Technical annex: modelling the cost effectiveness of selected decarbonisation policies

Introduction

Purpose of this technical annex

This document provides further technical details of the analysis that was conducted to evaluate the effectiveness of selected decarbonisation policies (described below) in electricity generation and other sectors.

The policies are evaluated against the following dimensions:

1. Emissions abated (tonnes of carbon dioxide equivalent);

2. Cost (in 2016 prices); and

3. Value for money of policies (expressed in pounds per tonne of carbon dioxide equivalent emissions reduction).

The selected policies

We focus on policies that were implemented from 2010 onwards for which robust costs data are available. Combined, these policies accounted for 40% of the electricity energy savings that fell within the scope of our analysis and were observed in the period 2010-2017.

The policies target both demand for, and the supply of energy, and we group them as follows:

Supply-side policies:

- Air quality directives:
  - Large Combustion Plants Directive (LCPD).
  - Industrial Emissions Directive (IED).
- Carbon price:
  - EU emissions trading scheme (ETS).
  - Carbon Price Support (CPS).
- Large scale renewable subsidies:
  - Renewable Obligation Certificate (ROC).
  - Levy Exemption Certificates (LECs).

  - Contracts for difference (CfD) – non-competitively procured Final Investment Decision Enabling for Renewables (FiDeR).

- Small scale renewable subsidies or Feed-in tariff (FiT).[1]

Demand-side policies:

- Carbon Emissions Reduction Target (CERT) Extension and +20%.
- Energy Company Obligation (ECO) and Extension.
- Renewable Heat Incentive (RHI) Domestic and Non-Domestic.
- Smart Metering Domestic and Commercial.
- Community Energy Saving Programme (CESP).

The policies are spelt out in greater detail in the below table.

[1] It could be argued that this is a demand side policy as embedded generation also reduces the need for electricity that is supplied through the transmission network.

Figure A1: Selected key decarbonisation policies, with a focus on those enacted in 2010-2017

Intervention type	**Policy** [Years]	**Description**	**Sector**
Carbon price	**EU emissions trading scheme (ETS)** [2005-ongoing]	Taxes carbon through a limited number of tradeable permits	Electricity
	Carbon Price Support (CPS) [2013-ongoing]	Tops up the carbon price as determined by the EU ETS	Electricity
Large scale renewable subsidies	**Renewable Obligation Certificate (ROC)** [2002-2017]	Obliged electricity suppliers to source a proportion of the electricity they supply from renewable sources	Electricity
	Levy Exemption Certificates (LECs) [2001-2015]	Granted a rebate to eligible renewable generators	Electricity
	Contracts for difference (CfD) – non-competitively procured Final Investment Decision Enabling for Renewables (FiDeR) [2014-ongoing]	Provides low-carbon generators a fixed price, topping up the wholesale price when it is lower than the agreed price (clawing money back otherwise)	Electricity
Small scale renewable subsidies	**Feed-in tariff (FiT)** [2010-ongoing]	Subsidises small-scale low-carbon electricity generators	Electricity
Demand-side policies	**Carbon Emissions Reduction Target (CERT) Extension and +20%)** [2008-2012]	Required larger gas and electricity suppliers to achieve reductions in carbon emissions from domestic premises	Multiple
	Energy Company Obligation (ECO) and Extension [2013-2017]	Obliged energy suppliers to deliver energy efficiency measures to domestic premises	Multiple
	Renewable Heat Incentive (RHI) Domestic and Non-Domestic [2012-ongoing]	Subsidises low carbon heat sources (scope is GB only)	Multiple
	Smart Metering Domestic and Commercial [2011-ongoing]	Mandates suppliers to roll out electricity and gas smart meters to homes and small businesses	Multiple
	Community Energy Saving Programme (CESP) [2009-2012]	Required gas and electricity suppliers / generators to deliver energy saving measures to domestic consumers in specific low income areas	Multiple
Other regulations[2]	**Building regulations** [2010-ongoing]	Regulations to improve the energy efficiency of buildings	Multiple
	Products policy [2010-ongoing]	Product standards that protect the environment	Multiple
Air quality directives (regulations)	**Large Combustion Plants Directive (LCPD)** [2001-ongoing]	Aims to reduce emissions of acidifying pollutants, particles and ozone precursors	Electricity
	Industrial Emissions Directive (IED) [2013-ongoing]	Assigns the cost of plant updates to the polluter	Electricity

[2] Note that these policies were not included in the framework of the LCP analysis, but we do consider their effects separately in the Chapter 4 of the State of the energy market 2018 report.

The policies target different parts of the energy sector. The supply-side policies listed above, broadly speaking, are concerned with the electricity sector, while the remaining policies are also concerned with other sectors.[3] The RHI is perhaps the only policy that has the non-electricity sector (ie heat) as its core focus.

In light of these differences in the design of policies and, in particular, the understanding that the EU ETS drives emissions abatement in the electricity sector alone, our analysis is composed of two parts: analysis of the electricity sector and analysis of other sectors.

The policies also focus on different types of consumer. For instance, the following policies are designed to influence energy usage by:

1. Domestic consumers:
    - CERT
    - CESP
    - ECO
    - RHI (although it also targets other consumers)
    - Smart Metering (the domestic aspect)
    - Small scale renewable subsidies (although it also targets other consumers)
2. Non-domestic consumers:
    - RHI (the commercial, public and agriculture components)
    - Smart metering (the commercial aspect)

Scope of the analysis

The analysis covers the period 2010-2017 to maintain consistency with the evaluation that was conducted in our 2017 State of the energy market report. This means that policies which drove investment and dispatch decisions prior to 2010 – such as in low carbon generation – are out of scope of the analysis and their effects are not simulated in the model.

Our scope is also restricted by data availability. For instance, the lack of comprehensive data on the cost of the other regulations (ie building regulations and products policy) meant that they were left out of the analysis.

In light of these constraints, the analysis should therefore be interpreted as shedding light on the effect of policies only where they:

- were active during the period 2010-2017. This rules out, for instance, ECO1, which ended before 2010, and the first wave of CERT, which was enacted prior to 2010.
- had a readily identifiable cost, which leads to the exclusion of building regulations and products policy.

[3] We use the term other sectors to refer to gas, oil, solid fuels and biofuels energy savings in the agriculture, commerce, domestic, industry and public sectors.

- helped to drive investment and dispatch decisions from 2010. This rules out, say, the effect of renewable investments that were enabled by the ROCs up to the end of 2009. These are simply assumed to be already in place and the effect of any support contracts agreed prior to 2010 are not explicitly modelled.

Key metrics

The key cost metrics that we consider compare each policy against the observed outcomes from the period 2010-2017:

1. **Policy cost:** the direct transfer of funds by energy consumers or UK taxpayers to pay for capital investment, subsides and other policies. This broad definition of policy cost can be negative if the policy generates tax receipts.

2. **Wholesale cost:** the impact that a policy has on wholesale energy costs through price effects. For instance, the carbon price adds to wholesale costs whereas renewables policies could potentially lower wholesale costs by displacing more expensive fossil fuel generation.[4]

3. **Consumer cost:** the sum of the impact of policy cost and wholesale cost. This can be negative if a policy reduces wholesale electricity cost above and beyond the policy cost.

4. **System cost:** the sum of resource costs including generation, balancing and network costs (but excluding the costs associated with carbon such that we can assess policies on a cost per tonne of carbon dioxide equivalent reduced basis). This metric is neutral as to whether costs are incurred by consumers or producers, and instead focuses on the GB electricity market as a whole.

Analysis of the electricity sector

EnVision model

We worked with LCP to employ its EnVision model to simulate what we saw in dispatch, investment and retirement of generation plants since 2010, as well as the accompanying emissions and costs. The model allows us to:

- aggregate individual power plant dispatch to determine the overall dynamics of the market;

- simulate counterfactuals where the selected decarbonisation policies that were enacted from the start of 2010 are 'turned off';

- evaluate the change in costs and emissions that were driven by each policy;[5]

- estimate the implications of these policies for the average household energy bill; and

[4] This is based on the wholesale price. We scope out balancing costs (National Grid's annual balancing costs were consistently within the range £850m - £1,150m in 2010-2017) and network effects that may need to be recouped regardless of whether these policies are in place.
[5] We focus on policy effects at the GB level. Only the EU ETS delivers global effects, as progress by one EU member state could in theory allow other members to pollute more.

- account for the estimated marginal carbon intensity of imported electricity, which we assume is provided by gas generation.[6]

The scenarios

Together with LCP, we developed a range of scenarios to explore the impact of a carbon reducing policy (or collection of policies) on the GB electricity sector over the period 2010-2017.

In the model, we used the following seven scenarios:

1. LCPD and IED constraints removed

This scenario removed the constraints that were put in place by the LCPD and IED. Although they are not low-carbon policies per se, these EU directives have led to the early closure of large coal and oil plants in GB. We run this first scenario to determine the carbon dioxide equivalent emission reductions that may be attributed to these policies, helping us to disentangle their effect from that of other policies, notably the carbon prices.

2. EU ETS and CPS removed

The UK government sets a carbon price floor and the CPS tops up the EU ETS allowance prices, as projected by the Government, to the carbon floor price target. All revenue from the CPS is retained by the Treasury, as are the EU ETS tax receipts. In this scenario the carbon price is removed in its entirety, ie both the EU ETS and the UK's CPS.

