Programme Area: Carbon Capture and Storage

Project: Hydrogen Turbines Follow On

Title: Scenarios 3 & 4 Results Pack

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.

CCS and H2 Dispatch modelling

Market and asset modelling results for Scenario 3 and Baringa Reference Case - DRAFT

Client: ETI
Date: 30 March 2017
Version: V1_0

Reputation built on results

Contents

Introduction

Baringa

Requirements and objectives of the analysis

Overview

- The purpose of this analysis is to present:
  - the market modelling results for Scenario 3 and Baringa Reference Case in 2030 and 2040
  - the asset modeling results based on the inputs from the wholesale market modeling scenarios above and considering four different asset types: existing OCGT, new CCGT, H2 GT and CCGT CCS
- Scenario 3 considers ESME capacity/demand with Baringa adjustments (same as Scenario 2c*), Baringa commodity prices for coal, gas and oil (same as Scenario 2c*)and ESME CO2 shadow price (different to Scenario 2c*)
- Baringa Reference Case is considered as the second market modelling scenario with higher share of intermittent renewables in 2040
- Scenario 4 focusses asset evaluation taking scenario 3 and Baringa Reference Case results as inputs (e.g. power and commodity prices)
- The asset parameters for the four asset types mentioned above are based on ESME and additional assumptions have been layered in from Baringa Reference Case where needed

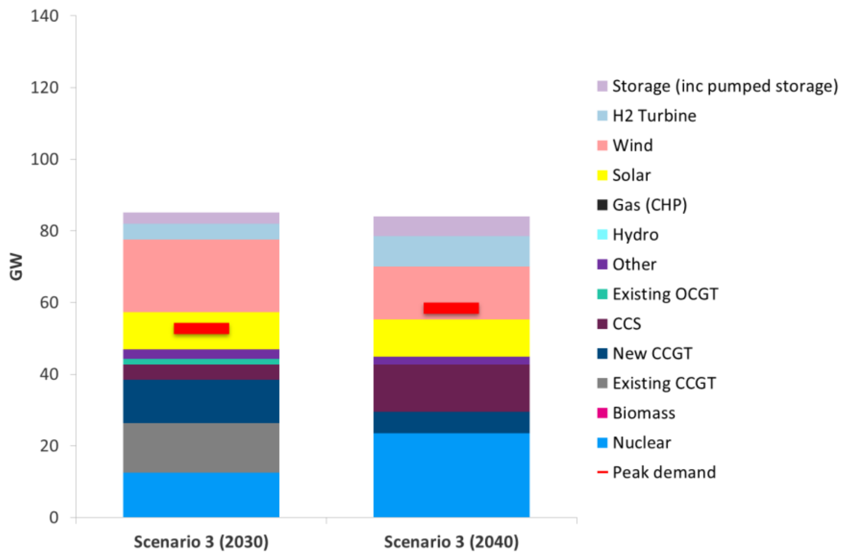
	Scenario 4	Scenario 5	Scenario 6
Title	Selected Asset Evaluation.	Evaluation of 'Thermal Power' Asset.	Evaluation of 'ETI GT'.
Objective/Scope	To explore the financial performance of specified individual plant operating in the market. Scope to cover three assets (e.g. specific GT, CCGT, Hydrogen GT).	To explore the financial performance of a '3GW CCGT with CCS' plant operating in the market. Scope to include sensitivity studies on the impact of CfD (CCGT with CCS) vs CM (unabated CCGT) contracts.	To explore the financial performance of an 'ETI GT' operating in the market. Assumed scope to include two off 'ETI GT' configurations, each operating in two fleet/market Scenarios.
Prime Contractor Inputs	Input data/results from agreed Scenario(s).	Input data/results from agreed Scenario(s).	Input data/results from agreed Scenario(s).
ETI Inputs	Review/update of all plant parameters.	Detailed cost and performance data of '3GW CCGT with CCS' plant. Revised fleet incorporating the plant.	Detailed cost and performance date for 'ETI GT'. Revised fleet including the GT.
Specific Results	Estimated gross margin from the 3 assets, capturing value from short term volatility.	Sensitivity study will report back gross margin to inform selection of agreed cases (two off). For the two agreed cases only, detailed financial and performance data for the '3GW CCGT with CCS' plant in the market (including load factors, gross margin, profitability etc.).	Detailed financial and performance data for the 'ETI GT' plant in the market (including load factors, gross margin, profitability etc.).

