Programme Area: Carbon Capture and Storage

Project: Hydrogen Turbines Follow On

Title: Power Sector CCS and H2 Turbine Asset Modelling

Abstract:

Various scenarios for the UK's power fleet composition in 2030 and 2040 were developed. Dispatch modelling in Plexos was carried out by Baringa on these fleets to investigate the role gas fed plants might have in future. This includes the ability to study load factors, stop/starts etc, and together with concomitant pricing, provide a picture of investment remuneration. The effect of key drivers is studied e.g. gas price.

Context:

Increasing amounts of subsidised renewable power is reducing load factors of gas fired power generation. This work set out to get a view on whether new gas GT looked investible, and if GTs with CCS could expect reasonable load factors. The work concludes with a comparison of gas usage in three scenarios , the first being a continuation of current trends in fleet composition, the second where renewable lead the decarbonisation , and a third where baseload plants lead decarbonisation . Slidepack and excel formats are provided.

Power sector CCS and H2 Turbine Asset Modelling

Central Decarb market modelling results

- **Client** ▶ ETI
- **Date** ▶ 16/11/2017
- **Version** ▶ V2_0

Agenda

- Introduction
- Overview of key assumptions
- Wholesale market modelling results
- Conclusions

Introduction

Requirements and objectives of the analysis

Overview

- ETI would like to characterise better the fundamental operation of different types of gas and H2 electricity plant in future GB electricity systems in 2030 and 2040 (the later date sufficient to enable meaningful consideration of the role of CCS) to support their internal programmes on financial viability of new low carbon generation and an understanding of the desirability of different technical characteristics (e.g. flexibility) within the wider electricity system.

- A new ***Central Decarb*** has been established for this analysis, which aims to provide a scenario that is somewhere between the previous *HiBaseDecarb* and *HiRenDecarb* scenarios in terms of capacity mix (provided by ETI) and emissions intensity and which also
  - Models 2025, 2030, 2035 and 2040 spot years
  - Constrains the operation of H2 turbines to a maximum of 40% as opposed to the baseload operation see in previous scenarios

- A number of sensitivities have also been run including:
  - *HiBaseDecarb* in 2040 with relaxed carbon intensity (by removing proxy CfDs and CO2 price) to see the resulting emission intensity
  - On *Central Decarb* in 2030 and 2040 to explore ‘small’ changes to Gas CCS capacity to see the impact on wholesale prices and emission intensity of power generation.
    - Increasing (and removing) CCS capacity and removing (adding) the same amount of CCGT in 2030 and 2040 to keep capacity margin at similar levels to Central Decarb (+/- 1 GW in 2030 and +/- 3 GW in 2040)

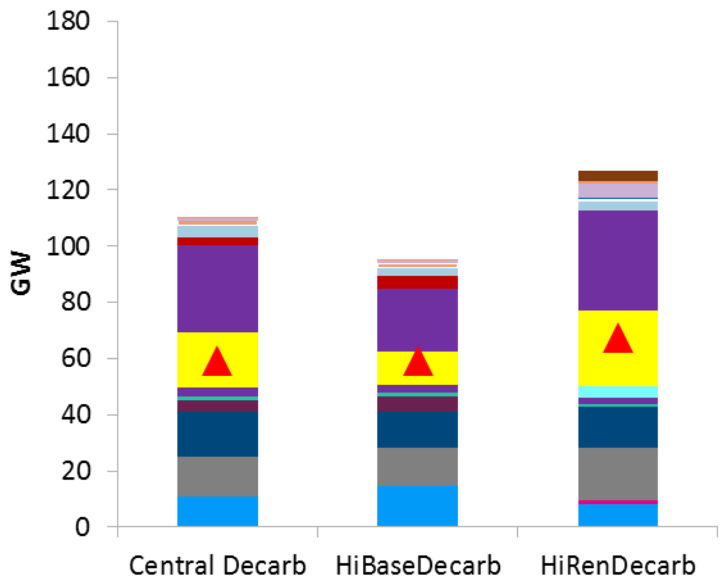
Capacity mix and demand

Comparison of supply and demand for 2030 and 2040 between the three scenarios

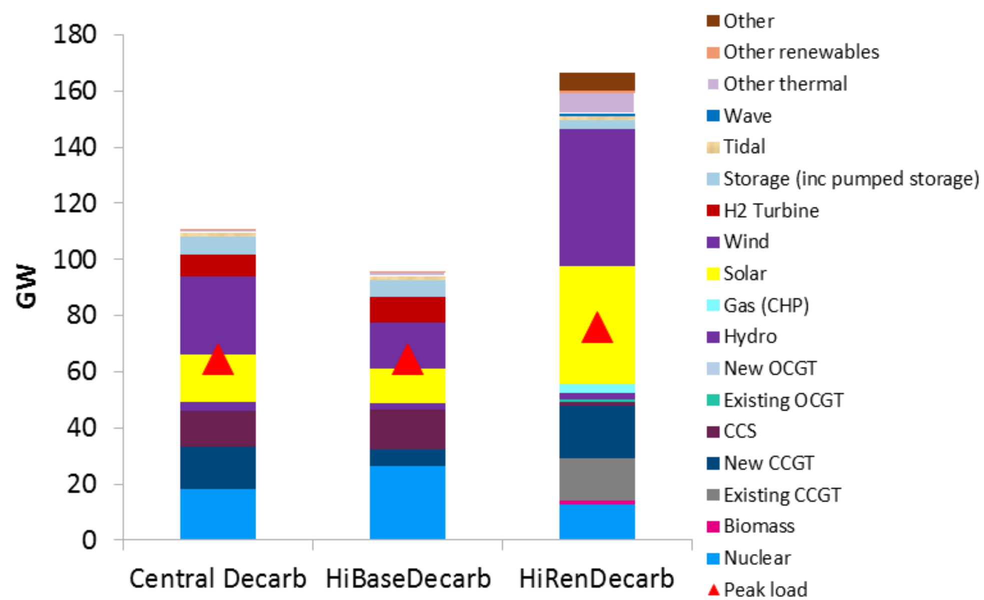
Installed Capacity (GW) (Scenarios: Central Decarb, HiBaseDecarb and HiRenDecarb)

- Target CO2 intensity for Central Decarb is between HiBaseDecarb and HighRenDecarb (~66 g/kWh in 2030 and ~42 g/kWh in 2040)
- Central Decarb also caps the maximum load factors for H2 turbines to 40% similar to a mid-merit plant.

