2	14.1	7.9

NPV of public support:	£3.8	billion
NPV of total welfare:	£38.9	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£68.06	/ MWh
Including support:	£73.48	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.0	billion
Fossil:	-£1.5	billion

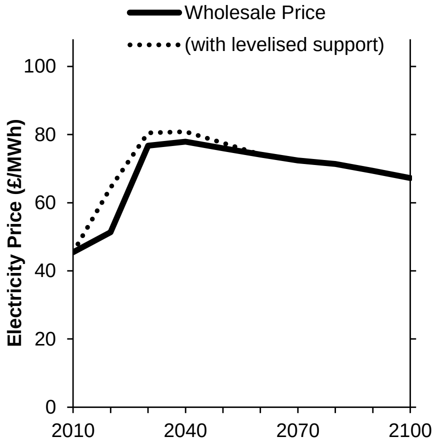
NPV of profits for 2020s nuclear:	£2.1	billion

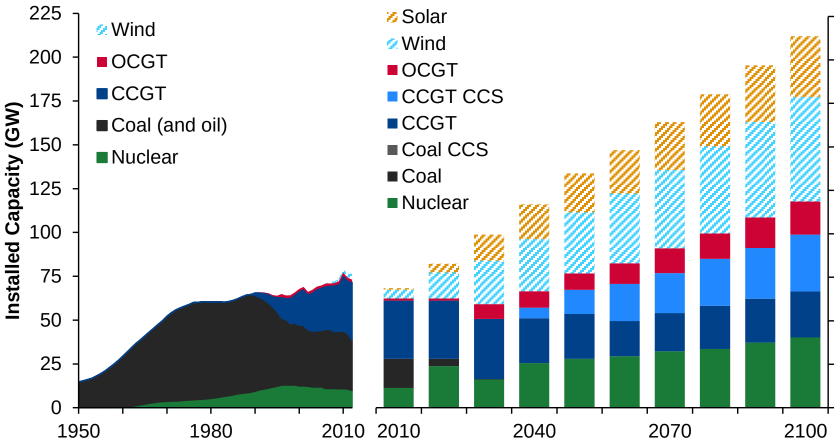
9.1% discount rate, 3.2 GW station

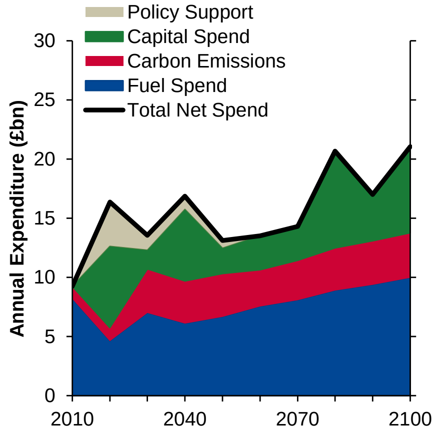
Carbon emissions (relative to 1990) in:

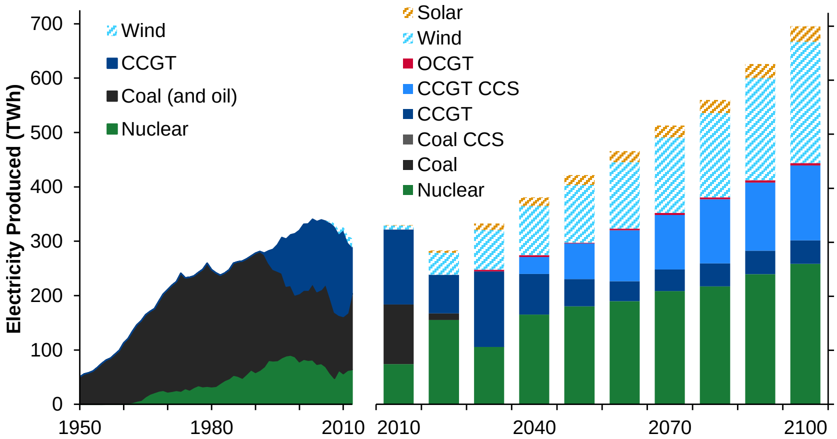
2010	2020s	2050s	2100s
-27%	-83%	-90%	-90%

Maximum carbon price:	£182	/ T
Cumulative emissions to 2100:	3.0	GT









C.2.4 CfD35, 8% WACC

Reducing the cost of capital further results in nuclear being built in all decades, and by the 2030s, the investment in both nuclear and fossil is the same as in the market scenario with an 8% WACC (C.1.5).

Wholesale prices are lower than in C.1.5, but with support included they are around £1.50/MWh higher.

The NPV of public support increases further (as strike prices remain at £89.50/MWh), as do the super-normal profits made by supported stations.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	5.4	10.9	3.6
Fossil:	0	21.8	14.4	6.2

NPV of public support: £4.5 billion
NPV of total welfare: £42.0 billion
3.5% discount rate, measured from 2020

Average wholesale price: £62.94 / MWh
Including support: £69.12 / MWh

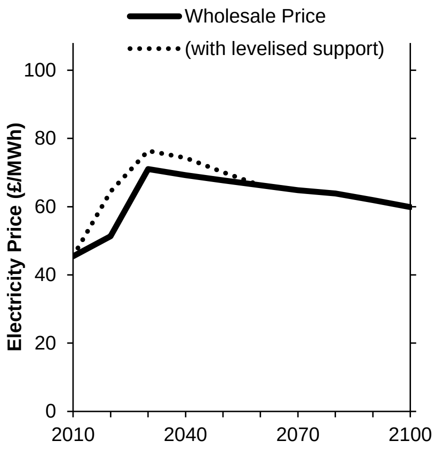
Annual profits of existing stations in the 2020s:
Nuclear: £2.0 billion
Fossil: -£1.5 billion

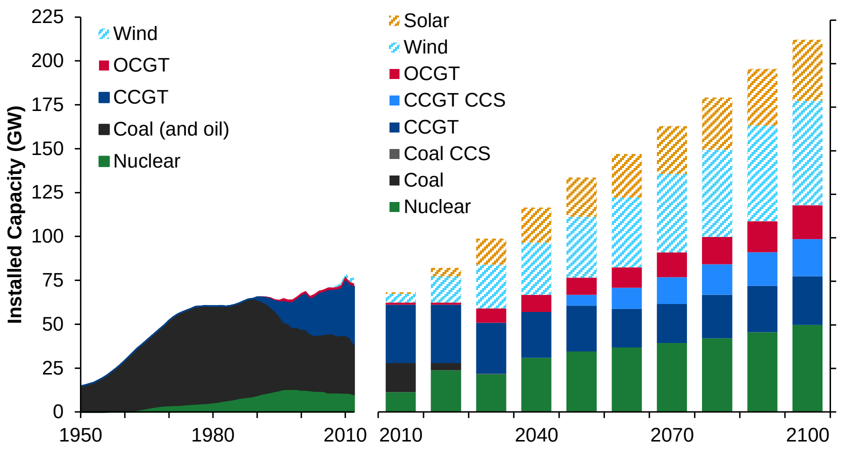
NPV of profits for 2020s nuclear: £4.5 billion
7.8% discount rate, 3.2 GW station

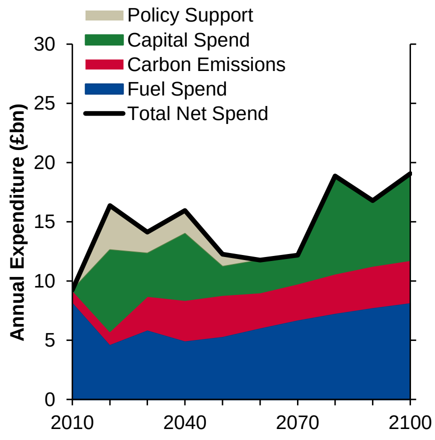
Carbon emissions (relative to 1990) in:

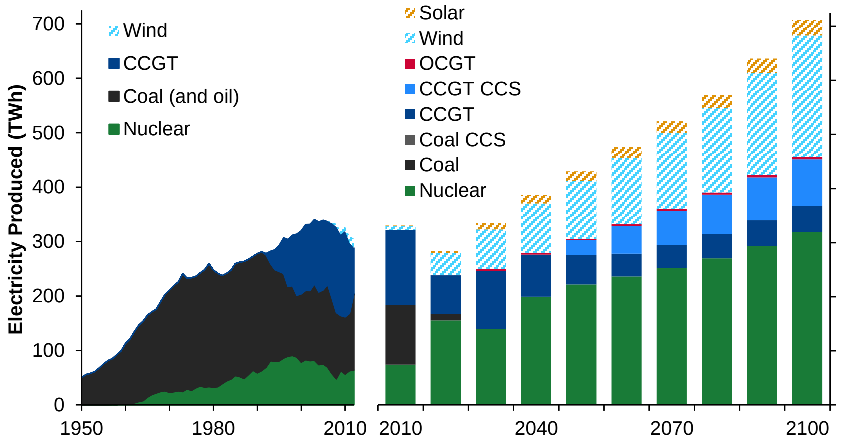
2010	2020s	2050s	2100s
-27%	-83%	-90%	-90%

Maximum carbon price: £175 / T
Cumulative emissions to 2100: 2.9 GT









C.2.5 CfD35, 6% WACC

Reducing the cost of capital further magnifies the effects explained in C.2.3 and C.2.4.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	15.2	7.2	2.7
Fossil:	0	12	18.6	5

NPV of public support: **£6.1** billion
NPV of total welfare: **£50.4** billion
3.5% discount rate, measured from 2020

Average wholesale price: **£51.59** / MWh
Including support: **£59.54** / MWh

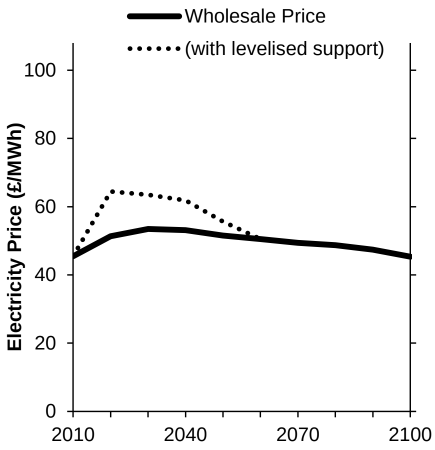
Annual profits of existing stations in the 2020s:
Nuclear: **£2.0** billion
Fossil: **-£1.5** billion

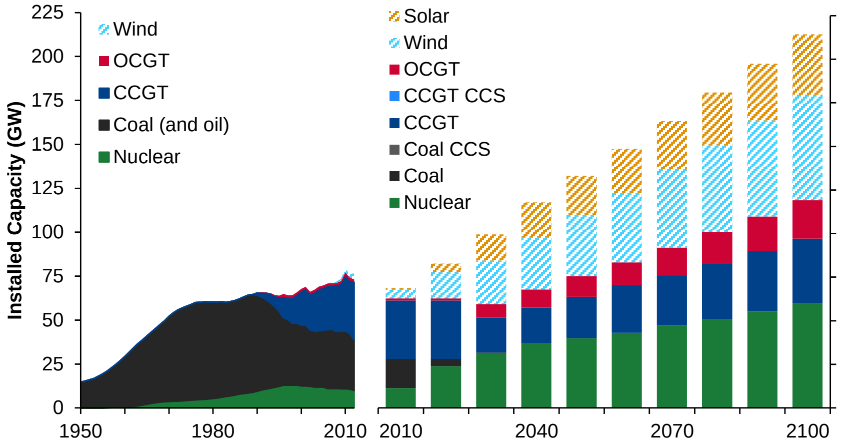
NPV of profits for 2020s nuclear: **£11.0** billion
5.4% discount rate, 3.2 GW station

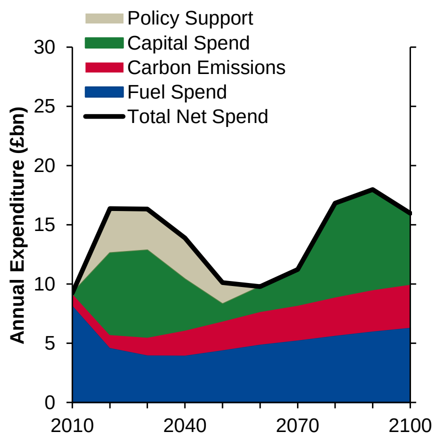
Carbon emissions (relative to 1990) in:

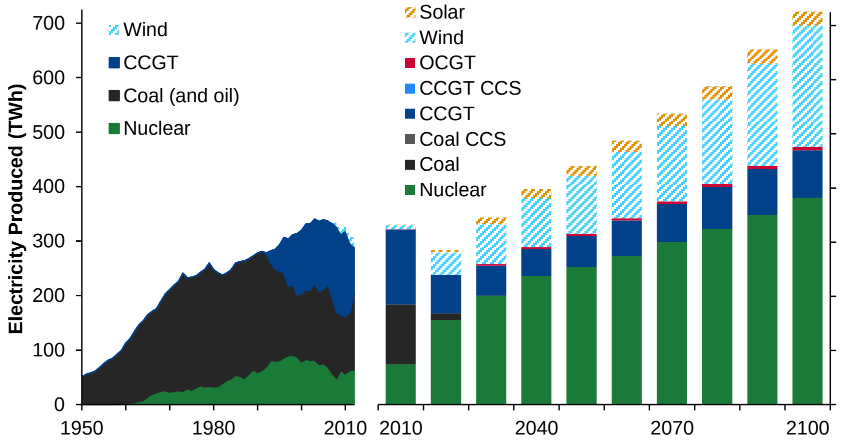
2010	2020s	2050s	2100s
-27%	-83%	-90%	-85%

Maximum carbon price: **£119** / T
Cumulative emissions to 2100: **3.0** GT









C.2.6 FiP35, 10% WACC

This case adds a Feed-in Premium of £32.10 to the market price received by nuclear stations built in the 2020s for their first 35 years of operation. The premium is calculated to give the same NPV of public support as C.2.1.

Slightly less nuclear capacity is built than with a CfD. Its presence depresses the market price in the 2020s (as in C.2.1) but since that price now affects the nuclear stations' revenues, this feeds back to the level of capacity built. More fossil capacity is built in the 2030s than in C.2.1, but by the end of the 2040s, the total installed capacities of both nuclear and fossil are the same in both cases.

Wholesale prices are £2/MWh higher than in C.2.1, but £6/MWh lower than with no government intervention (C.1.1).

Existing stations' profits in the 2020s are slightly less affected than in C.2.1. The carbon price required to hit the 2050 target is the same as in C.2.1, but cumulative emissions are slightly higher.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	9.9	0	8.1	2.3
Fossil:	0	32.3	16.9	8.4

NPV of public support: £3.5 billion
NPV of total welfare: £37.3 billion
3.5% discount rate, measured from 2020

Average wholesale price: £74.22 / MWh
Including support: £78.88 / MWh

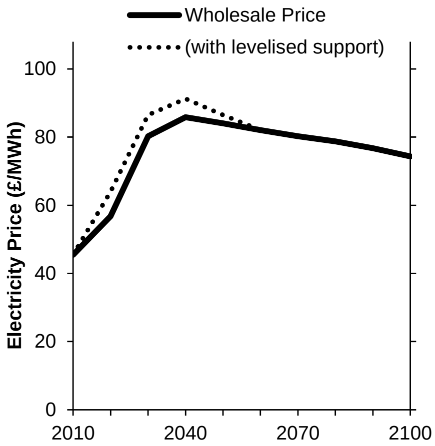
Annual profits of existing stations in the 2020s:
Nuclear: £2.3 billion
Fossil: -£1.4 billion

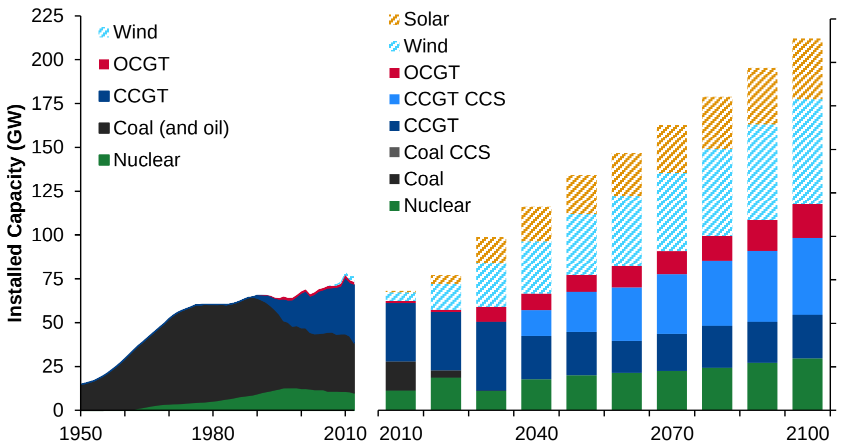
NPV of profits for 2020s nuclear: £1.8 billion
10.3% discount rate, 3.2 GW station