3. CPS removed

This scenario is similar to the previous one, where the CPS is removed, except now plants still pay the EU ETS price on any carbon dioxide equivalent emissions.

4. Demand-side policies removed (Energy Efficiency, RHI and Smart Metering)

This scenario examines the removal of demand-side policies that have been applied to reduce carbon emissions. The analysis includes a subset of policies where sufficient data on costs and demand reduction was available. In the analysis, we bundle these demand-side policies together into one single group as their individual effects are too modest relative to those of other policies to discern clearly.

5. Small scale renewable subsidies (FiTs) removed

In this scenario, the support scheme for small-scale renewable generators, which came into effect from April 2010, is removed.

6. Large scale renewable subsidies (ROCs, CFDs and LECs) removed

In this scenario, the support schemes for large-scale renewable generators are removed from 2010 onwards. This includes the ROC scheme and its replacement, the CfD scheme. We have also incorporated the removal of the LEC in this scenario as it had a smaller impact and would be difficult to isolate in a separate scenario.

[6] In reality, the carbon intensity will be dictated by which plant is at the margin in each country and time period (and this may not always be gas).

7. All policies removed

A final scenario is run to examine the combined impact if all the policies are removed. The impacts in this scenario may be more or less than the sum of impacts of the individual scenarios, depending on the interactions between policies.

In the model, apart from the case where all the policies are removed, the scenarios are run independently such that all other policies remain in force. This is depicted in the below figure.

Figure A2: Modelling scenario matrix

												Closure Year Extension					
	LCPD constraints	CPS	EU ETS	Energy Efficiency measures	RHI	Smart metre policy	FiTs	ROCs	CfDs	LECs	Biomass Conversions go ahead	LCPD constrained Coal	Non-LCPD constrained Coal	Oil	CCGT	Large-scale renewable Build	FiT Build
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	✓	✓
LCPD removed	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	× *	✓ *	×	✓	×	✓	✓
CPS removed	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×	✓	✓
Carbon price - CPS and EU ETS - tax	✓	×	×	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×	✓	✓
Energy Efficiency policies removed	✓	✓	✓	×	×	×	✓	✓	✓	✓	✓	×	×	×	×	✓	✓
FiTs removed	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	×	×	×	×	✓	×
ROCs, CFDs, and LECs removed	✓	✓	✓	✓	✓	✓	✓	×	×	×	×	×	✓	×	✓	×	✓
All removed	×	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓	×	×

Note: * Drax is an exception, we assume conversions still go ahead due to rising carbon prices and ROC / CfD support. The "All removed" scenario should be read as a mirror image of the "Baseline" and shows the effects of turning off all of the selected policies.

Defining the base case

Each scenario is compared to the base case where all policies remain in place as they were. The base case has been calibrated so that its outcomes align with historical results, ie the model produces similar costs and carbon dioxide equivalent emissions to observed outturns. However, there will be discrepancies due to the assumptions and simplifications that are employed by the model. For example, renewable generation is simulated under "average" weather conditions rather than under the actual historical conditions.

The modelling covers the period 2010-2017 inclusive. In each scenario, it is assumed that policies were only removed from 2010 onwards and that support contracts agreed prior to 2010 are grandfathered. So, for example, in the scenario where ROCs are removed we assume that ROC plants commissioned before 2010 are still commissioned and continue to receive support.

Assumptions

A number of assumptions were required to simulate each scenario. In particular, assumptions, which were informed by the analysis outlined below, were made to determine the plant build and closure decisions. These in turn determined the plant availability that would have occurred in the absence of each policy.

LCPD / IED and decisions made by affected plant

These EU directives aim to reduce emissions of sulphur oxides, nitrogen oxides and particulates from large combustion plant. Under this legislation three options were available to a plant:

1. **Opt-in:** meet new emissions limits and retrofit flue gas desulphurisation equipment.

2. **Opt-out:** choose Limited Life Derogation (LLD) – limited to 20,000 running hours (2008 – 2015) after which plants must close.

3. **Close:** prior to 1 January 2008.

Some units chose a fourth option, bypassing the LCPD entirely by electing to convert to biomass burn.

In the base case, we limited the running hours of coal and oil units in the period 2010-2015 to their remaining running hours, where remaining hours is defined as the remainder of LCPD constrained hours minus actual running hours in 2008 and 2009.

Under the "LCPD and IED constraints removed" scenario, the LCPD affected units:

- No longer undergo biomass conversion;
- Are not forced to close by 2015, so only close if it makes economic sense to do so; and
- Are not subject to running hours constraints.

The analysis, therefore, allows for the identification of plant that would close as a result of air quality directives.

We apply a similar approach for IED affected units, removing their running hour constraints and only closing the units if it makes economic sense to do so.

Plant closure

Analysis is also conducted to identify plant which would find it economic to close when all policies are kept in place with the exception of the carbon price policies (which are turned off). This allows us to see plant that would close as a result of carbon price policies.

Similarly, analysis is conducted to identify plant which would find it economic to close when all policies are kept in place except for the subsidies for renewables (again, which are turned off). This allows identification of plant that would close as a result of these subsidies not being available.

Finally, analysis is conducted to identify plant that would not find it economic to remain open when all policies are removed.

Results of this analysis are summarised below. This shows that even in the absence of all policies, oil plant would have closed (denoted by the crosses in the all policies removed scenarios). It suggests that the LCPD affected the decisions of numerous plant (represented by the ticks) and the renewables subsidies helped to drive out certain plant, such as some CCGTs. Removal of the carbon price would not have impeded the retirement of any of the coal plants retired by the LCPD (for example Cockenzie and Didcot) as they would still have been forced to close under LCPD restrictions.[7]

[7] While the carbon price does not on its own appear to force closure of fossil fuel plant, we will see later that it stimulates a reduction in their deployment.

Figure A3: Simulated economic decisions of plant to delay or abandon retirement / conversion

				Scenario where retirement/conversion may be delayed/removed			
Plant Name	Closure Year	Capacity, GW	Type	LCPD removed	EU ETS + CPS removed	RO, CfD & LEC removed	All policies removed
Barking	2014	1.00	CCGT	×	×	✓	✓
Roosecote	2012	0.23	CCGT	×	×	✓	✓
Killingholme A	2016	0.67	CCGT	×	×	✓	✓
Cockenzie	2013	1.20	Coal	✓	×	×	✓
Didcot A	2013	2.00	Coal	✓	×	×	✓
Ferrybridge 1 & 2	2014	0.98	Coal	✓	×	×	✓
Ferrybridge 3 & 4	2016	0.98	Coal	✓	✓	✓	✓
Kingsnorth	2012	1.94	Coal	✓	×	×	✓
Uskmouth*	2013, 2014	0.35	Coal	✓	×	×	✓
Longannet	2016	2.28	Coal	✓	✓	✓	✓
Rugeley	2015, 2016	0.97	Coal	✓	✓	✓	✓
Tilbury**	2011	1.08	Coal -> Biomass	✓	×	✓	✓
Ironbridge	2014, 2015	1.00	Coal -> Biomass	✓	×	✓	✓
Drax (3 units)	2013-16	1.94	Coal -> Biomass	×	×	✓	✓
Lynemouth	2015-18	0.42	Coal -> Biomass	✓	×	✓	✓
Fawley	2013	1.00	Oil	×	×	×	×
Littlebrook D	2015	1.37	Oil	×	×	×	×
Grain	2012	1.30	Oil	×	×	×	×

Note: * Currently undergoing refit to EfW. ** Began conversion to biomass, but fire during conversion led to closure.

Demand scenarios

The model takes demand for electricity as a given input. This data is important in shaping the results of the analysis in relation to demand-side policies.

We use BEIS reference demand scenarios for our analysis. As certain demand-side policies may directly affect demand (and this is not directly captured in the model) we also adjust the reference demand based on the TWh savings attribution of a subset of demand-side policies (provided by BEIS). This level of demand is then used in the analysis where all demand-side policies are turned-off.

The demand data includes both annual demand and peak demand. The peak demand adjustment assumes that the policies represented the same proportion of total peak MW adjustment as the proportion of the annual TWh demand adjustment.

Figure A4: Electricity demand data, GB

	Annual demand		Peak demand	
	BEIS Reference, TWh	BEIS Selected demand policies removed, TWh	BEIS Reference, GW	BEIS Selected demand policies removed, GW
2010	356.5	357.6	64.7	64.3
2011	346.3	348.4	62.7	62.5
2012	346.7	348.8	62.9	62.9
2013	344.7	347.4	62.5	62.9
2014	332.7	336.3	60.3	61.1
2015	331.9	336.3	60.2	61.6
2016	331.8	336.0	60.2	62.3
2017	334.9	339.9	60.9	63.8

Source: BEIS.