2030 supply and demand



2040 supply and demand

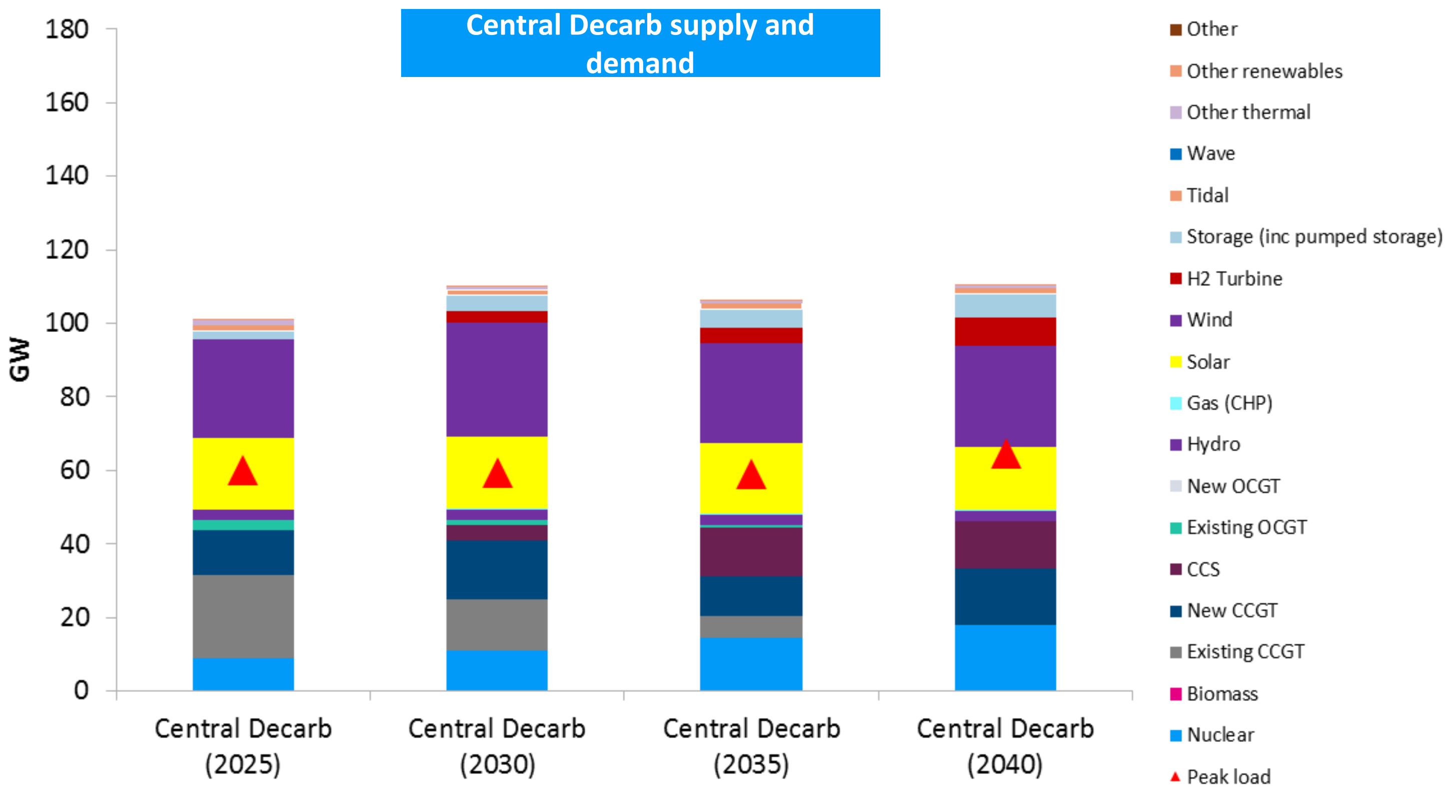


Capacity mix and demand

Central Decarb supply and demand in from 2025 to 2040

Installed Capacity (GW) (Scenarios: Central Decarb)

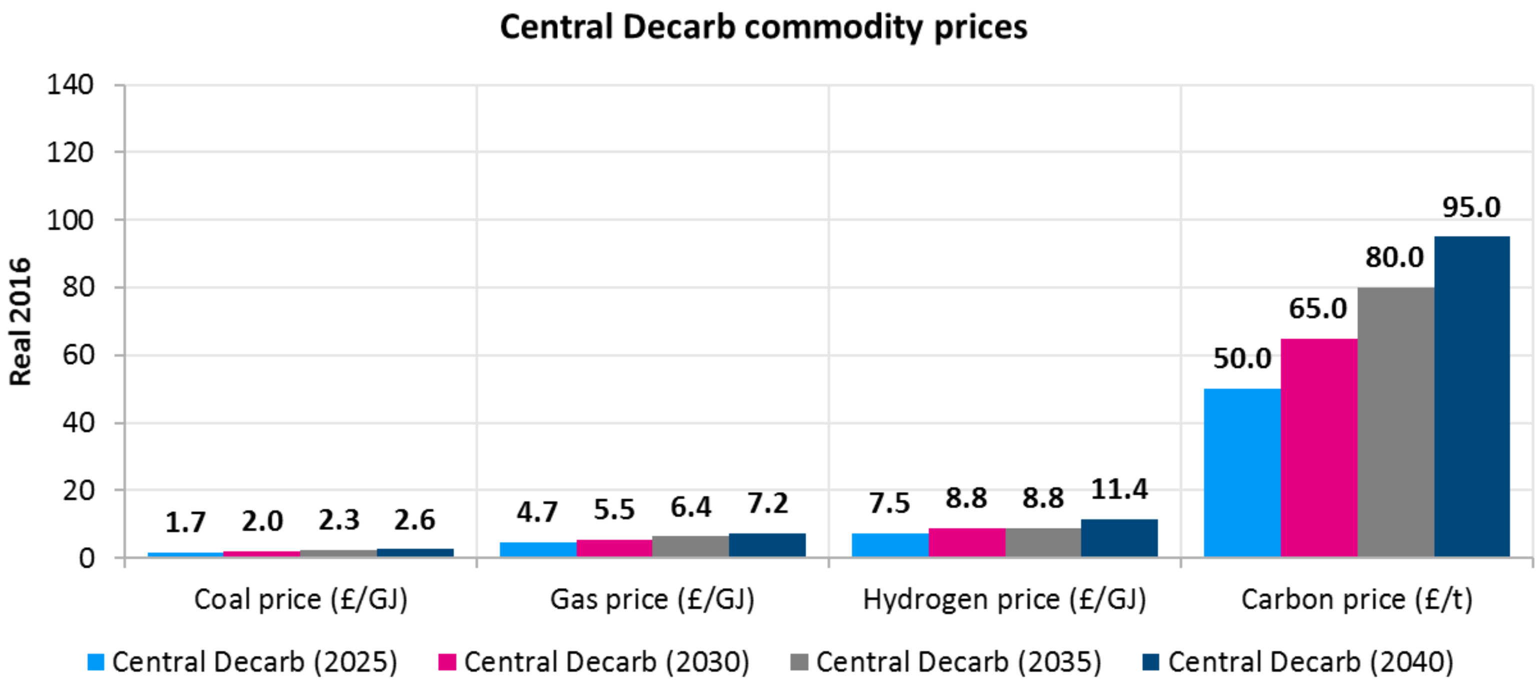
- For 2025 and 2035 the implied CO_2 price trend from the other years has been extrapolated and applied rather than a target intensity (i.e. for these years CO_2 intensity is an outturn result rather than a constraint)



Commodity prices (real 2016 prices)