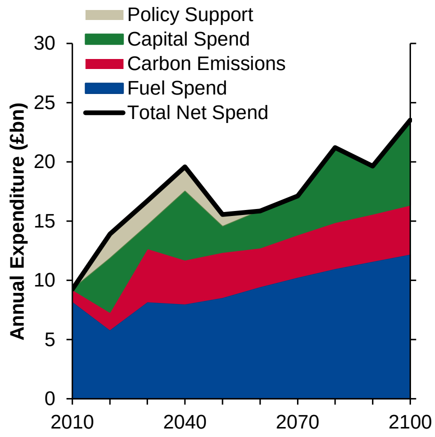
Carbon emissions (relative to 1990) in:

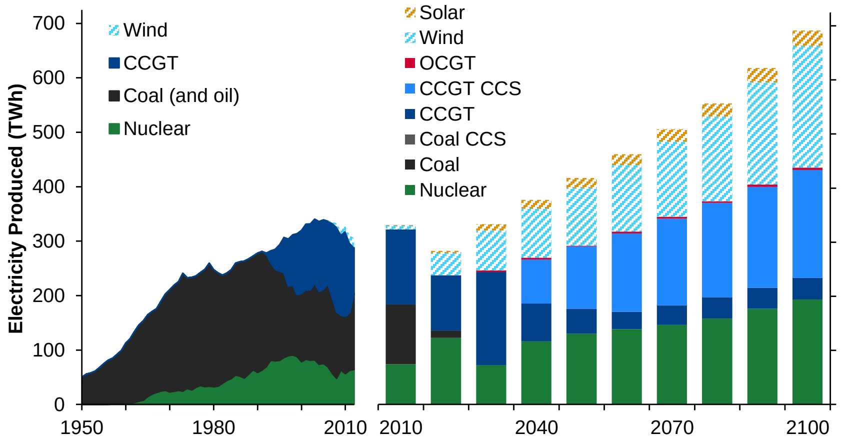
2010	2020s	2050s	2100s
-27%	-77%	-90%	-89%

Maximum carbon price: £190 / T
Cumulative emissions to 2100: 3.3 GT









C.2.7 FiP35, 8% WACC

With the cost of capital for nuclear reduced to 8%, this case adds a premium of £27.50/MWh to the market price received by nuclear stations, to give the same NPV of support as with a CfD delivering an 8% cost of capital (C.2.4). This premium is lower than in C.2.6 as more nuclear capacity gets built.

The full 15 GW of supported nuclear capacity is built in the 2020s, followed by higher levels than in C.2.6 in subsequent decades as the cost of capital remains lower.

Market prices are depressed significantly by this extra capacity, taking the same path as in the CfD with an 8% WACC (C.2.4). Total welfare and the level of public support are the same as with the CfD (C.2.4), however market prices including support are slightly lower, as are the profits for supported stations.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	5.4	10.9	3.6
Fossil:	0	21.8	14.3	6.2

NPV of public support:	£4.5	billion
NPV of total welfare:	£42.0	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£62.94	/ MWh
Including support:	£68.91	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.0	billion
Fossil:	-£1.5	billion

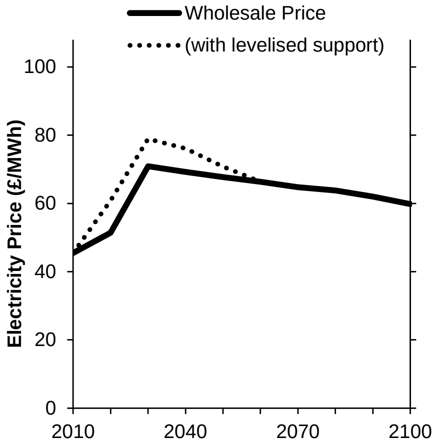
NPV of profits for 2020s nuclear:	£3.8	billion

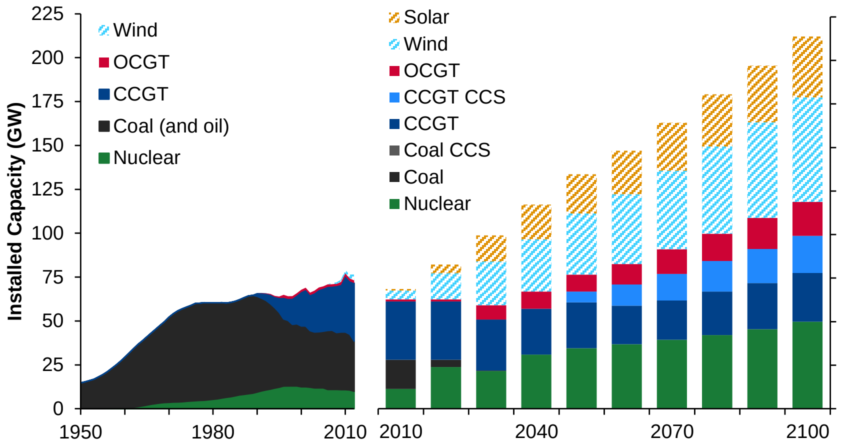
7.8% discount rate, 3.2 GW station

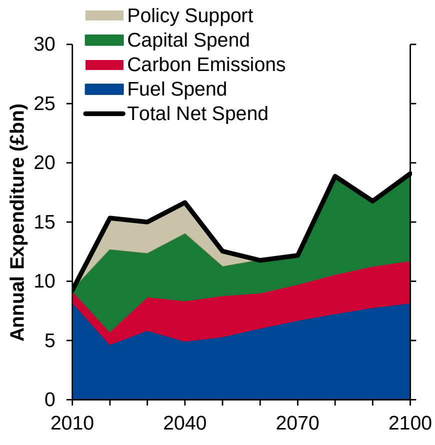
Carbon emissions (relative to 1990) in:

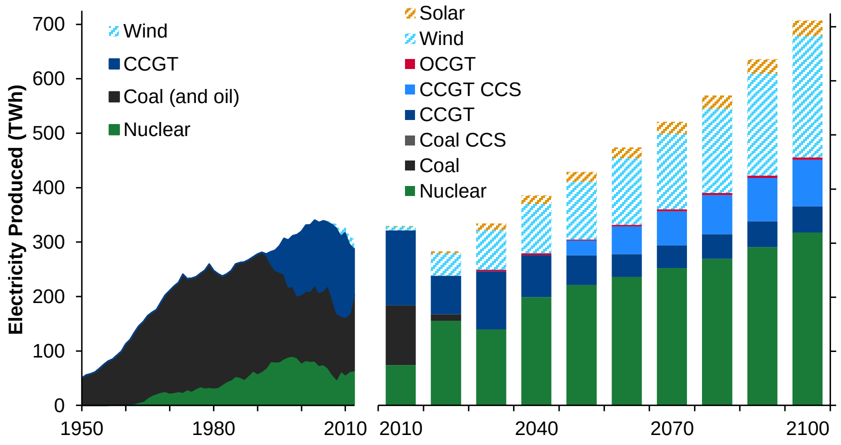
2010	2020s	2050s	2100s
-27%	-83%	-90%	-90%

Maximum carbon price:	£175	/ T
Cumulative emissions to 2100:	2.9	GT









C.2.8 FiP35, 6% WACC

With the cost of capital for nuclear reduced further to 6%, this case increases the premium for nuclear stations to £37.10/MWh, to give the same NPV of support as C.2.5 (the CfD with a 6% cost of capital).