Policy costs

The model calculates the estimated costs of policies (in 2016 prices), although these were also sourced directly in order to calibrate model outturns against historic data and determine historical policy rates, such as £/tonne EU ETS prices. The policy analysis data sources are as follows:

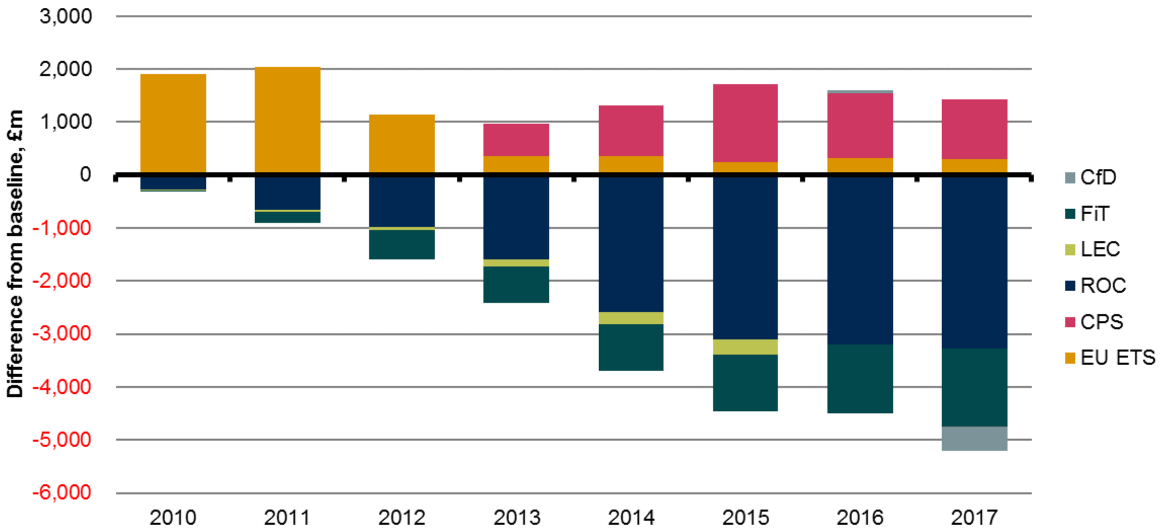
- LCPD (BEIS).[8]
- CPS (HMRC).[9]
- EU ETS (Investing.com).[10]
- FiT (Ofgem).[11]
- ROC Buy-Out Price (Ofgem).[12]
- ROC Bandings (Ofgem).[13]
- CfD (LCCC).[14]
- LEC (HMRC).[15]
- Energy Efficiency policies (BEIS).

For the average abatement cost curve analysis we adjust demand-side policy costs so that they are annualised over twenty years, and only consider costs that then fall within the period 2010-2017. This is to assist comparability with other policies (such as ROCs, which offer support over many years) and have considerable up-front capital costs.

Figure A5 shows the policy costs that form part of the model's base case scenario. Note that the tax receipts from the carbon prices are entered as a negative policy cost.

8 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/65919/6483-running-hours-lcpd-et-article-sep-2012.pdf
9 http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN05927#fullreport
10 https://uk.investing.com/commodities/carbon-emissions-historical-data and https://uk.investing.com/currencies/eur-gbp-historical-data
11 https://www.ofgem.gov.uk/publications-and-updates/feed-tariff-installation-report-31-december-2017
12 https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-buy-out-price-and-mutualisation-ceilings-2018-19-ro-year
13 https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-guidance-generators
14 https://www.lowcarboncontracts.uk/cfds
15 https://www.uktradeinfo.com/Statistics/Tax%20and%20Duty%20Bulletins/ccl0116.xls

Figure A5: Simulated policy costs



Note: Costs deflated to 2016 terms using the Consumer Price Index.

Further modelling assumptions

The model builds on a number of important input assumptions for plant. We used the database maintained by LCP, which is based on public data where possible. We collected data from BEIS publications on the levelised costs of electricity generation to apply the most relevant input assumptions for each of the years 2010-2017 in question.[16]

Additional key parameters in the model include:

- Hurdle rates;
- Pre-development periods;
- Construction periods;
- Plant efficiencies;
- Plant availability rates;
- Commodity prices;
- Capital cost; and
- Operating cost (fixed and variable).

Results

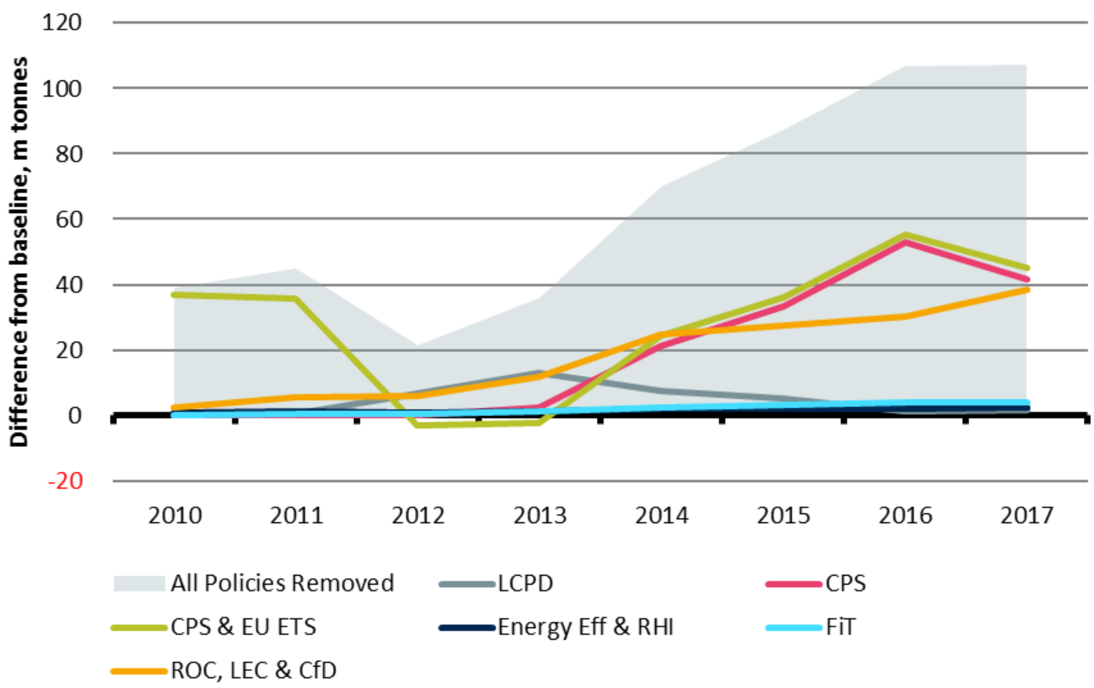
The model generates a range of results for each scenario and these are now summarised in the following section.

[16] See: https://www.gov.uk/government/collections/energy-generation-cost-projections. We used data from publications from 2010, 2011, 2012, 2013 and 2016.

Carbon dioxide equivalent emissions

The below figure shows the simulated effect on emissions of the removal of policies. Note that the combined effect of all the policies is one-sixth greater than the sum of individual policy contributions, with the model suggesting that there are "synergies" that augment the effect of each individual policy when they work in tandem.

Figure A6: Change in carbon emissions from base case (million tonnes carbon dioxide equivalent)



The results in Figure A6 can be summarised as follows:

- The removal of the **carbon prices (CPS & EU ETS)** sees far higher emissions, as coal displaces gas generation at the beginning (high EU ETS) and end (high CPS) of the analysis period. Note the effect of policy in reducing emissions fell dramatically in 2012, when the carbon price collapsed. Indeed, removing these policies leads to a *reduction* in simulated emissions in 2012. This is attributable to LCPD units fully utilising their constrained running hours earlier and, therefore, not being able to operate in this period.

- The removal of **renewables subsidies (ROC, LEC, CfD and FiT)** eliminates the incentive (during this time period) to build renewable generation. Zero-marginal cost renewable generation is reduced (although plant already in place pre-2010 is unaffected), as is displacement of traditional thermal plant, and this leads to a resulting emissions increase. Figure A6 also shows the steadily growing impact of large scale renewable subsidies (ROC, LEC and CfD) over the period.

- With the **LCPD & IED** constraints removed, in 2010-11 there is little change in how the units operate. However, from 2012 onwards coal units remain open, displacing gas generation, and emissions increase (units that were constrained by the LCPD generally closed earlier in around 2012/13).[17] The impact of air quality directives diminishes in 2014 and thereafter as, in the absence of these

[17] Further, units that did not close are now unconstrained.

directives, the growing carbon price from 2014 would have stimulated a switch from coal to gas.