Commodity prices in Central Decarb

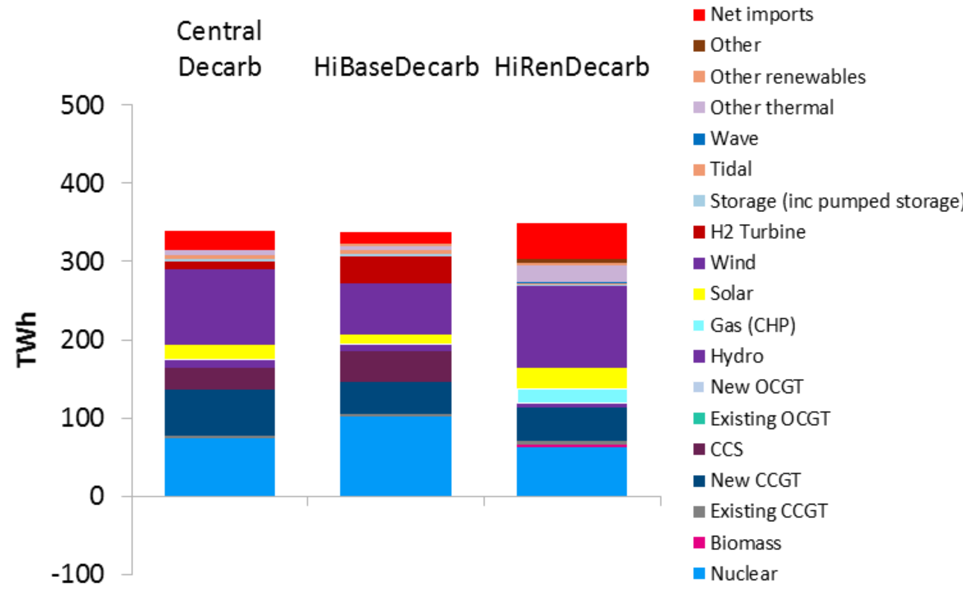
- Central Decarb commodity prices (apart from carbon) are the same as those in the HighRenDecarb and HiBaseDecarb scenarios and based on IEA assumptions (with SMR based conversion for H2 using ETI conversion efficiency assumptions)
- Carbon prices for 2030 and 2040 in this scenario have been determined to achieve a target carbon intensity between HiBaseDecarb and HiRenDecarb as mentioned in the previous slide.
- Carbon prices for 2025 and 2035 for Central Decarb are based on extrapolation from above values for 2030 / 2040



Gas generation in the power mix in 2030

2030 Generation mix overview across scenarios

- We have included an estimate of CfD prices for eligible generation types in 2030 and 2040 in all the three scenarios (based on BEIS administered strike prices with adjustments for changes future technology and commodity costs)*
- In 2030, due to the high share of baseload low carbon generation (e.g. nuclear and CCS) in HiBaseDecarb and Central Decarb, imports to GB are significantly reduced
- Nuclear and CCS generation are reduced in Central Decarb compared to HiBaseDecarb due to lower capacity
- New and existing CCGT load factors are slightly higher in Central Decarb compared to HiBaseDecarb as a result
- In HiBaseDecarb with the high carbon price and CfD levels for H2 GT and CCS, they run baseload at an annual level.
- Due to the same reasoning, CCS runs baseload in Central Decarb. H2 GTs run at the maximum annual capacity factor of 40% allowed in this scenario with CfDs in place



Gas plant generation (TWh) and load factors	HiBaseDecarb	Central Decarb	HiRenDecarb
Existing CCGT	2.8 (2%)	3.6 (3%)	5.6 (3%)
New CCGT	40 (37%)	58.1 (41%)	42.1 (33%)
Existing OCGT	0 (0%)	0 (0%)	0 (0%)
New OCGT	0 (0%)*	0 (0%)*	0 (0%)
CCS	40.4 (85%)	29 (84%)	0 (0%)*
H2 Turbine	34.4 (90%)	10.9 (40%)	0 (0%)*

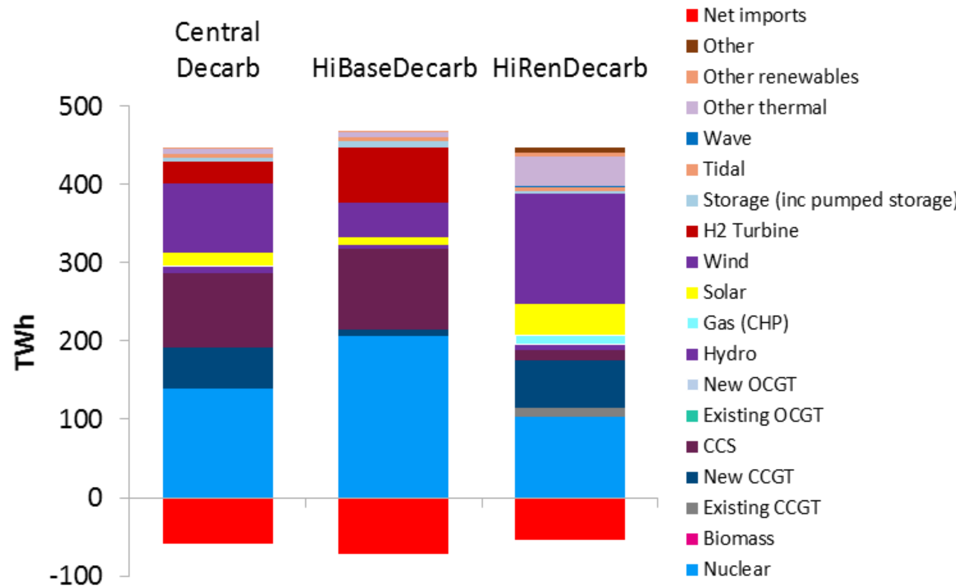
**The CfDs incentivise plant to remain on the system, so can impact dispatch and prices*

**The installed capacity is 0, so the load factor, generation and gas consumption are 0%*

Gas generation in the power mix in 2040

2040 Generation mix overview across scenarios

- In 2040, GB exports to a significantly higher extent in all cases with high share of low carbon generation (to a higher extent in HiBaseDecarb due to high nuclear and CCS generation, which generates baseload)
- Existing CCGT runs low load factors (~10%) in the HiRenDecarb scenario - albeit increasing slightly compared to 2030 – mainly due to higher requirement for back up capacity in the HiRenDecarb world with a high share of intermittent generation
- New CCGT load factors are the highest in Central Decarb, due to lower carbon prices, remaining at similar levels to 2030. New CCGT load factors increase slightly in HiRenDecarb helping to accommodate more intermittent wind and solar, however, they are significantly reduced in HiBaseDecarb as they are displaced by H2 turbines.
- CCS runs baseload in all cases, with the CfD being in place. Similarly, H2 GTs run baseload in HiBaseDecarb (no H2 GT comes online in the HiRenDecarb case).
- H2 GTs run at the maximum capacity factor of 40% allowed in Central Decarb due to the CfDs being in place