The results are almost identical to C.2.5, except for a slight shift of support payments from the 2020s to the 2030s.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	15.2	7.2	2.7
Fossil:	0	12	18.6	5

NPV of public support:	£6.1	billion
NPV of total welfare:	£50.4	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£51.63	/ MWh
Including support:	£59.55	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.0	billion
Fossil:	-£1.5	billion

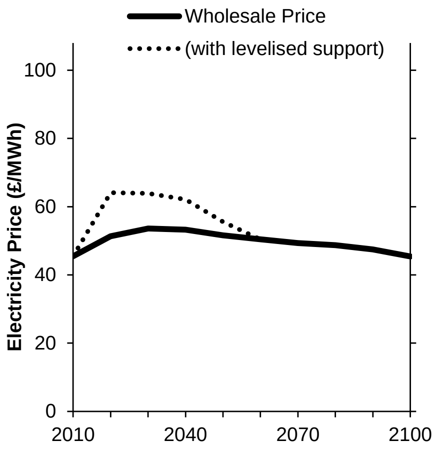
NPV of profits for 2020s nuclear:	£10.9	billion

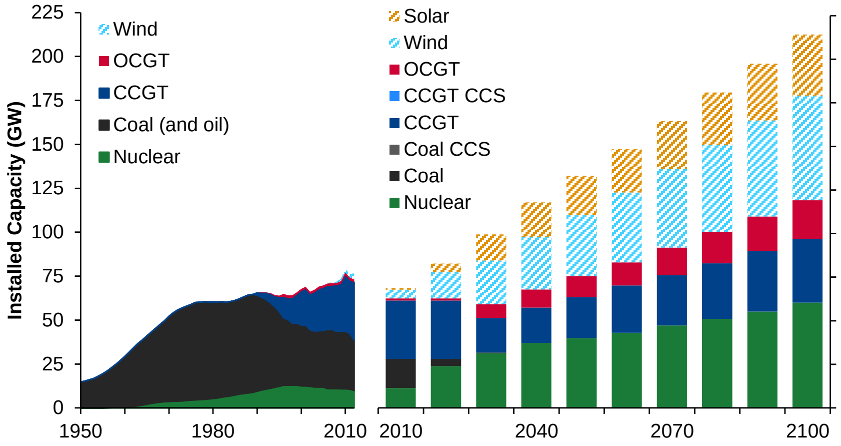
5.4% discount rate, 3.2 GW station

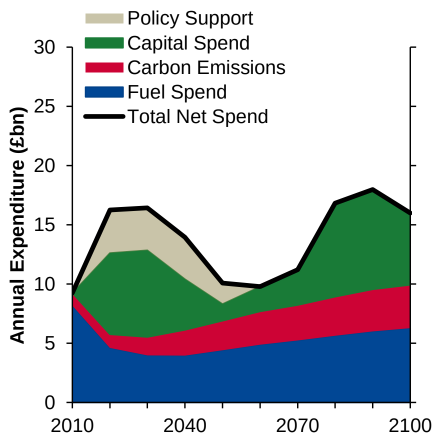
Carbon emissions (relative to 1990) in:

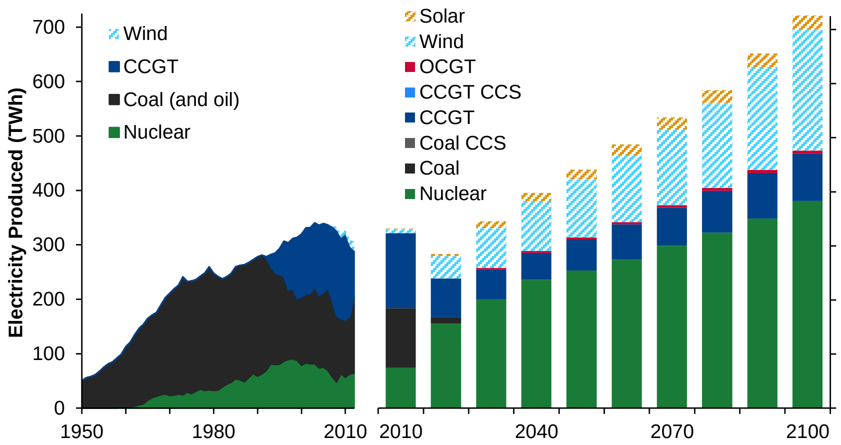
2010	2020s	2050s	2100s
-27%	-83%	-90%	-85%

Maximum carbon price:	£119	/ T
Cumulative emissions to 2100:	3.0	GT









C.2.9 CfDall, 10% WACC

This case offers all capacity built in the 2020s a CfD, with each technology's strike price set £26.70 above its levelised cost. Again, this value is set to give the same NPV of public support as C.2.1.

Only CCGT stations are built in the 2030s, up to the maximum of 15 GW. By the 2040s, the amount of nuclear capacity is similar to the level with a CfD for nuclear plant alone, but there is slightly more fossil capacity.

Electricity prices are higher than with the nuclear-only CfD, both with and without the support payments. These higher prices are concentrated in off-peak periods, as CCGT (with higher fuel costs than nuclear) provides much of the baseload supply. Higher off-peak prices mean existing nuclear stations make greater profits than in C.2.1, but existing fossil stations are equally unprofitable.

The carbon price needed to cut emissions in 2050 is relatively low, but relatively high emissions in the 2020s produce a larger cumulative amount over the century.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0	16.9	2.8
Fossil:	15	27.2	9	19.5

NPV of public support:	£3.5	billion
NPV of total welfare:	£38.9	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£74.93	/ MWh
Including support:	£79.81	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.4	billion
Fossil:	-£1.5	billion

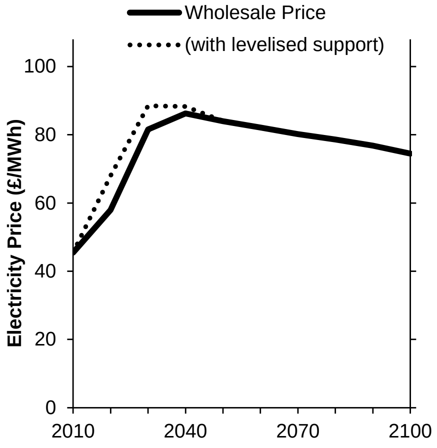
NPV of profits for 2020s nuclear:	-£0.3	billion

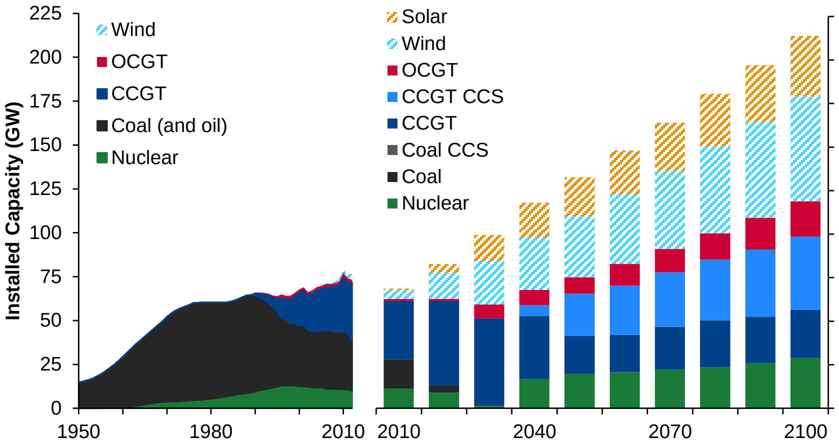
10.3% discount rate, 3.2 GW station

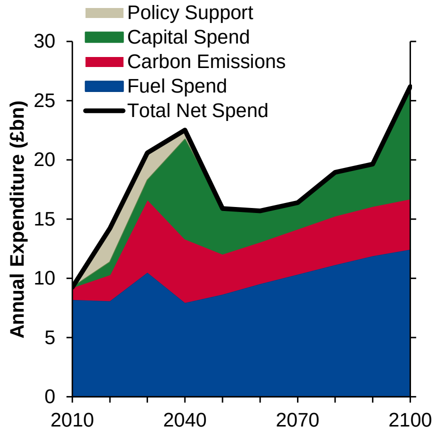
Carbon emissions (relative to 1990) in:

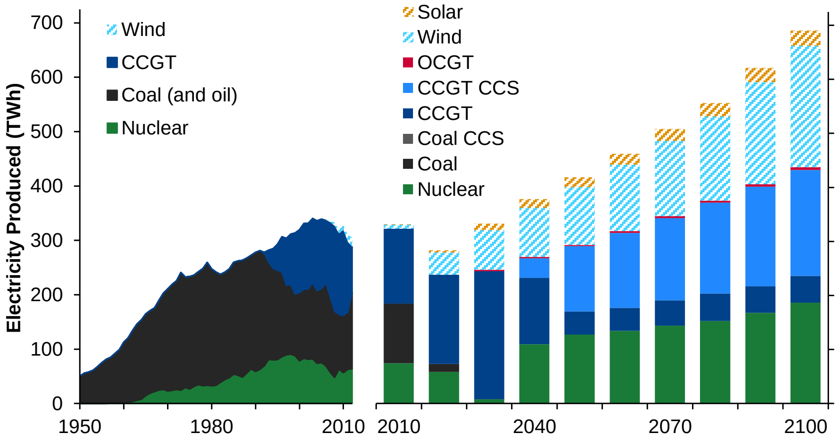
2010	2020s	2050s	2100s
-27%	-66%	-90%	-88%

Maximum carbon price:	£171	/ T
Cumulative emissions to 2100:	4.0	GT









C.2.10 CfD60, 9% WACC

This imposes a 60-year CfD for 2020s nuclear stations, with 35 years at a strike price of £89.50 per MWh as in C.2.1, followed by 25 years at £44.75/MWh. This second strike price is around £30/MWh below the wholesale prices of the 2060s and 2070s, and so the nuclear stations (which have written down their capital by this point) return around £3 billion a year to consumers. This is seen with the net annual spend (black line, bottom left figure) falling below fuel + carbon + capital.