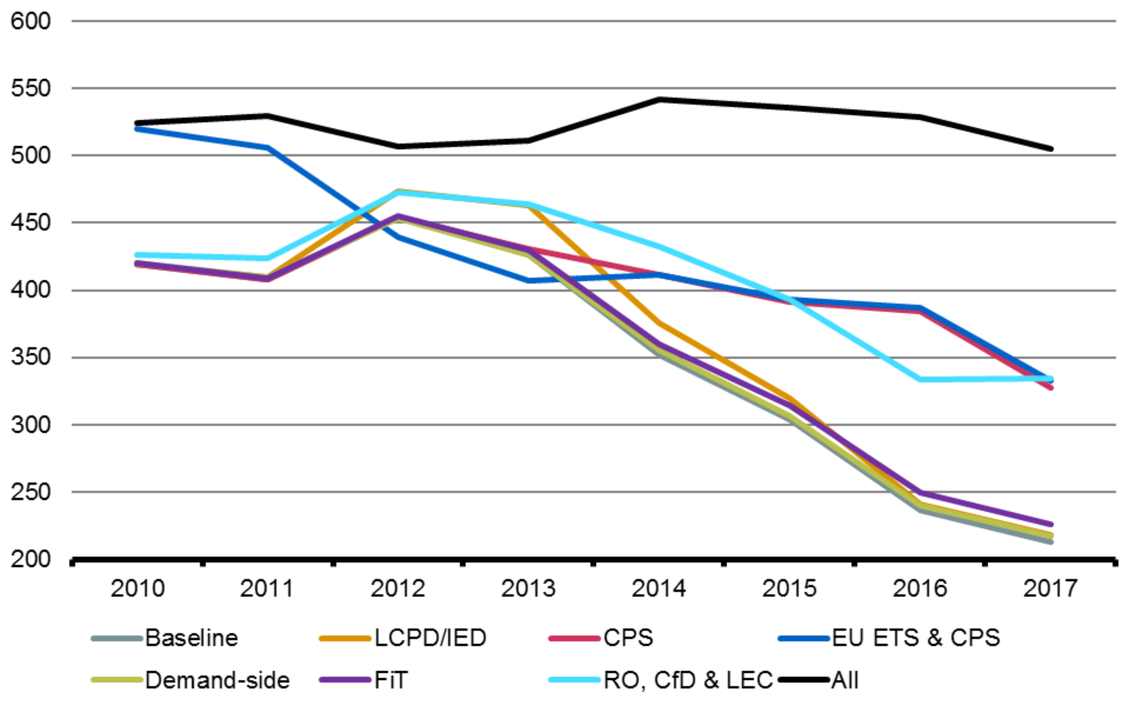
- Removing **Energy Efficiency & RHI** has a limited impact on emissions, with only a slight increase in emissions due to the higher levels of demand.

The effect of removing all policies dips in 2012, again reflecting the crash in carbon prices, but grows towards the end of the period. The effect of removing all policies is greater than the sum of the individual effects of each individual policy. This multiplier, while not visually obvious, is typically around 20% and likely arises due to the synergies between different policies.

Carbon intensity of the electricity grid

The below figure shows the simulated carbon intensity of the GB power system, in grams of carbon dioxide equivalent emissions per kWh of domestic generation.[18] It suggests that, absent the policies, grid intensity would have stayed broadly flat from 2010. The biggest contributor to the decline has been carbon pricing (EU ETS and CPS) and the support of large scale renewable generation (ROCs, LECs & CFDs).

Figure A7: Simulated carbon dioxide equivalent intensity of the grid after removing policies (g/kWh)



Electricity generation

Figure A8 to Figure A13 show the simulated effect on generation of removing each policy individually.

[18] Interconnector imports are excluded from the calculation. We later conduct sensitivities on carbon intensity of interconnector imports using a marginal emissions factor of 400g/kWh on net imports into GB, the approximate carbon intensity of gas generation, and find this does not substantially change the conclusions.

Figure A8 shows that the carbon price has the greatest effect of all the policies. It is effective in displacing coal, in years when the price was high enough, and replacing it with gas. It is also complemented somewhat by interconnection.

Figure A8: Simulated effect on generation of removing EU ETS and CPS only (TWh)

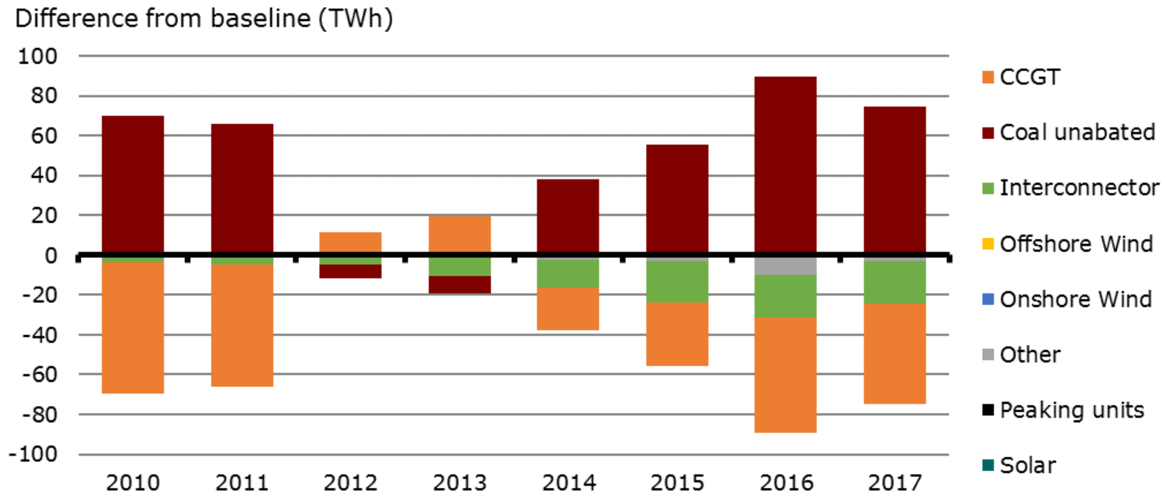


Figure A9 shows that large scale renewable policies have been effective in displacing both coal and gas, and replacing them with wind, solar and other generation (notably biomass). This effect has grown over 2010-2017 as the policies have driven a stock of new renewable capacity.

Figure A9: Simulated effect on generation of removing ROCs, CfDs and LECs only (TWh)

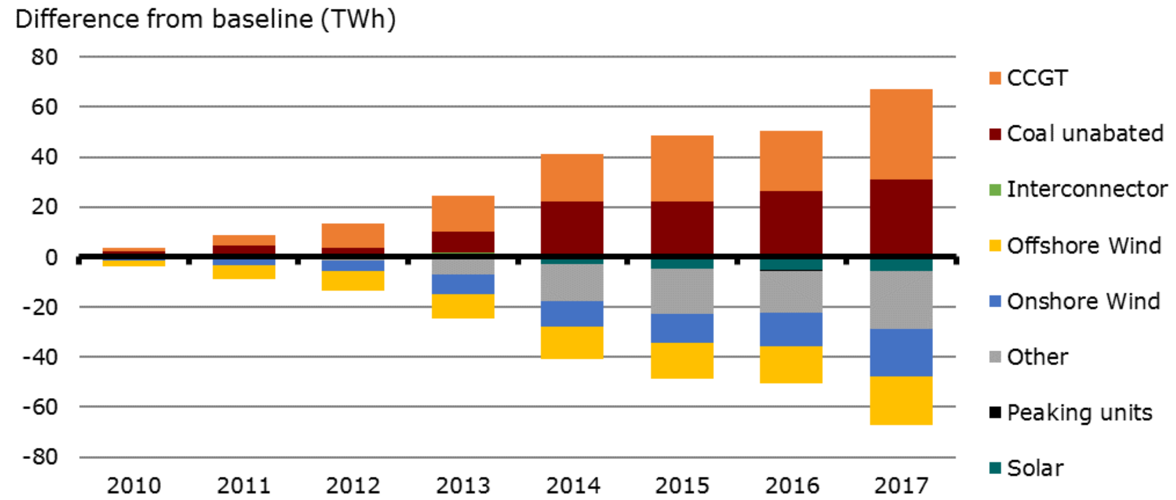


Figure A10 shows that the effect of the air quality directives (LCPD and IED) is less substantial and has a shorter duration. The directives helped to close coal plants, notably over 2012-2014. The diminishing impact from 2014 suggests that, while the directive helped to drive the closure of a number of coal plants, in its absence coal would have run relatively rarely in any case largely thanks to the carbon price.

Figure A10: Simulated effect on generation of removing LCPD and IED only (TWh)

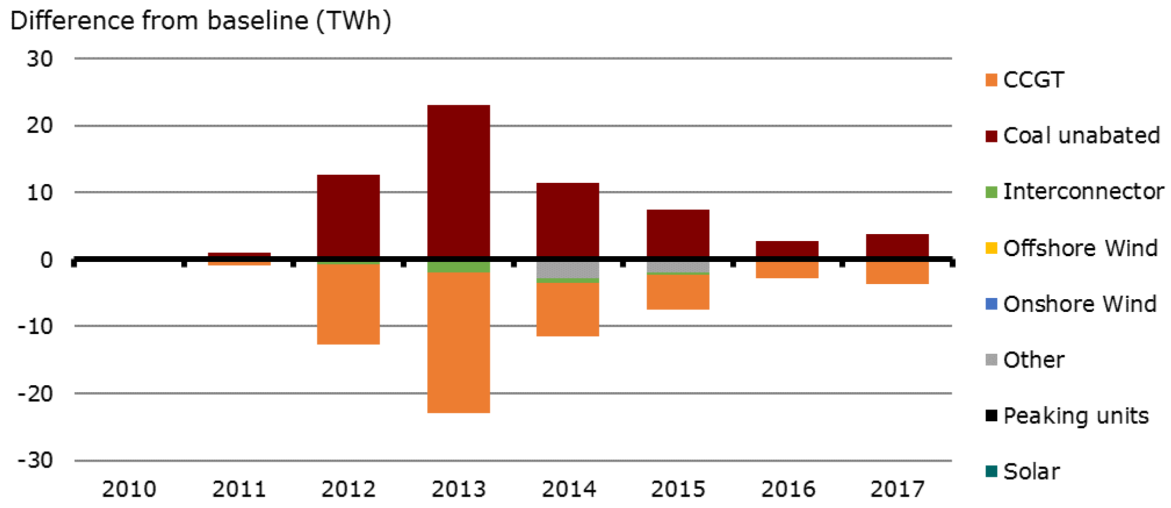


Figure A11 suggests that small scale renewable subsidies have displaced coal and gas (CCGT) with solar, wind and other generation. The net effect is small (note the y-axis scale).