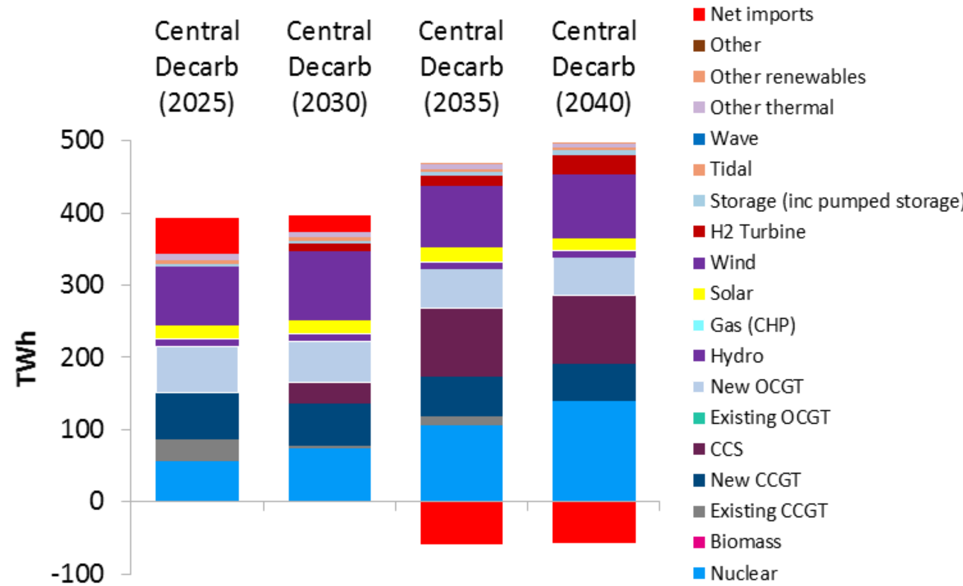
Gas plant generation (TWh) and load factors	HiBaseDecarb	Central Decarb	HiRenDecarb
Existing CCGT	0 (0%)*	0 (0%)*	12.1 (9%)
New CCGT	9 (18%)	52 (39%)	59.8 (37%)
Existing OCGT	0 (0%)*	0 (0%)*	0 (0%)
New OCGT	0 (0%)*	0 (0%)*	0 (0%)
CCS	103.1 (84%)	95.6 (84%)	13.7 (87%)
H2 Turbine	70.7 (90%)	27.3 (40%)	0 (0%)*

**The installed capacity is 0, so the load factor, generation and gas consumption are 0%*

Gas generation in the power mix in Central Decarb

Evolution of generation mix in Central Decarb from 2025 to 2040

- We have included an estimate of CfD prices for eligible generation types from 2025 to 2040 (based on BEIS administered strike prices with adjustments for changes future technology and commodity costs)*
- Going from 2025 to 2040, GB switches from being a net importer to being net exporter as the penetration of low carbon generation increases
- As a result, total generation from CCGTs decreases in the same period, being offset by the increase in CCS, H2 GT and CCS generation
- CCS runs baseload in all cases due to CfDs being in place, whereas H2 GTs run at the maximum allowed annual capacity factor of 40% with CfDs



Gas plant generation (TWh) and load factors	2025	2030	2035	2040
Existing CCGT	28.9 (15%)	3.6 (3%)	12.8 (24%)	0 (0%)*
New CCGT	64.7 (61%)	58.1 (41%)	54.4 (57%)	52 (39%)
Existing OCGT	0.1 (0%)	0 (0%)	0 (0%)	0 (0%)*
New OCGT	0 (0%)*	0 (0%)*	0 (0%)*	0 (0%)*
CCS	0 (0%)*	29.0 (84%)	95.5 (84%)	95.6 (84%)
H2 Turbine	0 (0%)*	10.9 (40%)	14.8 (40%)	27.3 (40%)

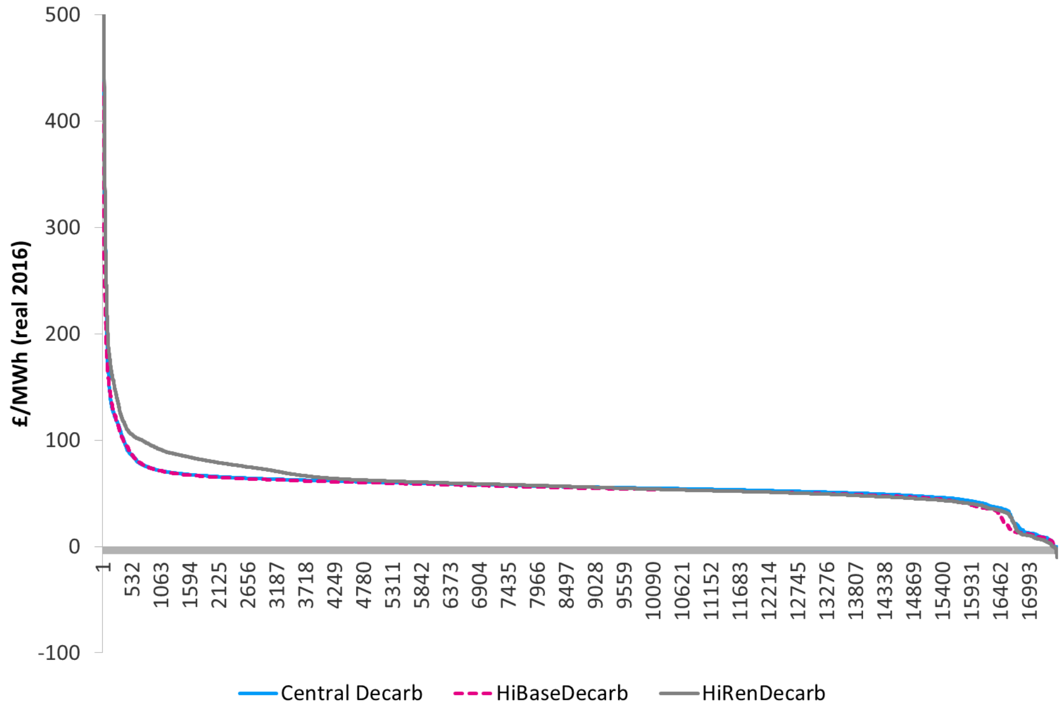
**The CfDs incentivise plant to remain on the system, so can impact dispatch and prices*

**The installed capacity is 0, so the load factor, generation and gas consumption are 0%*

Comparison of GB price duration curves in 2030

GB (day-ahead wholesale station gate basis) power price in 2030 (real 2016 prices) including scarcity and technical uplift

- The comparison of the price duration curves for GB in 2030 is shown below. There are fewer hours with very high power prices in the HiBaseDecarb scenario with significant CCS and nuclear baseload generation compared to the other scenarios
- Annual price levels are slightly higher in Central Decarb compared to HiBaseDecarb due to lower share of low carbon baseload capacity
- The level of decarbonisation achieved in the power sector in Central Decarb is targeted to be around the level of 66 gCO2/KWh as the midpoint between the HighBaseDecarb and HighRenDecarb cases