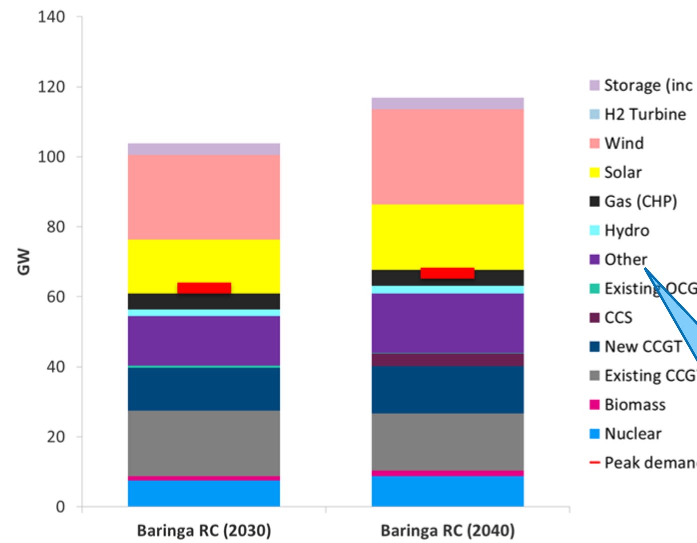
Capacity mix and demand

Comparison of Scenario 3 supply and demand in 2030 and 2040 with Baringa Reference Case

Installed Capacity (GW) (Baringa Reference case and ESME)

- The comparison of GB supply and demand in scenario 3 in 2030 and 2040 is shown in the charts below compared to Baringa Reference Case
- The capacity is generally less tighter in the Baringa Reference Case, implying a higher capacity margin and therefore lower scarcity uplift on its own
- The penetration of renewables including hydro, solar and wind is higher in both years in the Reference Case, with the difference being larger in 2040





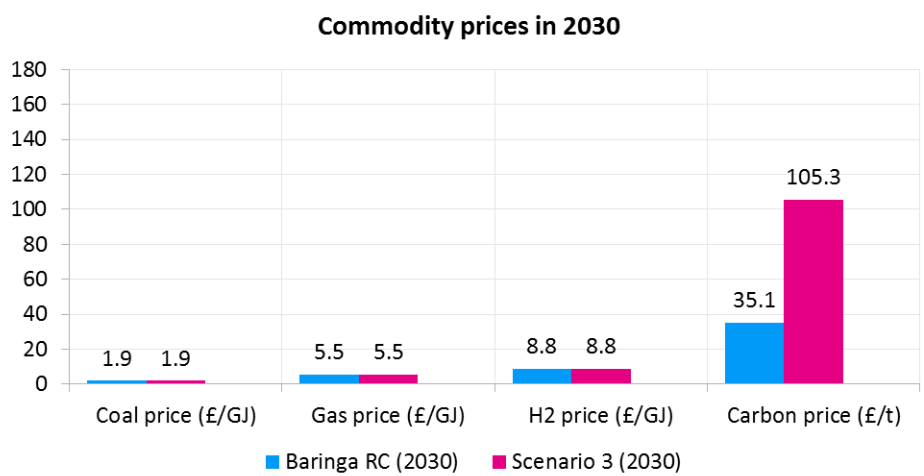
Other category includes: other thermal (e.g. diesel engines): 22%/18%, small gas:41%/34%, other generation for DSR and balancing services: 25%/28%, and other renewables (e.g. tidal, wave):12%/20% in 2030/2040