Figure A11: simulated effect on generation of removing FiTs only (TWh)

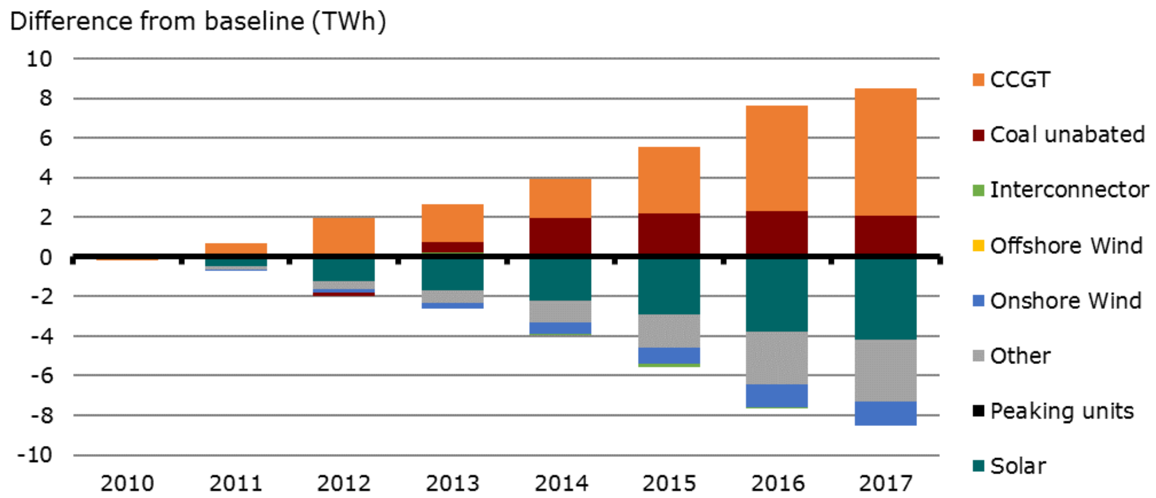


Figure A12 shows that demand-side policies have driven reductions in overall consumption, although some – such as smart meters – have also led to shifts in demand. This has enabled smaller reductions (note the scale of the y-axis again) in coal and gas generation.

Figure A12: simulated effect on generation of removing demand-side policies only (TWh)

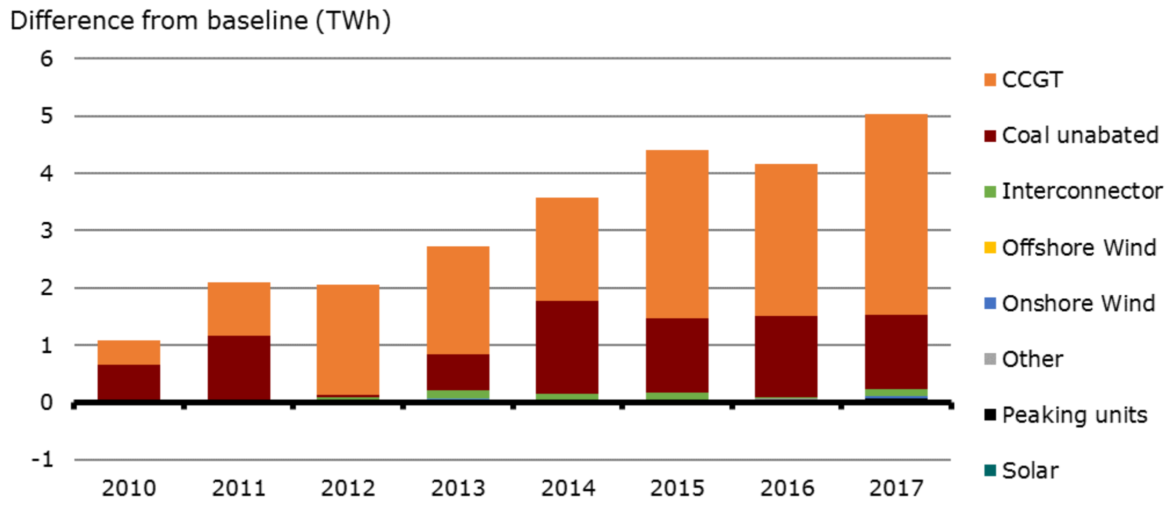
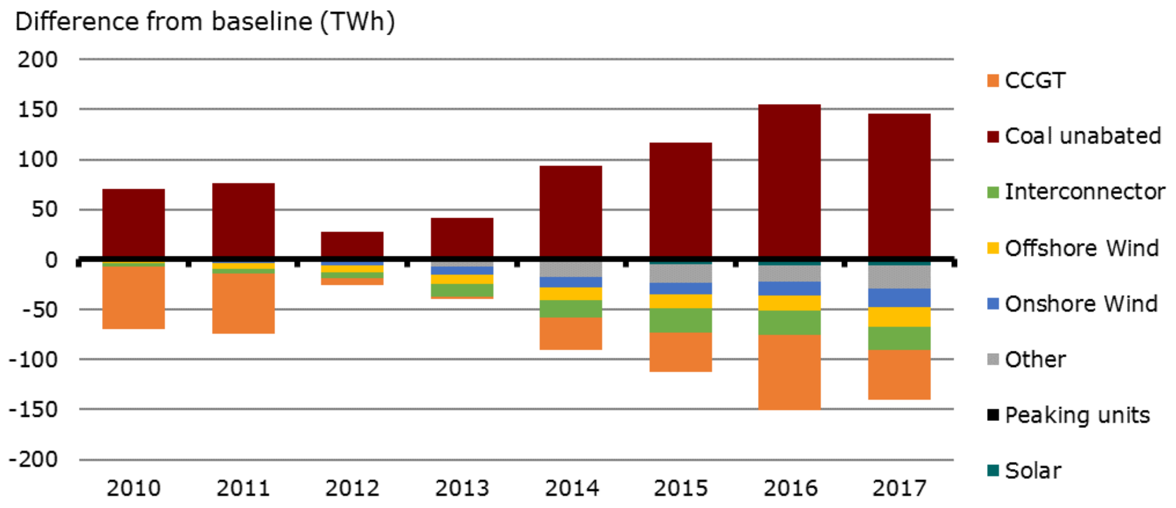


Figure A13 shows the effect of all the policies combined. As a group they displace coal, replacing it with less carbon intensive gas generation, interconnection and zero carbon generation such as wind and solar.

Figure A13: simulated effect on generation of removing all policies (TWh)



Wholesale cost

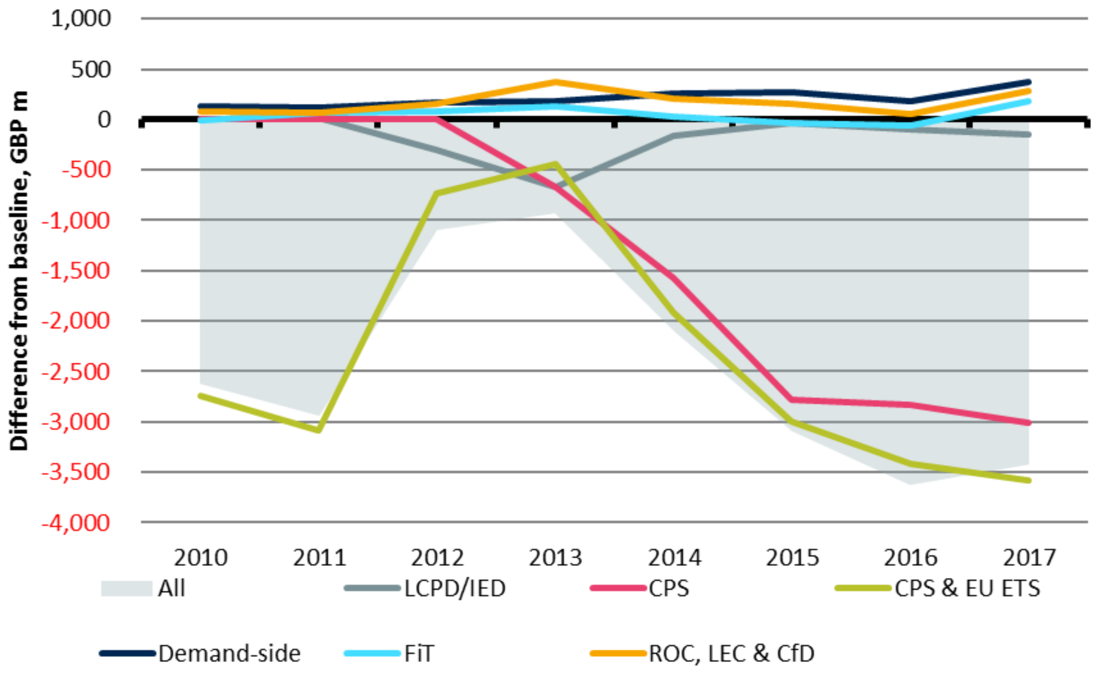
Wholesale cost effects may be transmitted through the impact on prices, notably the effect of the carbon price on wholesale prices. Alternatively, for demand-side policies, they may also include energy cost savings as consumers lower their demand or shift it to periods where the cost is lower.