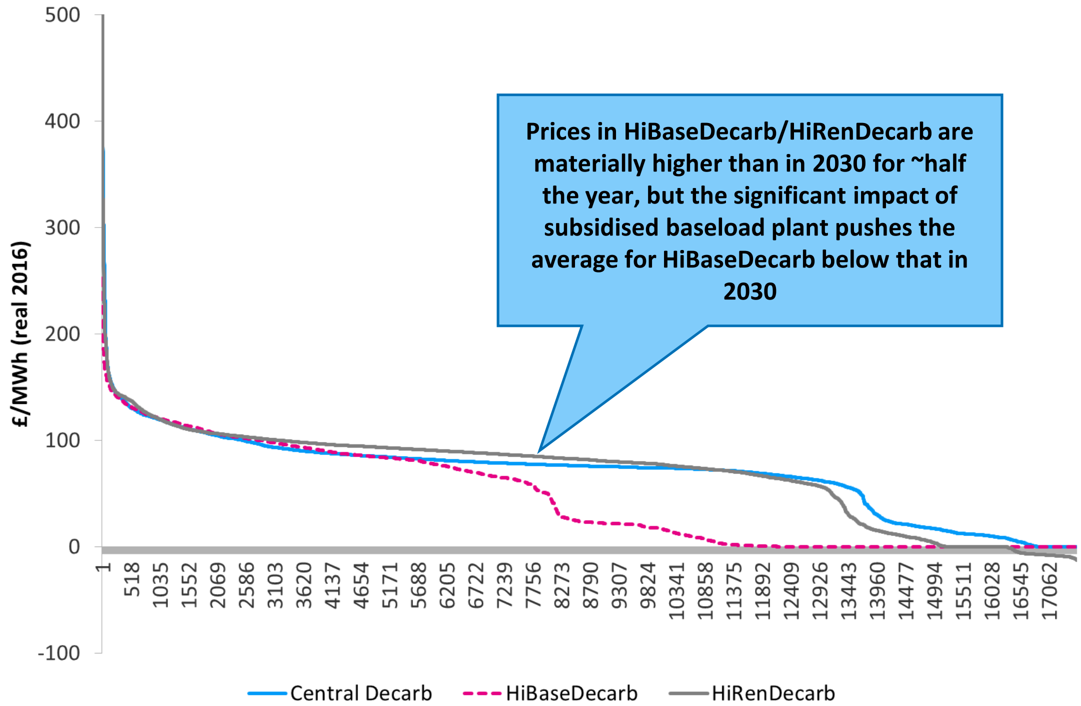
Scenarios	GB time weighted price (£/MWh)	Carbon intensity (gCO2/kWh)
HiBaseDecarb	56.0	50.2
Central Decarb	58.0	68.4
HiRenDecarb	60.4	82.3

Scenarios	No of half hours with negative prices	No of half hours with prices above 500 £/MWh
HiBaseDecarb	20	19
Central Decarb	25	33
HiRenDecarb	46	32

Comparison of GB price duration curves in 2040

GB (day-ahead wholesale station gate basis) power price in 2040 (real 2016 prices) including scarcity and technical uplift

- The difference in the price duration curves in the three scenarios becomes more significant in 2040. The number of hours with low or near zero prices is highest in HiBaseDecarb with a significant increase in baseload nuclear, CCS and H2 GT generation in the long term, which are also eligible for CfDs.
- Central Decarb carbon intensity is in between HiBaseDecarb and HighRenDecarb whereas annual baseload price is very close to HiRenDecarb case due to limitation on the running hours for H2 GTs and unabated gas setting the price in a large number of hours



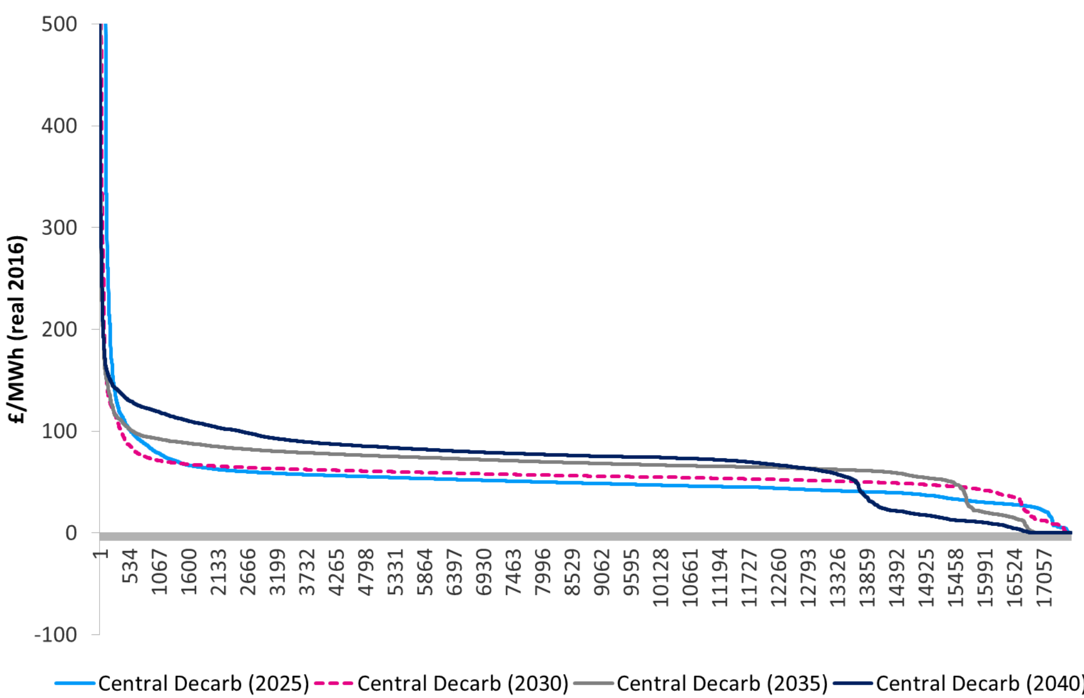
Scenarios	GB time weighted price (£/MWh)	Carbon intensity (gCO2/kWh)
HiBaseDecarb	46.2	15.3
Central Decarb	69.9	45.4
HiRenDecarb	69.9	69.3

Scenarios	No of half hours with negative prices	No of half hours with prices above 500 £/MWh
HiBaseDecarb	2,002	0
Central Decarb	396	5
HiRenDecarb	1,254	7

Comparison of GB price duration curves in Central Decarb

Evolution of GB (day-ahead wholesale station gate basis) power prices in Central Decarb from 2025 to 2040 including scarcity and technical uplift (real 2016 prices)

- Annual baseload price levels increases from 2025 to 2040 mainly driven by increasing commodity and carbon prices and CCGT still often the marginal plant. Emission intensity of power generation decreases with increasing penetration of low carbon generation
- The number of negative price periods increases to 2040 with increasing generation from CfD eligible plant such as CCS and H2 GTs