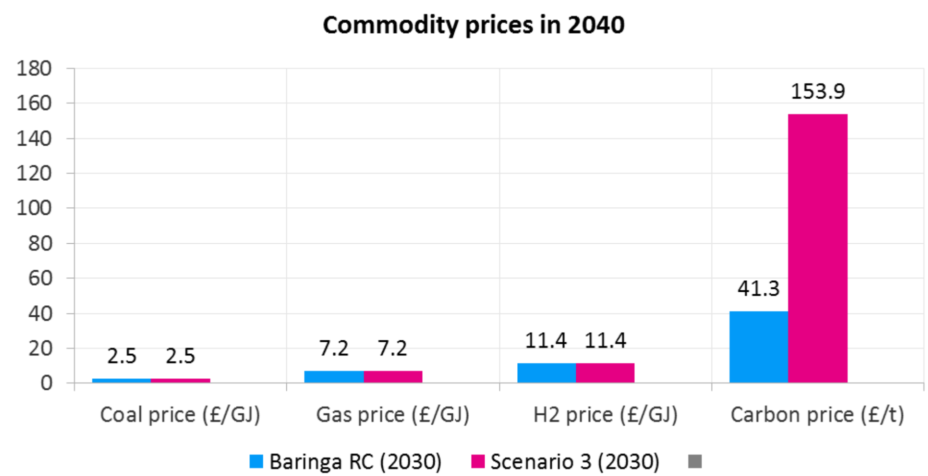
GB power demand	Scenario 3 (2030)	Scenario 3 (2040)	Baringa RC (2030)	Baringa RC (2040)
Annual demand (TWh)	334	373.5	329.4	349.2
Peak demand (GW)	52.7	58.3	62.5	66.7

Commodity prices (real 2016)

Comparison of Baringa Reference Case and Scenario 3 assumptions

- Scenario 3 assumes the same commodity prices for coal, oil and gas as the Baringa Reference Case as shown below. The hydrogen price is calculated using the conversion efficiency from natural gas assumed in ESME and the Reference Case gas price
- The main difference between the two scenarios is the carbon price which is significantly higher under ESME (scenario 3) case, as it is based on an electricity system solution with an explicit 100gCO2/kWh target in 2030, alongside the standard system wide CO2 constraints
- The Baringa Reference Case reflects a world in which carbon abatement is achieved largely in the power sector through coal-to-gas switching, therefore the long term carbon price in 2040 is determined on that switching principle. We have assumed the same carbon price in the interconnected markets as in GB