We capture these effects in the analysis by valuing these savings at the wholesale price. We do not directly incorporate the value of any additional "comfort taking" as a result of policies in the analysis.[19]

[19] Comfort taking arises when consumers opt to maintain their pre-policy levels of energy use and enjoy the greater comfort this provides. For example, it might be that households carry on using

The below figure shows the simulated wholesale cost impact of removing the policies.

Figure A14: Change in wholesale costs from base case (£ million)



The results in Figure A14 can be summarised as follows:

- The removal of the **carbon prices (CPS & EU ETS)** reduces total wholesale energy costs as the carbon price is no longer passed through into wholesale prices. Unsurprisingly, the saving is most pronounced at times when the carbon prices are high (high EU ETS prices in 2010/11, rising CPS in later years) and also in early years where coal plant are on the margin a greater proportion of the time.
- The removal of **renewable subsidies (ROC, LEC, CfD and FiT)** sees total wholesale energy costs increase as low-cost renewable generation no longer displaces higher cost thermal generation. This results in higher cost thermal generation at the margin. In the case of the FiT, there are some years where this benefit is outweighed by lower start-up/ramping costs without intermittent FiT generation.
- From 2013 onwards, removal of **LCPD & IED** constraints mean that LCPD and IED coal units remain online and displace CCGT units in the merit order in some periods. The impact is to lower the wholesale price, although this falls away in later years as the CPS forces coal plant out of merit.
- Removing **demand side policies** increases total wholesale energy costs due to the higher levels of demand (both annual and peak) that now need to be met.

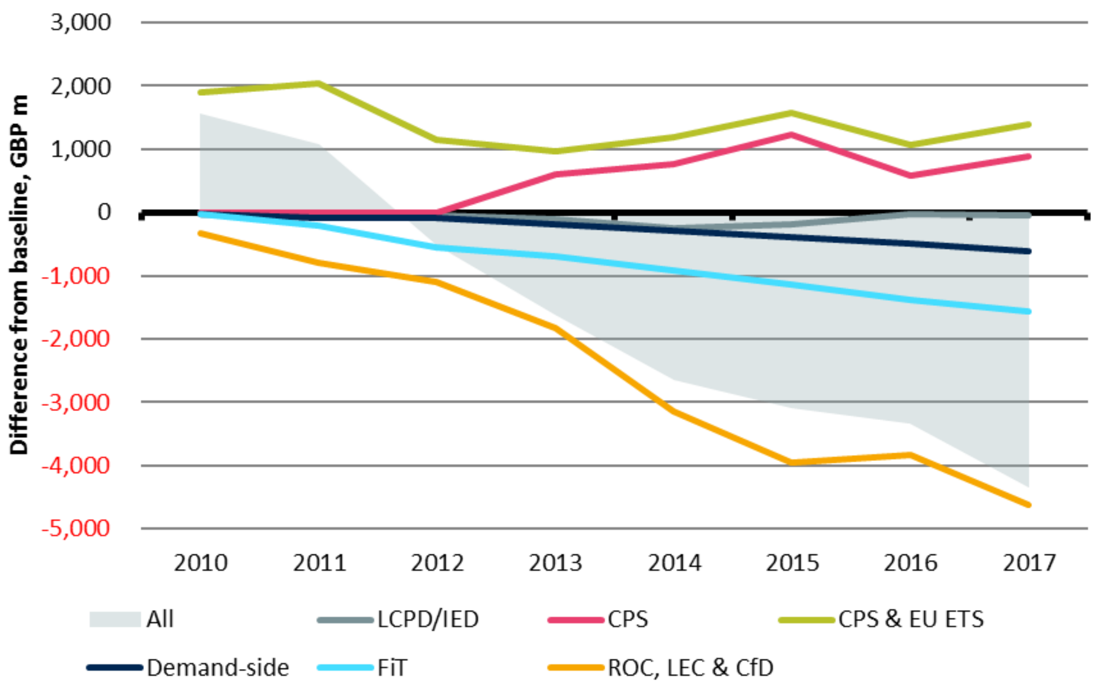
(and paying for) the same total amount of electricity, despite the fall in its price, as they choose to use more lighting in their home.

Policy cost

The removal of policies can also alter the overall cost of support, both directly and indirectly. This includes changes to revenues collected by the exchequer through the CPS.

The below figure shows the simulated effect of policy removal on their overall costs.

Figure A15: Change in policy costs from base case (£ million)



The results in Figure A15 can be summarised as follows:

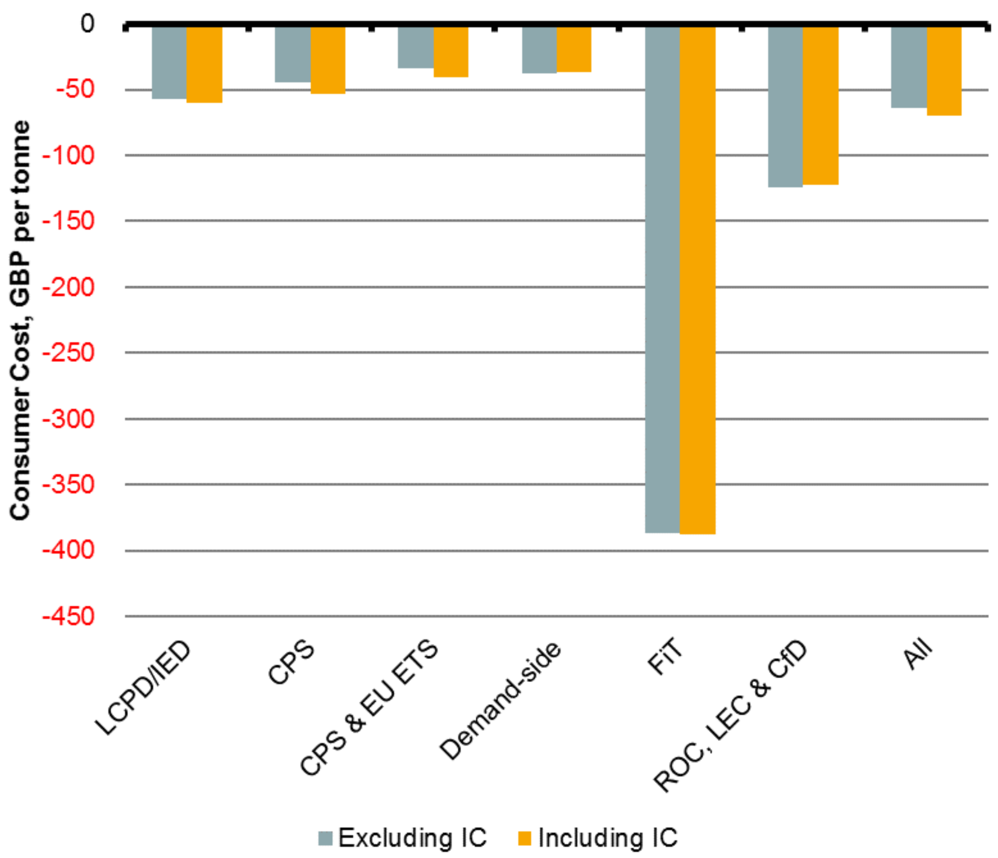
- The removal of the **carbon prices (CPS & EU ETS)** deprives "GB plc" of sources of tax revenue and leads to a net increase in policy costs.
- Withdrawal of the **renewable subsidies (ROC, LEC, CfD and FiT)** leads to significant reductions in policy costs due to the removal of support for renewable generation.
- The **LCPD & IED** constraints do not have a direct policy cost. Nevertheless, their removal sees a small increase in revenues as higher carbon tax receipts are recovered when coal fired generation displaces gas. This results in a small net decrease in policy costs.
- The cessation of **demand side policies** sees a reduction in policy costs through the removal of energy efficiency policies.

Consumer cost metric: policy and wholesale cost per tonne of carbon dioxide

We consider the consumer cost metric, which is calculated as the consumer cost saving for each tonne of carbon dioxide equivalent added by removal of each policy. Consumer costs include policy costs (plus taxes) and wholesale costs.[20]

Figure A16 shows in grey the cost per tonne that is associated with changes in domestic carbon dioxide equivalent emissions.

Figure A16: Consumer cost per tonne of carbon dioxide equivalent emissions (including and excluding interconnector flows)



Note: The direct benefits to consumers who are recipients of policy support is not netted off (eg recipients of FiT support for installing rooftop solar panels).

The results in Figure A16 can be compared against the non-traded value of carbon, which averaged around £62 per tonne of carbon dioxide emitted over the period 2010-2017.[21] The non-traded value of carbon was originally introduced for emissions outside the non-traded sector (i.e. emissions outside the EU ETS), although it is set to converge with the alternative traded value of carbon from 2030 onwards.

The results can be summarised as follows:

[20] When we refer to the consumer we are referring more broadly to both consumers and taxpayers.
[21] See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/666406/Data_tables_1-19_supporting_the_toolkit_and_the_guidance_2017.xlsx

- Measures that placed a price on emissions or restricted the running of the most polluting plant, such as the **LCP / IED and carbon prices (CPS & EU ETS)**, have delivered emissions reductions at a similar cost to the non-traded value of carbon. These policies were instrumental in curbing carbon emissions by incentivising coal to gas switching.

- Support for **large scale renewables (ROC, LEC, CfD)** at £124/tonne and, in particular, **small scale renewables (FiT)** at £387/tonne have, over this period, represented comparatively less good value to consumers.

- The **demand side policies** have represented a net cost to consumers, in addition to their carbon dioxide equivalent reductions, as their energy savings were not sufficient to outweigh their policy costs.