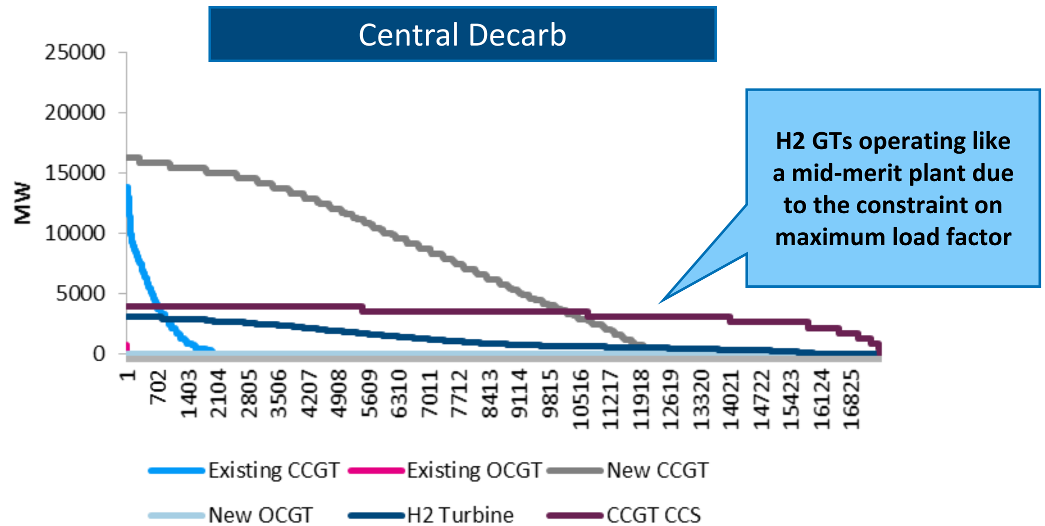


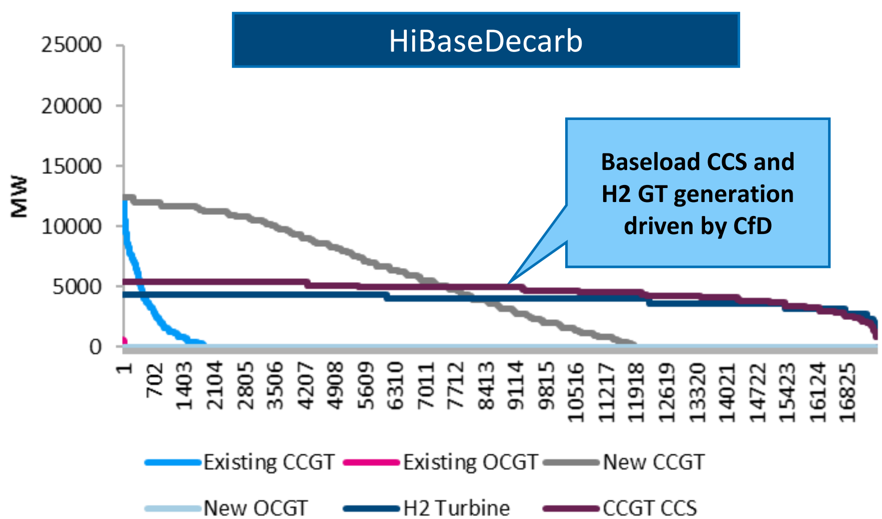
Scenarios	GB time weighted price (£/MWh)	Carbon intensity of power generation (g CO2/kWh)
Central Decarb (2025)	56.6	120.7
Central Decarb (2030)	58.0	68.4
Central Decarb (2035)	67.3	60.8
Central Decarb (2040)	69.9	45.4

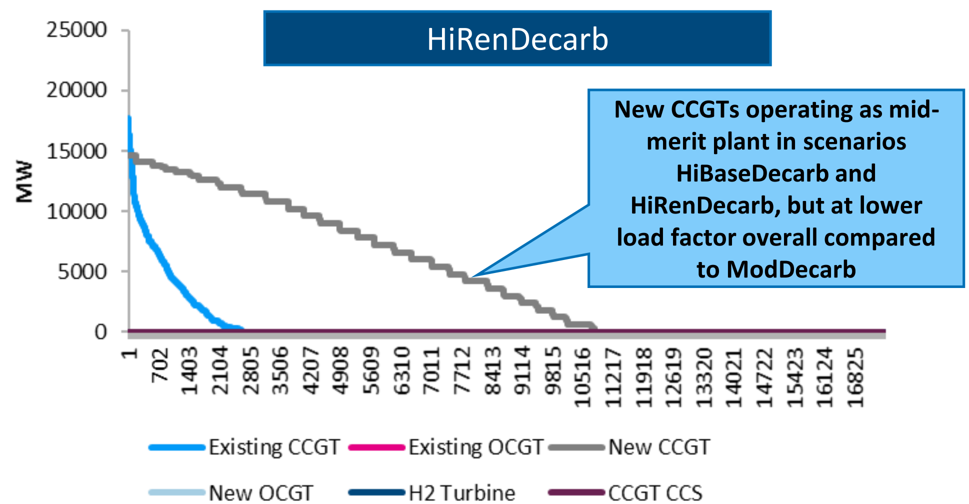
Scenarios	No of half hours with negative prices	No of half hours with prices above 500 £/MWh
Central Decarb (2025)	1	113
Central Decarb (2030)	25	33
Central Decarb (2035)	358	13
Central Decarb (2040)	396	5