The policy still proves sufficiently attractive for the full 15 GW of nuclear stations to be built in the 2020s. The NPV of their profits (after the return on capital) is higher than the government's proposed CfD (C.2.1) due to the lower assumed cost of capital. The NPV of public support (at the public discount rate) falls to £2.6 billion, from £3.5 billion in C.2.1.

The average wholesale market price is lower than in C.2.1 and significantly lower than with no intervention (C.1.1). The wholesale price including support is similar to the market with a 9% WACC (C.1.4), while the carbon price is similar, and total emissions are lower.

GW of capacity built in:

	2020s	2030s	2040s	205
Nuclear:	15	0	10.8	2
Fossil:	0	27.2	14	

NPV of public support:	£2.6	billion
NPV of total welfare:	£38.9	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£68.06	/ MWh
Including support:	£72.35	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£2.0	billion
Fossil:	-£1.5	billion

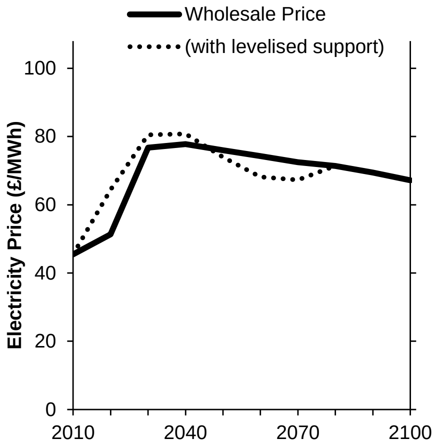
NPV of profits for 2020s nuclear:	£1.8	billion

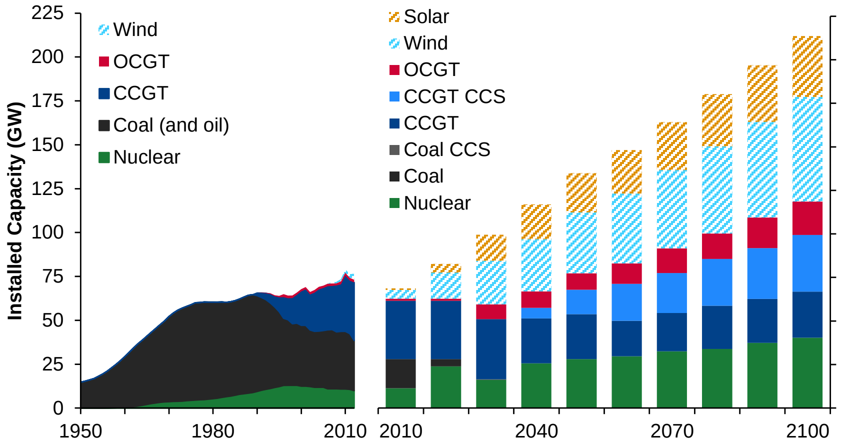
9.1% discount rate, 3.2 GW station

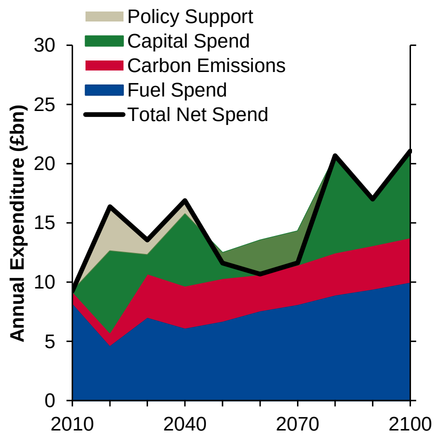
Carbon emissions (relative to 1990) in:

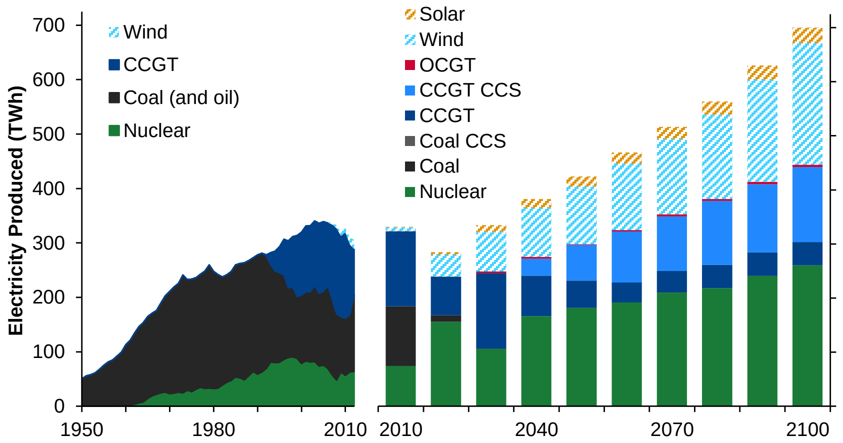
2010	2020s	2050s	210
-27%	-83%	-90%	-90

Maximum carbon price:	£182	/ T
Cumulative emissions to 2100:	3.0	GT









C.2.11 CfD60, 8% WACC

If the 60-year CfD reduced the cost of capital further to 8%, the second phase still returns around £2 billion per year to consumers in the 2060s and 2070s. Wholesale prices are the same as with the CfD35 and an 8% WACC (C.2.4), but prices including support are around £1/MWh lower on average due to this transfer.

The NPV of public support is £0.9 billion lower than in C.2.4. In other respects, the two scenarios give the same results.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	5.4	10.9	3.7
Fossil:	0	21.8	14.4	6.2

NPV of public support: £3.6 billion
NPV of total welfare: £42.0 billion
3.5% discount rate, measured from 2020

Average wholesale price: £62.93 / MWh
Including support: £68.30 / MWh

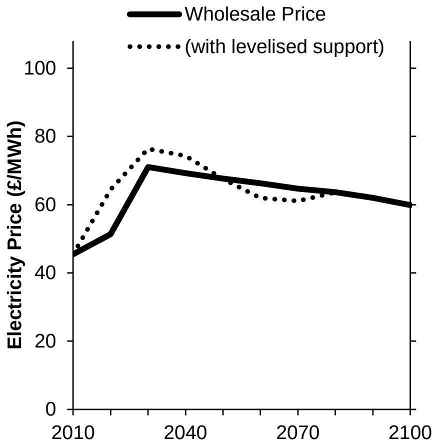
Annual profits of existing stations in the 2020s:
Nuclear: £2.0 billion
Fossil: -£1.5 billion

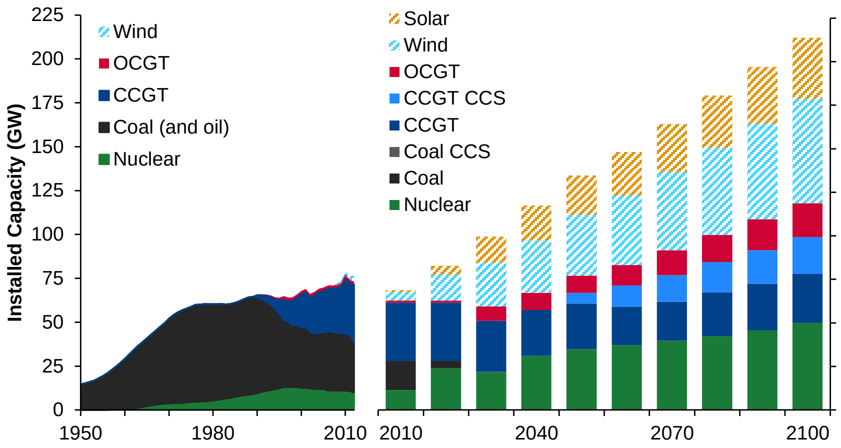
NPV of profits for 2020s nuclear: £4.1 billion
7.8% discount rate, 3.2 GW station