Overall, the polices analysed reduced carbon dioxide emissions at a cost to the consumer of £64/tonne, which was slightly higher than the non-traded value of carbon of £62.

However, policies such as a higher carbon price on GB emissions may have the effect of "exporting" emissions abroad, if GB satisfies a greater proportion of its demand from interconnector imports. To guard against this risk, we assume a marginal emissions factor of 400g/kWh on net imports into GB to approximate the carbon intensity of gas generation. This is based on the observation that CCGT typically occupies the margin for the majority of the year in France, Ireland and the Netherlands (ie the countries we import electricity from).

The orange bars in Figure A16 show the impact of recalculating the consumer cost metric to include an estimate for the change in foreign emissions due to the change in interconnector flows into GB. The overall cost to the consumer of carbon emissions reduction is now estimated to be £70, which suggests that our consumer cost estimates are not hugely sensitive to our assumed carbon intensity of imports.

Consumer cost metric: average abatement cost curve

For this analysis, we consider the "All policies removed" scenario. Consequently, the carbon emissions saving of each individual policy are scaled up and the results are not directly comparable with the preceding section.[22]

Figure A17 shows the average cost to the consumer per tonne of carbon dioxide equivalent emitted versus the total emissions saving associated with the policy. The net cost to the consumer and taxpayer per tonne of carbon dioxide equivalent emissions saved over 2010-2017 varies substantially with the selected decarbonisation policy in the electricity sector.[23] Note that:

- Net costs here include any changes to the costs or revenues the consumer of taxpayer incurs due to carbon pricing.

- Costs are annualised (over twenty years) in order to assist comparison with policies such as large scale renewable subsidies.

The chart reveals that:

[22] Recall that the combined effect of all the policies is one-sixth greater than the sum of individual policy contributions, with the model suggesting that there are 'synergies' that augment the effect of each individual policy when they work in tandem.
[23] Net costs here include any changes to the costs or revenues the consumer of taxpayer incurs due to carbon pricing.

- Per tonne of carbon dioxide equivalent saved, the **carbon price (CPS & EU ETS)** policies cost about £27/tonne.

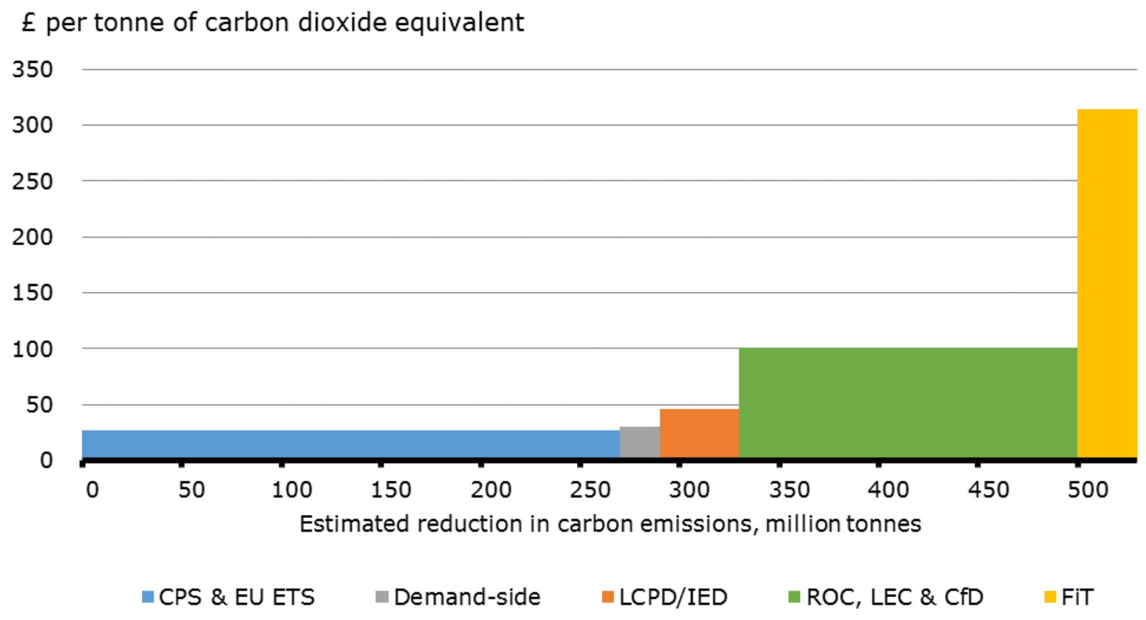
- **Demand side policies** as a group cost around £30/tonne. This would likely have been lower if earlier phases of CERT had fallen within the scope of our analysis.

- The **subsidies to large scale renewables (ROC, LEC, CfD)** cost about £101/tonne. Note this does not include the competitively procured contract for difference auctions – in some case subject to substantial cost reductions – which are largely too recent for inclusion.[24]

- **Small scale renewable subsidies (FiT)** are estimated to cost some £315 per tonne of carbon dioxide equivalent saved. While the total net cost to the consumer of the feed-in-tariff policy (£6.1 billion) is comparable to the carbon price policy (£7.5 billion), the carbon price achieves an emissions reduction almost 15 times that of the feed-in-tariff.

Combined, we estimate that the policies cost around £70 per tonne of carbon dioxide equivalent saved, which is slightly higher than the average non-traded value of carbon of £62.

Figure A17: Average consumer cost of carbon dioxide equivalent emissions abatement (£ per tonne)



Note: The carbon emissions saving of each individual policy has been scaled up so that the total emissions saving are equal to that of the "All policies removed" scenario run. This improves the cost effectiveness of each policy. The CPS scenario is excluded due to overlap with the combined EU ETS & CPS scenario.

System cost metric: policy and wholesale cost per tonne of carbon dioxide

The alternative system cost metric is calculated as the system costs (ie excluding carbon costs) saved per tonne of carbon dioxide equivalent added by the removal of each policy.

[24] The CCC shows that CfD auctions are now delivering greater value for money than both the ROC and the FiDeR contracts. See: CCC Prices and Bills report 2017.

Figure A20 suggest that:

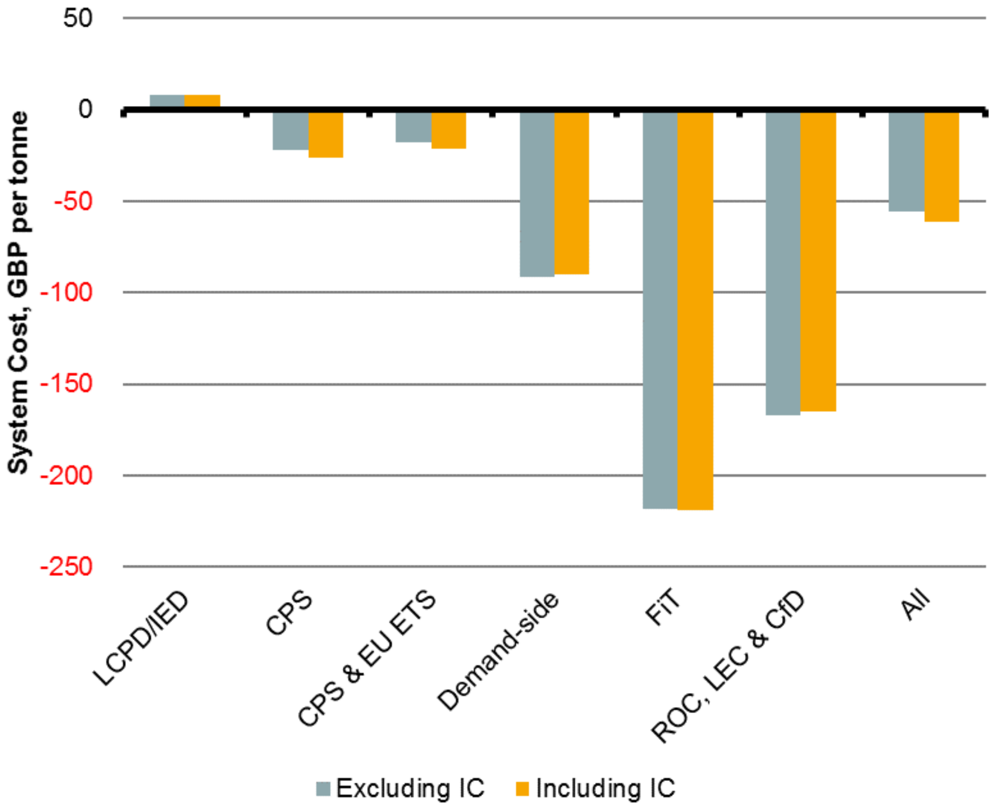
- **LCPD & IED** removal leads to a slight increase in system costs across the period as the removal of these policies leads to increased operating expenditure costs in later years that negate the generation costs benefits. This means the policy represented a positive overall impact, reducing emissions and other system costs.

- For the **carbon price (CPS & EU-ETS)**, compared to the non-traded value of carbon, our analysis shows these measures represented good value in terms of the additional system costs incurred per tonne of carbon dioxide equivalent removed.

- As in the consumer cost metric, the **support for renewables (ROC, LEC, CfD, FiT)** has resulted in high system cost increases per tonne of carbon dioxide equivalent removed. This is largely down to the additional system costs associated with the capex and opex of the renewable plant outweighing the generation cost savings of displacing thermal generation with renewable generation.