Generation duration curves 2030

Flexible gas generation

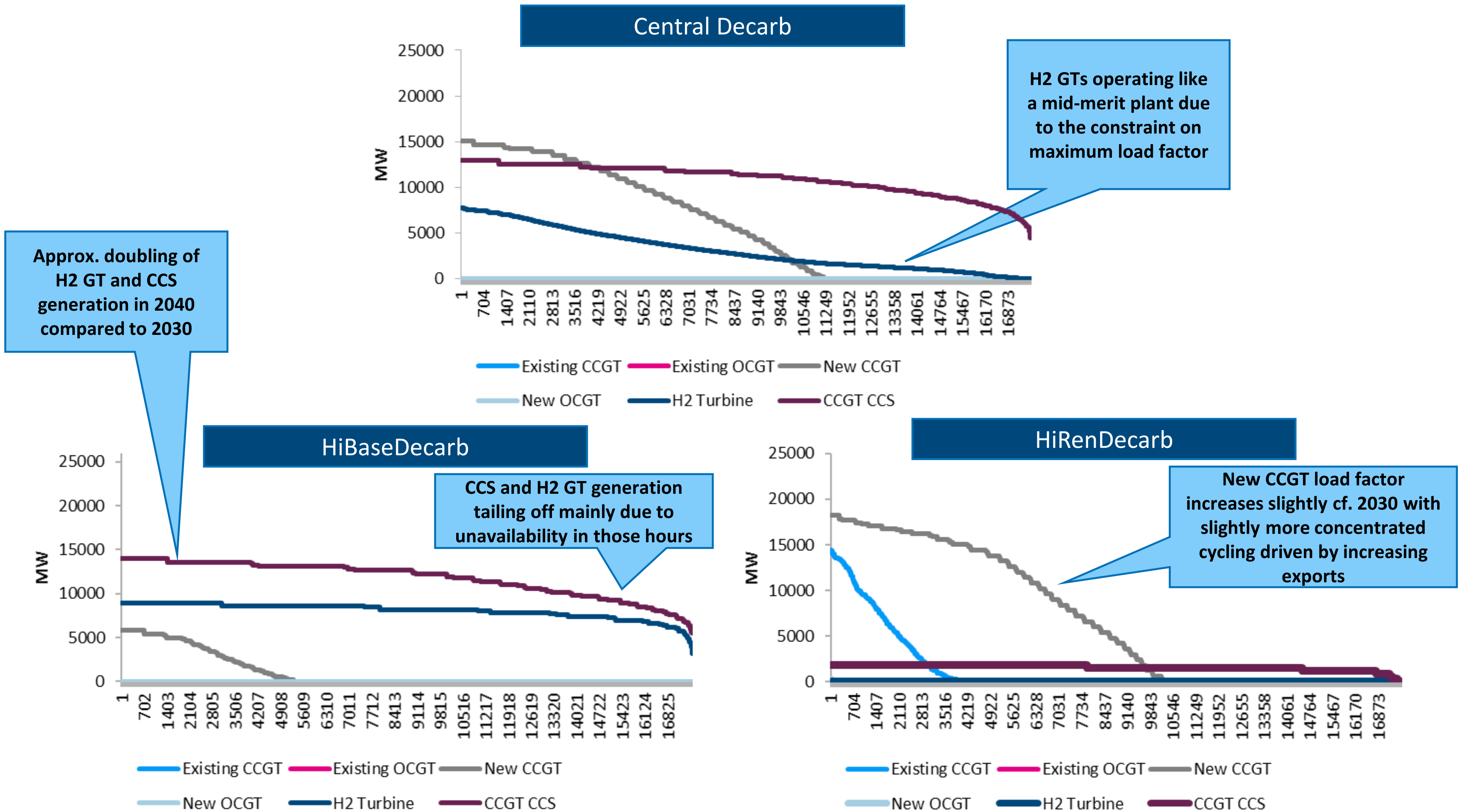






Generation duration curves 2040

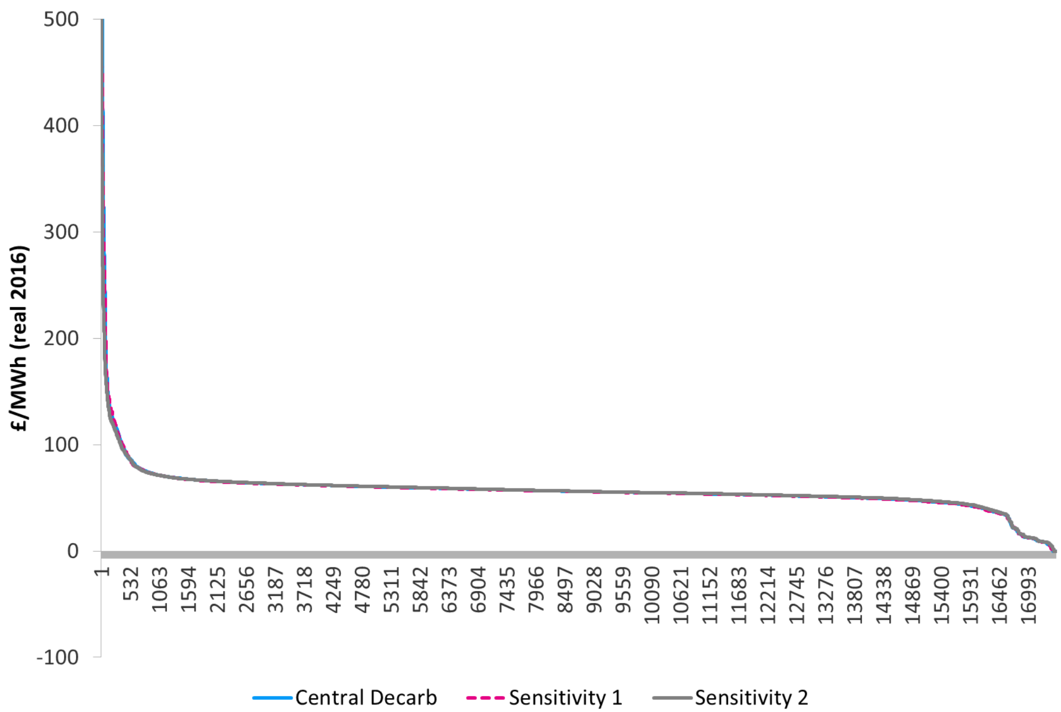
Flexible gas generation



Central Decarb sensitivities for 2030

GB (day-ahead wholesale station gate basis) power price in 2030 (real 2016 prices) including scarcity and technical uplift

- We have also carried out two sensitivities for Central Decarb in 2030 and 2040 to see the impact on prices and emission intensity
- **Sensitivity 1 for 2030** includes **adding 1 GW of CCS** and **removing 1 GW of CCGT** to keep the capacity margin at similar levels to Central Decarb. **Sensitivity 2 for 2030 includes removing 1 GW of CCS** and **adding 1 GW of CCGT** accordingly
- As can be seen below, the annual baseload prices remain at very similar levels to Central Decarb given the role of unabated gas at the margin in the two sensitivities, whereas the emission intensity is more materially affected by the change in CCS.



Scenarios	GB time weighted price (£/MWh)	Carbon intensity (gCO2/kWh)
Central Decarb	58.0*	68.4
Sensitivity 1	57.5*	63.9
Sensitivity 2	57.4*	73.4