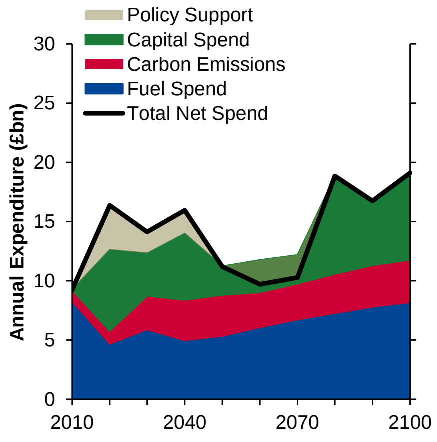
Carbon emissions (relative to 1990) in:

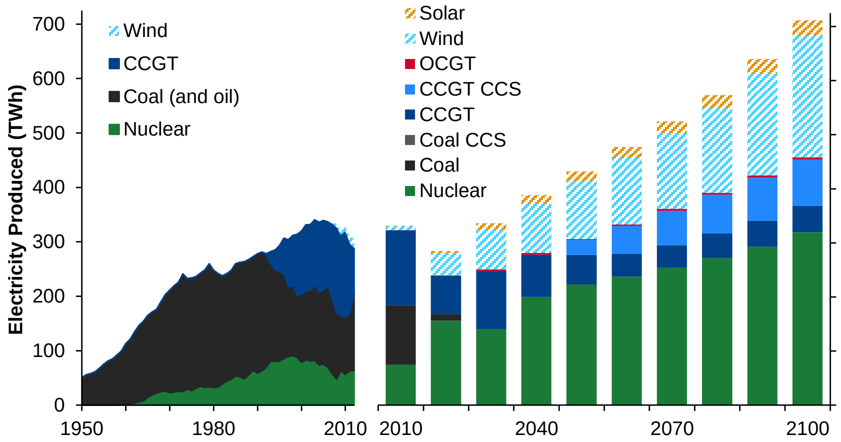
2010	2020s	2050s	2100s
-27%	-83%	-90%	-90%

Maximum carbon price: £175 / T
Cumulative emissions to 2100: 2.9 GT









C.2.12 CfD60, 6% WACC

If the 60-year CfD reduced the cost of capital further to 6%, the profit-sharing feature of the support becomes ineffective with the second-phase strike price held at £44.75. Market prices fall to almost this level by the 2050s, and so almost no revenue is transferred back to consumers. Consequently, the NPV of profits for supported stations are almost the same as for the CfD35 with a 6% WACC (C.2.5).

All other aspects of this scenario are unchanged from C.2.5.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	15.2	7.2	2.7
Fossil:	0	12	18.6	5

NPV of public support: £5.8 billion
NPV of total welfare: £50.4 billion
3.5% discount rate, measured from 2020

Average wholesale price: £51.60 / MWh
Including support: £59.33 / MWh

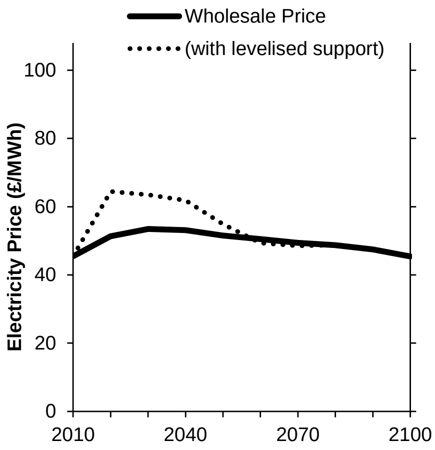
Annual profits of existing stations in the 2020s:
Nuclear: £2.0 billion
Fossil: -£1.5 billion

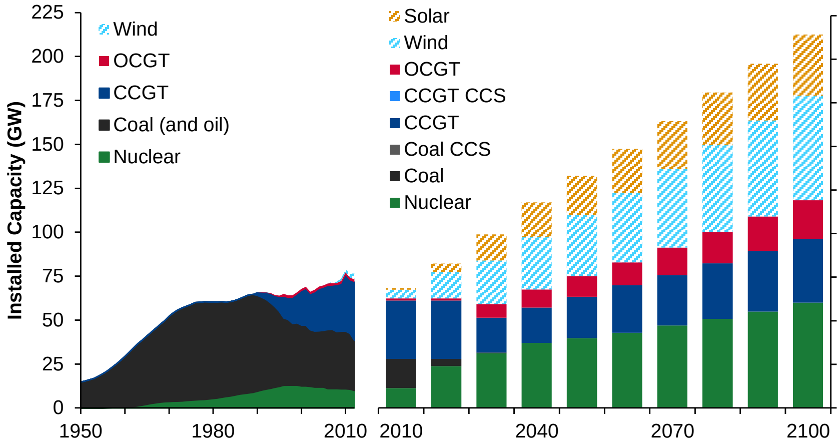
NPV of profits for 2020s nuclear: £10.7 billion
5.4% discount rate, 3.2 GW station

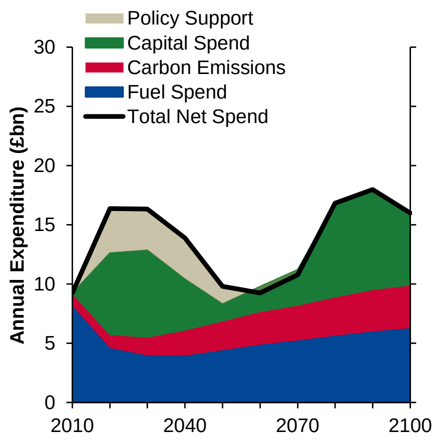
Carbon emissions (relative to 1990) in:

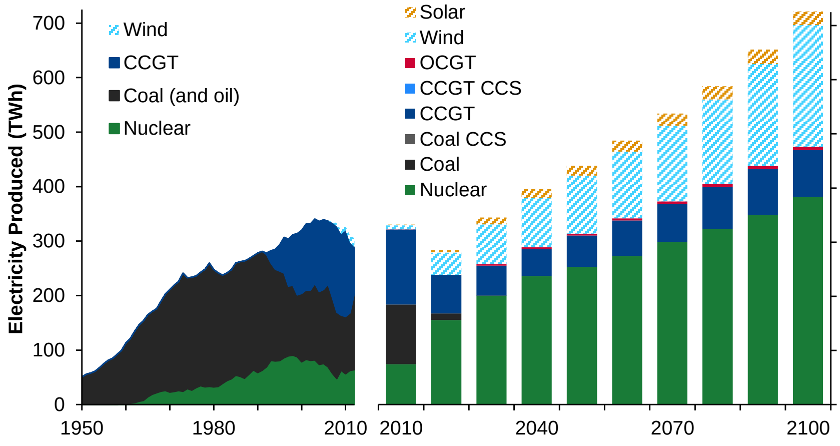
2010	2020s	2050s	2100s
-27%	-83%	-90%	-85%

Maximum carbon price: £119 / T
Cumulative emissions to 2100: 3.0 GT









C.3 Sensitivity to Fuel Prices

Our two main scenarios were run with high and low predictions for fuel prices:

C.3.1: No Aid, 13% WACC, Low Fuel
C.3.2: No Aid, 13% WACC, High Fuel
C.3.3: CfD35, 10% WACC, Low Fuel
C.3.4: CfD35, 10% WACC, High Fuel

C.3.1 No Aid, 13% WACC, Low Fuel

With low fuel prices, a high cost of capital for nuclear stations and no government intervention in the market, no nuclear stations are built at any time. Decarbonisation is achieved through a very high carbon price which makes it economic to fit CCS to CCGT stations. Even so, we have higher emissions in this scenario than in any other main scenario.