- In addition, the high system costs for **ROC, LECs & CFDs** includes increased network costs (particularly for wind) and fuel costs associated with burning biomass.

Figure A18: System cost per tonne of carbon dioxide equivalent emissions (including and excluding interconnector flows)



System cost metric: average abatement cost curve

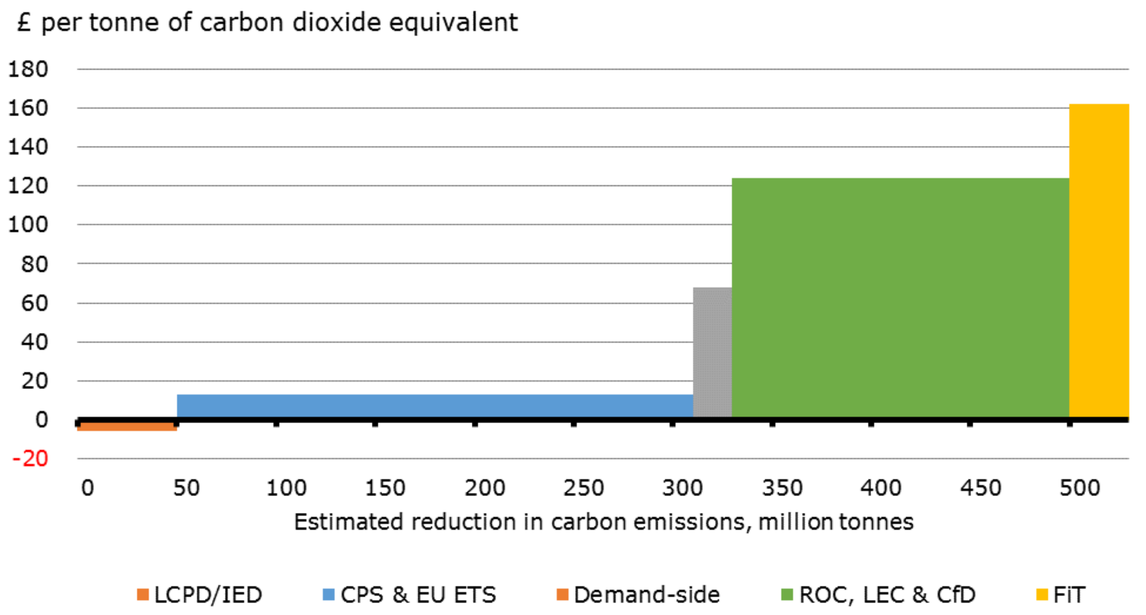
Again this analysis considers the "All policies removed" scenario and the scaled up results are not directly comparable with the preceding section.

Figure A19 shows, for the selected abatement policies, the average cost to the system per tonne of carbon dioxide equivalent emitted versus the total emissions saving associated with the policy. It can be seen that:

- **Carbon prices (CPS & EU ETS)** delivered substantial emissions reductions at a low cost of around £13/tonne.
- **Large scale renewables subsidies (ROC, LEC, CfD)** achieve reductions at a similar cost as before of around £124/tonne. This greater cost reflects the capex and opex costs incurred.
- **Demand side policies** are shown to be reasonably good value for money at around £68/tonne.
- **Air quality directives (LCPD & IED)** are the best value for money compared with the estimated social cost of emissions with a saving of £6/tonne. This net benefit mostly arises due to avoided opex costs incurred by out of merit coal plant in later years.
- **Small scale renewables subsidies (FiT)** are still the most expensive, now at around £161/tonne, with the lower cost compared with the consumer metric reflecting a generous transfer.

The combination of all policies over 2010-2017 saved a tonne of carbon dioxide equivalent at a cost of roughly £59, lower than the non-traded value of carbon of £62.

Figure A19: Average system cost of carbon dioxide equivalent emissions abatement (£ per tonne)



Note: The carbon emissions saving of each individual policy has been scaled up so that the total emissions saving are equal to that of the "All policies removed" scenario run. This improves the cost effectiveness of each policy. The CPS scenario is excluded due to overlap with the combined EU ETS & CPS scenario.

Analysis of other sectors

Overview

This analysis covers gas, oil, solid fuels and biofuels energy savings in the agriculture, commerce, domestic, industry and public sectors.

We focused on energy efficiency policies, which together account for an estimated 17 million tonnes of carbon dioxide equivalent reductions over 2010-2017.[25] Note many of these policies do not have decarbonisation as their sole or even central objective, eg "ECO to 2017" is more focused on assisting vulnerable consumers. This implies that their value for money in terms of reducing carbon dioxide emissions may vary considerably.

Methodology

The key areas that we consider in gas, oil, solid fuels and biofuels are the policy cost, the wholesale energy saving and carbon dioxide equivalent emissions effects over the period 2010-2017. Our analysis then allows us to compare the average cost to the consumer per tonne of carbon dioxide equivalent emitted.

The approach relies on a slightly different set of assumptions than those that were used in the analysis of the electricity sector. As GB is a price taker of gas, we consider that demand-side policies are unlikely to drive wholesale price effects. This is unlike the electricity sector, where demand-side policies have wholesale price effects that are linked to the electricity supply curve.

Energy savings

We use BEIS estimates of the energy consumption reductions (in TWh) by fuel (gas, oil, solid fuels, biofuels) that is associated with our selected policies. In most instances, the energy savings of the policy are consistent with the values that are available in published Impact Assessments.

Electricity savings are then converted to emissions reduction using annual carbon dioxide equivalent per KWh values.[26] For gas, liquid fuels and solid fuels we use DEFRA conversion factors to identify the carbon emissions impact.[27] The approach we use is to:

- Identify the annual carbon dioxide equivalent per KWh conversion factor for each fuel type in the gas, liquid fuels and solid fuels categories.
- Construct a weighted annual carbon dioxide equivalent per KWh conversion factor for gas, liquid fuels and solid fuels using the conversion factors and consumption volumes for each fuel type.

Wholesale price effects

We value the energy savings at the relevant wholesale price for each fuel type and year. Specifically, we use the following prices with the data source given in parenthesis:

- Day ahead gas prices (ICIS);
- Brent crude oil (Bloomberg); and

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[25] This analysis draws on BEIS estimates of the energy consumption impact of these policies.
[26] See: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2017
[27] See: https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

- NWE coal $/tonne (ICIS).

Where appropriate, we use annual exchange rate data from the Bank of England to express the price effects in sterling.[28]

Policy cost data

We drew policy cost data from a range of sources and these are summarised below. We apportioned these below costs to the other sectors (gas, oil, solid fuels and biofuels) according to the portion of total emissions savings of the policy attributed to these sectors by BEIS. This implies that around 11% of the below policy costs are attributable to the other sectors.

Figure A20: Breakdown of policy costs attributed to other sectors (£ m)

Policy	2010	2011	2012	2013	2014	2015	2016	2017	Source
CERT (extension)	-	436	523	-	-	-	-	-	DECC[29]
CERT (+20%)	382	64	-	-	-	-	-	-	
CESP	101	101	101	-	-	-	-	-	
Smart Metering (domestic)	-	-	-	64	58	154	261	347	BEIS[30]
Smart Metering (non-domestic)	-	-	-	11	10	9	9	13	
ECO	-	-	-	108	123	50	46	10	NAO and BEIS[31]
ECO (extension)	-	-	-	-	-	-	-	86	BEIS[32]
RHI (domestic)	-	-	-	-	2	24	36	59	Ofgem[33]
RHI (non-domestic)	-	-	2	24	69	217	374	588	Ofgem[34]
Total	**483**	**601**	**627**	**207**	**263**	**454**	**726**	**1,103**	

Note: Costs deflated to 2016 terms using the Retail Price Index.

28 See: http://www.bankofengland.co.uk/boeapps/iadb/fromshowcolumns.asp?excel97.x=yes&Datefrom=01/Jan/1992&Dateto=Now&SeriesCodes=XUMABK67,XUMAUSS,XUMAJYS,XUMAERS&UsingCodes=Y&VPD=Y

29 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/350957/CERT_CESP_Evaluation_Exec_summary.pdf

30 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/567168/OFFSEN_2016_smart_meters_cost-benefit-update_Part_II_FINAL_VERSION.PDF

31 https://www.nao.org.uk/wp-content/uploads/2016/04/Green-Deal-and-Energy-Company-Obligation.pdf and https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/586266/ECO_Transition_Final_Stage_IA__For_Publication_.pdf

32 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/586266/ECO_Transition_Final_Stage_IA__For_Publication_.pdf

33 https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/contacts-guidance-and-resources/public-reports-and-data-domestic-rhi

34 https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/contacts-guidance-and-resources/public-reports-and-data

Consistent with the analysis of the electricity sector, for the abatement cost curves we adjust demand-side policy costs so they are annualised over twenty years, and only consider costs that then fall within the period 2010-2017.[35] This is to assist comparability with other policies (such as ROCs, which offer support over many years) as we acknowledge that some policies may have large upfront capital costs.

We have not included detailed analysis of the cost effectiveness of individual demand-side policies within this report. This is due to the aforementioned concern that it may not be reasonable to compare policies on the basis of their cost effectiveness in reducing carbon dioxide emissions when they were potentially designed to deliver different objectives from decarbonisation of the energy system.

[35] We calculate the equivalent annual cost over 20 years using a discount rate of 3.5%.