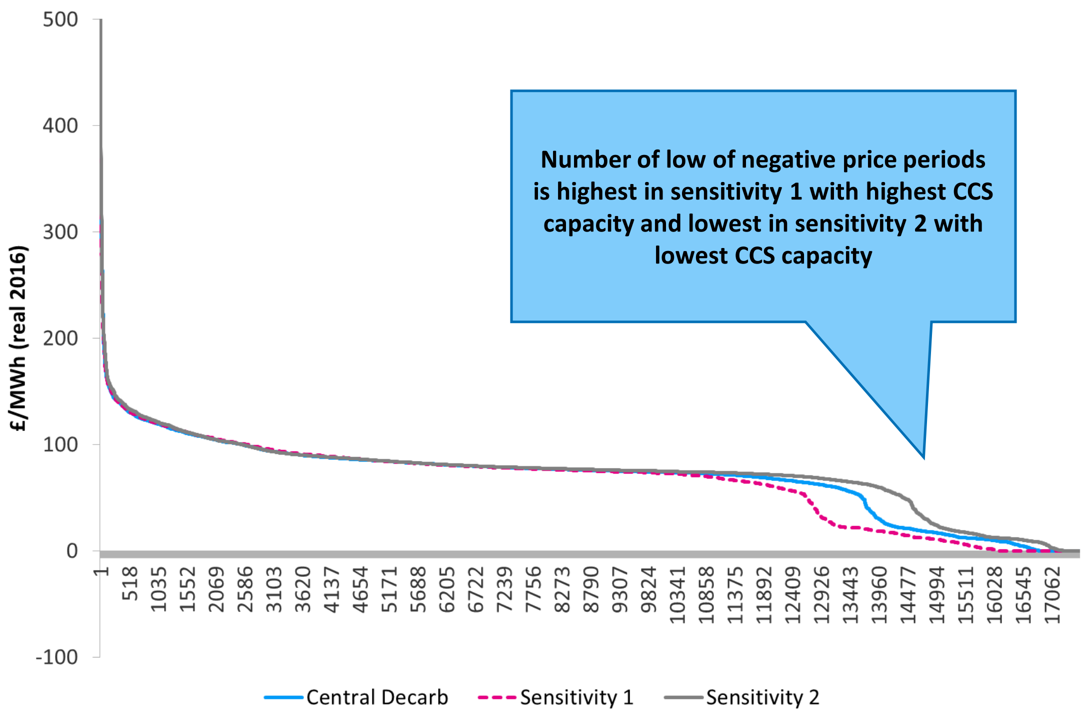
Scenarios	No of half hours with negative prices	No of half hours with prices above 500 £/MWh
Central Decarb	25	33
Sensitivity 1	30	22
Sensitivity 2	20	23

*Minor differences due to e.g. scheduled maintenance

Central Decarb sensitivities for 2040

GB (day-ahead wholesale station gate basis) power price in 2040 (real 2016 prices) including scarcity and technical uplift

- **Sensitivity 1 for 2040** includes **adding 3 GW of CCS** and **removing 3 GW of CCGT** to keep the capacity margin at similar levels to Central Decarb. **Sensitivity 2 for 2040 includes removing 3 GW of CCS** and **adding 3 GW of CCGT** accordingly
- The variation in average annual baseload price is more material, in particular it highlights the sensitivity of prices in low demand periods across the year when there is a significant quantity of subsidised low carbon baseload



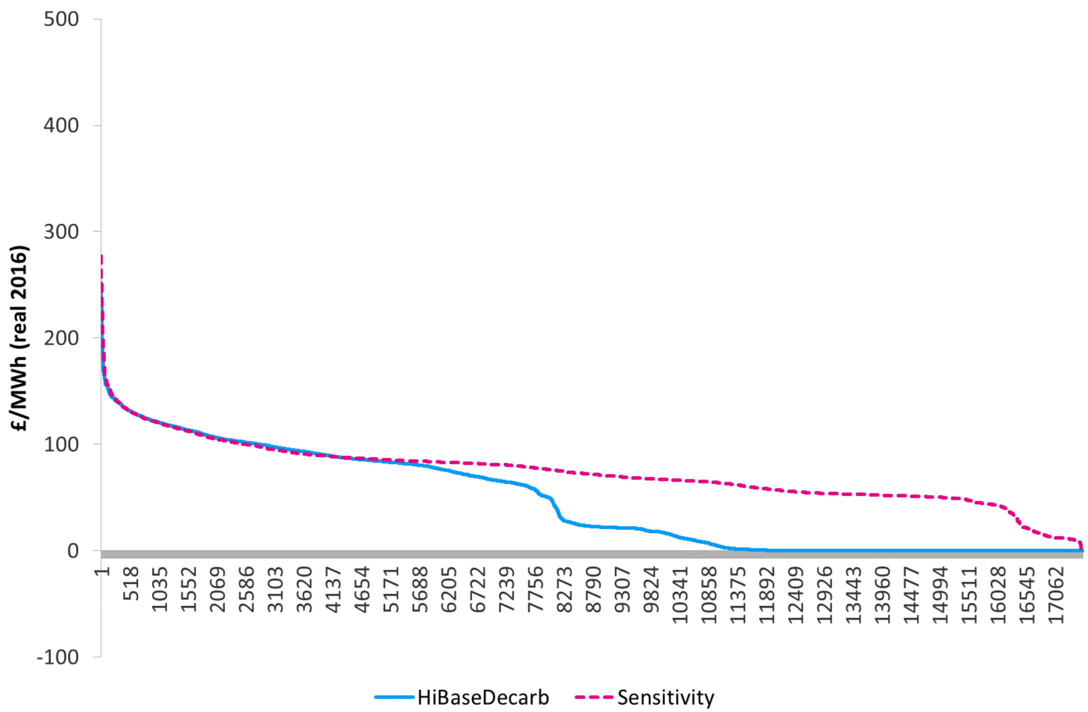
Scenarios	GB time weighted price (£/MWh)	Carbon intensity (gCO2/kWh)
Central Decarb	69.9	45.4
Sensitivity 1	66.1	35.4
Sensitivity 2	73.5	56.1

Scenarios	No of half hours with negative prices	No of half hours with prices above 500 £/MWh
Central Decarb	396	5
Sensitivity 1	768	5
Sensitivity 2	139	9

HiBaseDecarb sensitivity for 2040

GB (day-ahead wholesale station gate basis) power price in 2040 (real 2016 prices) including scarcity and technical uplift

- Sensitivity to explore impact on prices through relaxing emission intensity constraint (reducing CO2 price from £119/tCO2 to 0) and removal of proxy CfDs influencing dispatch.
- The resulting intensity of power generation in the sensitivity is still only 35.8 gCO2/kWh given the large quantity of low carbon baseload plant, however, removal of the CfDs shows the material impact on power prices once the incentive to price below their short run operating costs (primarily for CCS and H2 turbines) is removed
- The highest 1/3 of prices seen across the year remains unaffected



Scenarios	GB time weighted price (£/MWh)	Carbon intensity (gCO2/kWh)
HiBaseDecarb	46.2	15.3
Sensitivity	73.3	35.8

Scenarios	No of half hours with negative prices	No of half hours with prices above 500 £/MWh
HiBaseDecarb	2,002	0
Sensitivity	0	0

Conclusions

The modelling results for Central Decarb and sensitivities indicate the sensitivity of wholesale prices and emission intensity of power generation to CfD eligible low carbon baseload plant on the system

- Central Decarb results in an annual baseload price level between HiBaseDecarb and HiRenDecarb in 2030 but a very similar price level to HiRenDecarb (higher than HighBaseDecarb) in 2040 given the ongoing role of unabated gas plant at the margin

- Although outturn hourly prices can be volatile in the presence of significant intermittent renewables they appear particularly sensitive to the level to the level of subsidized low carbon baseload plant in the 2040s, as this leads to collapse in prices for a significant portion of the year when demand is low, as seen in the Central Decarb sensitivities and the original HighBaseDecarb run

- Removing the distortions to dispatch and prices caused by CfDs on baseload plant is unlikely to change the economics for a mid-merit H2 turbine plant as this does not materially change the highest 1/3 of prices seen across the year (as shown in the HighBaseDecarb sensitivity)