This scenario has wholesale prices £20/MWh than the no aid scenario with central fuel prices (C.1.1). Existing nuclear stations accordingly make much lower profits in the 2020s. With lower prices, electricity demand is slightly higher and slightly more capacity is built in the 2020s and 2050s.

The NPV of welfare is £12.3 billion higher in this case than with the central fuel prices, reflecting the lower cost of producing electricity.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0	0	0
Fossil:	4.4	37.1	30	18

NPV of public support: £0.0 billion
NPV of total welfare: £49.1 billion
3.5% discount rate, measured from 2020

Average wholesale price: £64.55 / MWh
Including support: £64.55 / MWh

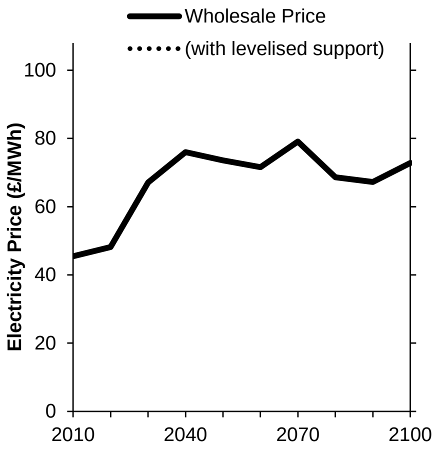
Annual profits of existing stations in the 2020s:
Nuclear: £1.9 billion
Fossil: £0.6 billion

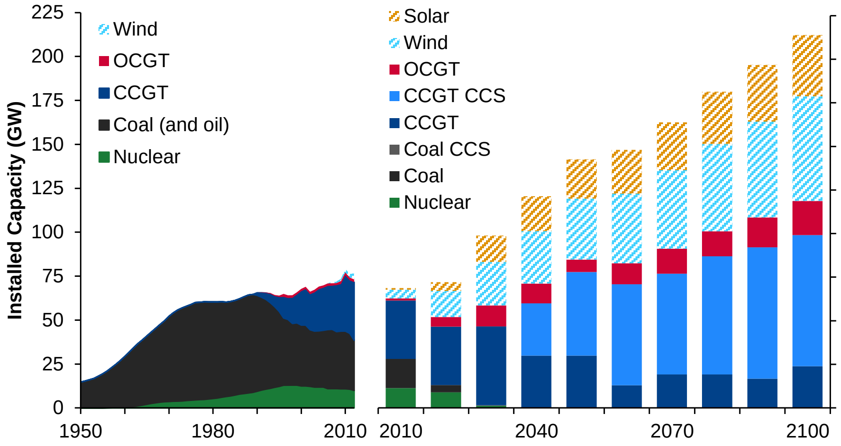
NPV of profits for 2020s nuclear: -£8.9 billion
14.0% discount rate, 3.2 GW station

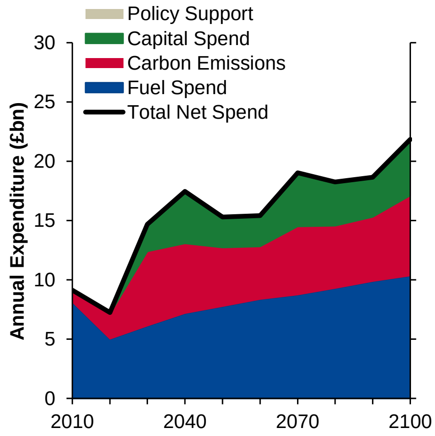
Carbon emissions (relative to 1990) in:

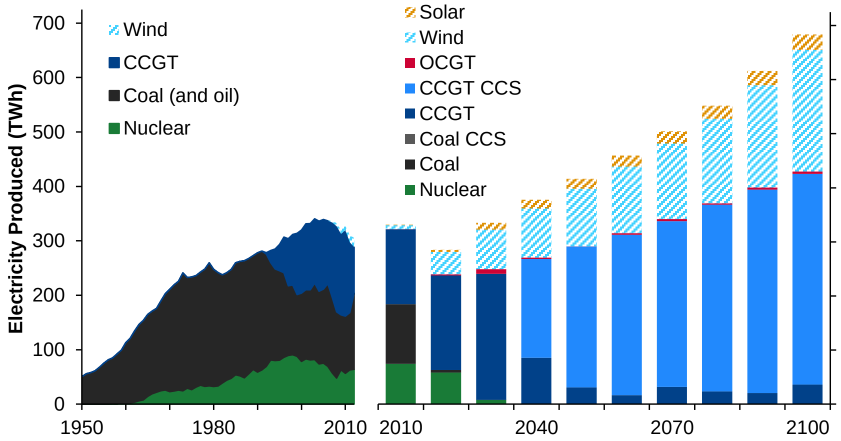
2010	2020s	2050s	2100s
-27%	-68%	-90%	-86%

Maximum carbon price: £245 / T
Cumulative emissions to 2100: 3.9 GT









C.3.2 No Aid, 13% WACC, High Fuel

This case uses our high fuel price estimates and assumes no government intervention to support nuclear power. Nuclear investment is unprofitable in the 2020s and 30s, but large amounts of nuclear capacity are built in the 2040s as rising fuel prices make fossil fuel less competitive for baseload operation.

This case has the highest average wholesale prices and the lowest level of welfare of any scenario we tested.

Carbon emissions are lower than in the other cases without government intervention and a 13% WACC (C.1.1 and C.3.1) and the carbon price needed to hit the target level of emissions is also lower.

Existing stations make large profits in the 2020s.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	0	0	10.1	4.6
Fossil:	3.5	37.4	18.8	10.6

NPV of public support: £0.0 billion
NPV of total welfare: £26.1 billion
3.5% discount rate, measured from 2020

Average wholesale price: £100.35 / MWh
Including support: £100.35 / MWh

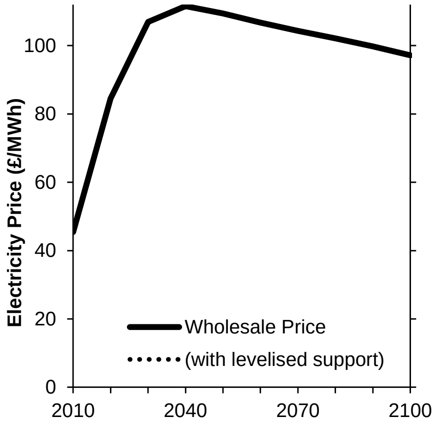
Annual profits of existing stations in the 2020s:
Nuclear: £3.9 billion
Fossil: £1.0 billion

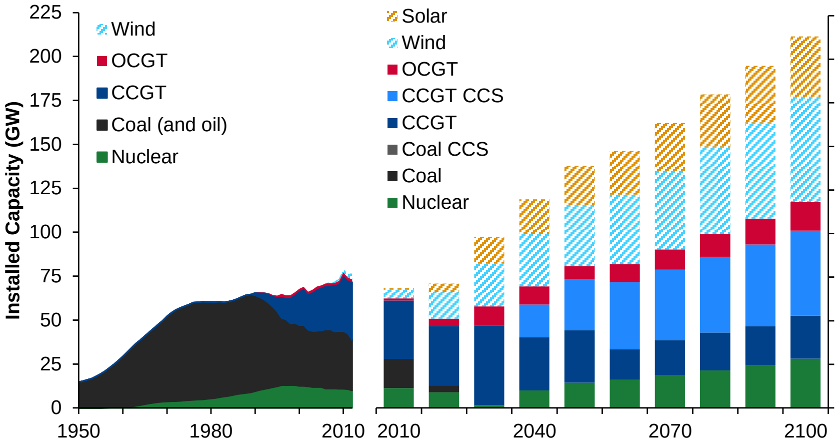
NPV of profits for 2020s nuclear: -£3.8 billion
14.0% discount rate, 3.2 GW station

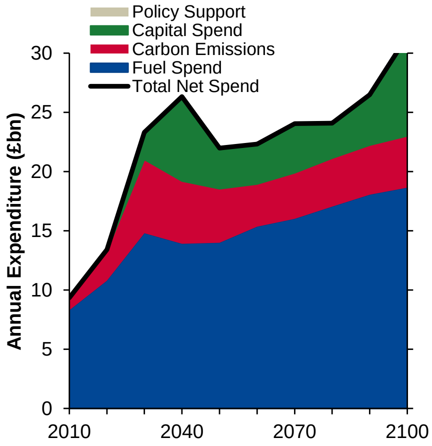
Carbon emissions (relative to 1990) in:

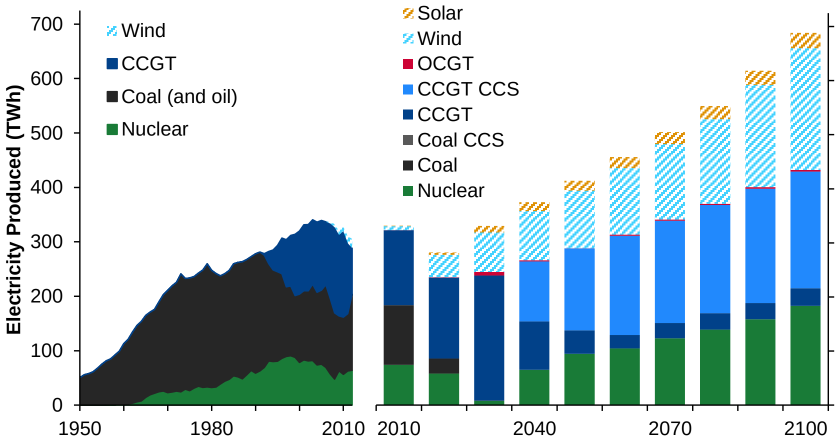
2010	2020s	2050s	2100s
-27%	-62%	-90%	-90%

Maximum carbon price: £223 / T
Cumulative emissions to 2100: 3.8 GT









C.3.3 CfD35, 10% WACC, Low Fuel

This scenario combines our low fuel prices with the UK government's proposed CfD. As in C.2.1 (the CfD with central prices), a full 15 GW of nuclear capacity is built in the 2020s, and no fossil is built. More gas-fired capacity is built in the following decades than in C.2.1, as the low fuel prices make it more competitive.

Substantially less fossil capacity is built than with low fuel prices and no aid (C.3.1), and the total capacity is lower than it would be without the CfDs from the 2030s onwards.

The average wholesale price is reduced by almost £10/MWh by the intervention, although this is cut to less than £1/MWh after the cost of support is included. The amount of public support is much higher than with the central fuel prices because the strike price is unchanged whereas the market price is lower.

Existing stations earn much less in the 2020s than without the government intervention. The carbon price is similar to C.2.1 (central fuel prices) but cumulative emissions over the century are slightly higher.

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	0	0	0
Fossil:	0	27.5	25.1	10.3

NPV of public support:	£6.4	billion
NPV of total welfare:	£44.4	billion

3.5% discount rate, measured from 2020

Average wholesale price:	£55.13	/ MWh
Including support:	£63.98	/ MWh

Annual profits of existing stations in the 2020s:

Nuclear:	£1.1	billion
Fossil:	-£1.6	billion

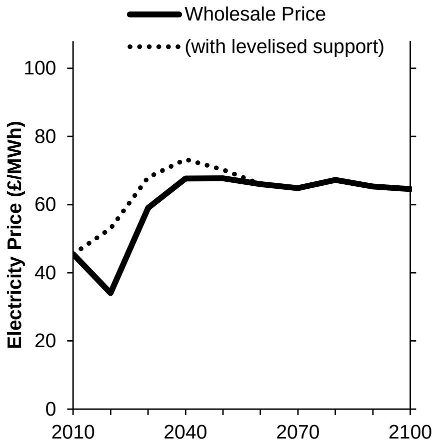
NPV of profits for 2020s nuclear:	£0.4	billion

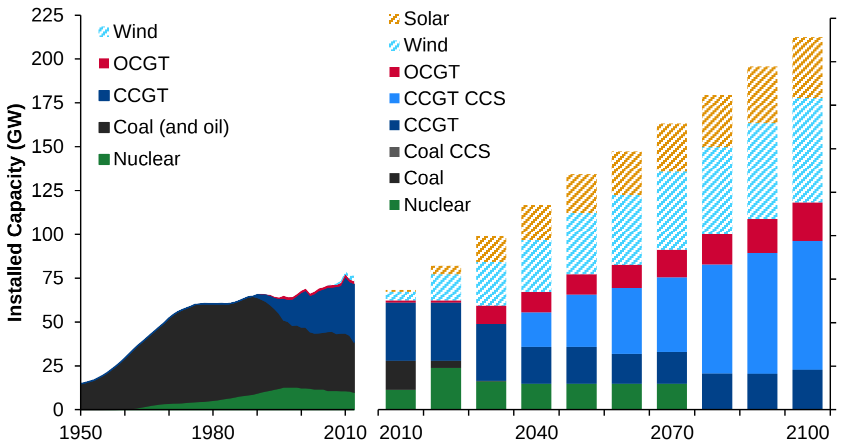
10.3% discount rate, 3.2 GW station

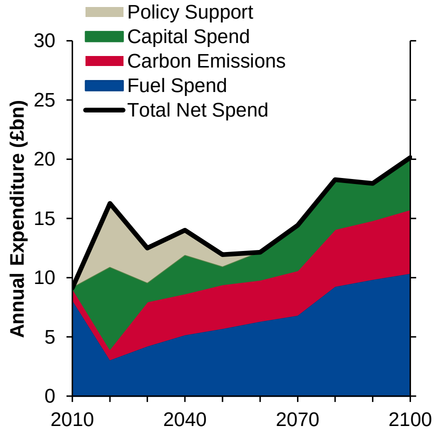
Carbon emissions (relative to 1990) in:

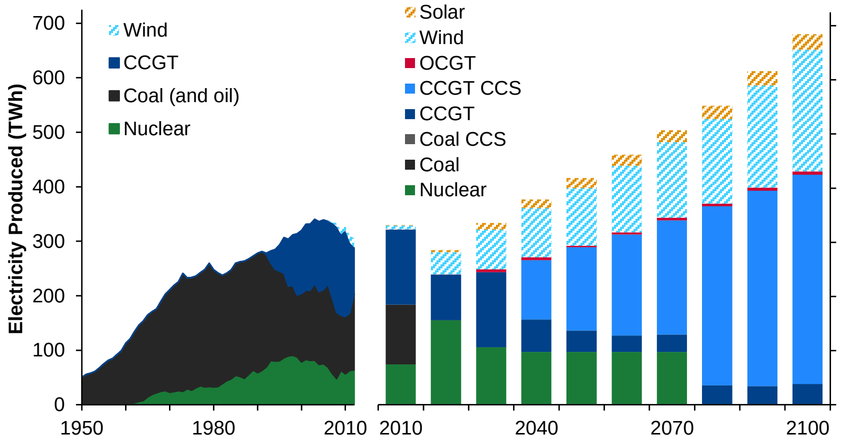
2010	2020s	2050s	2100s
-27%	-86%	-90%	-86%

Maximum carbon price:	£186	/ T
Cumulative emissions to 2100:	3.1	GT









C.3.4 CfD35, 10% WACC, High Fuel

This scenario combines our high fuel price assumptions with the UK government's proposed CfD for 35 years. The full 15 GW of nuclear plant is built in the 2020s. In every succeeding decade, the total installed capacity of nuclear plant is greater, and that of fossil stations is smaller, than without the CfD (C.3.2).

Very little support is paid to nuclear stations after the 2020s, as wholesale prices stay close to the strike price.

The average wholesale price is £18.45/MWh lower than without the CfD (with the cost of public support included). This price is £5.10/MWh higher than with the CfD and central fuel prices (C.2.1), whereas the scenario with no aid gives wholesale prices which are £15.56/MWh higher with high fuel prices than with central fuel prices.

Existing stations make less money in the 2020s than they do with no aid (C.3.2).

GW of capacity built in:

	2020s	2030s	2040s	2050s
Nuclear:	15	5.1	10.6	3.3
Fossil:	0	21.7	14.5	6.6

NPV of public support: £1.9 billion
NPV of total welfare: £30.8 billion
3.5% discount rate, measured from 2020

Average wholesale price: £79.16 / MWh
Including support: £81.90 / MWh

Annual profits of existing stations in the 2020s:
Nuclear: £2.8 billion
Fossil: -£1.3 billion

NPV of profits for 2020s nuclear: £0.3 billion
10.3% discount rate, 3.2 GW station

Carbon emissions (relative to 1990) in:

2010	2020s	2050s	2100s
-27%	-80%	-90%	-90%

Maximum carbon price: £185 / T
Cumulative emissions to 2100: 2.9 GT