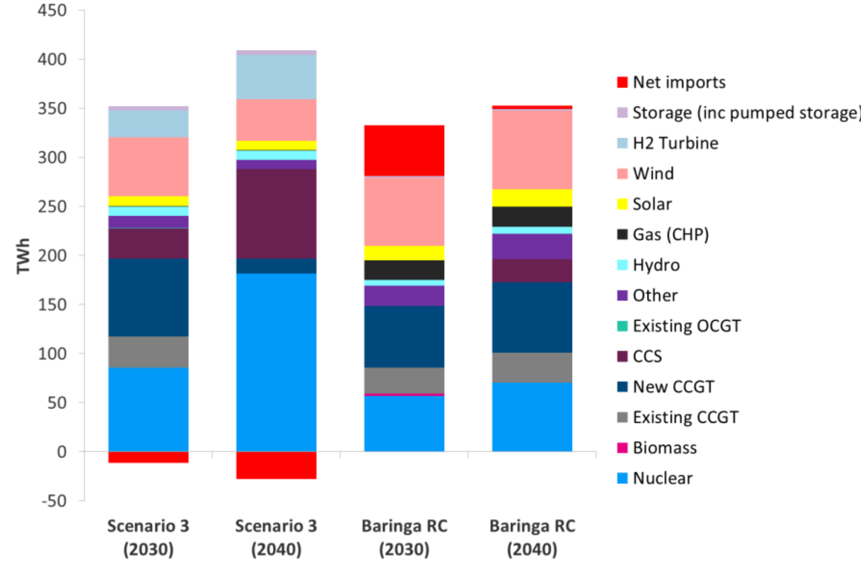




Gas generation in the power mix

2030 and 2040 Generation mix overview across scenarios

- Overall generation level in 2030 in both scenarios is similar, with higher generation in 2040 in Scenario 3 due to higher annual demand
- Existing and new CCGTs have a significant share in generation in 2030 in both cases. This is displaced to an extent by H2 GT and CCGT CCS generation in scenario 3 in 2040 as more capacity is built. In the Baringa RC where there is much less CCGT CCS capacity and no H2 GT is assumed, CCGTs still remain to be an important source of generation in 2040
- CCGT CCS provide baseload power in all cases and years. H2 GTs also run at significant load factors (>60%), driven by the high carbon price in scenario 3
- Both existing and new CCGTs run at a lower load factor in 2030 in the Baringa RC, mainly driven by the lower efficiency of the fleet assumed. In 2040, new CCGTs run at a much higher load factor in this scenario as CCGT CCS and H2 GTs displace some of their generation in scenario 3
- GB is a net exporter in scenario 3 in both years, whereas it is a net importer in the Baringa RC. This can be attributed to the fact that the higher carbon price in scenario 3 results in gas (main price setter in GB) being more competitive against coal which sets the price at times in the interconnected markets to GB



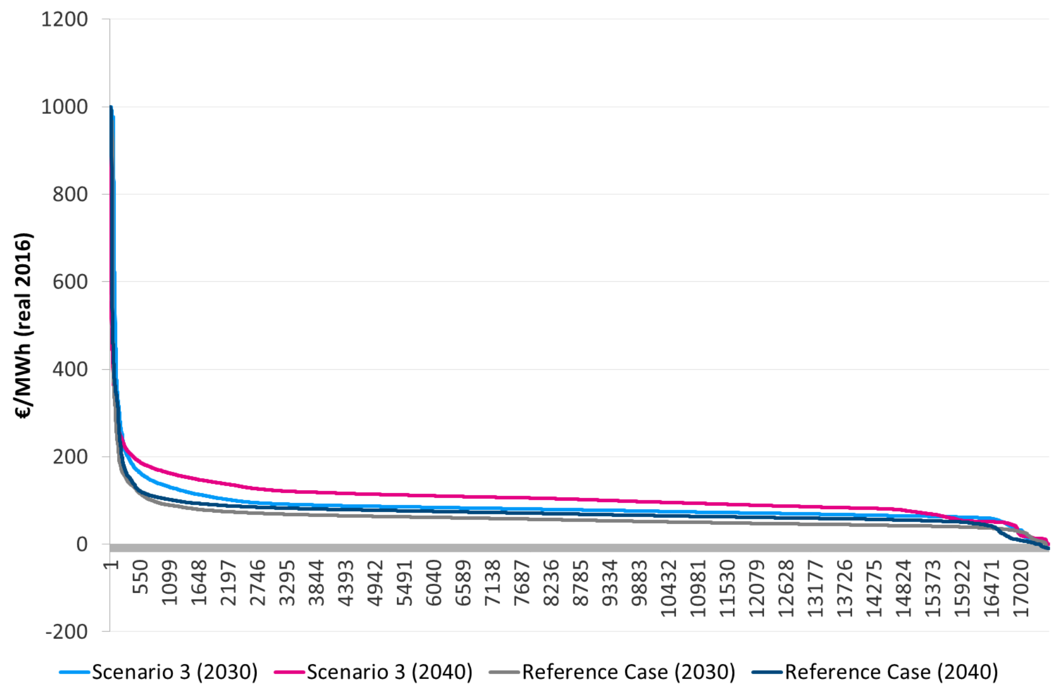
	Scenario 3 (2030)	Scenario 3 (2040)	Baringa RC (2030)	Baringa RC (2040)
Generation (TWh)				
CCS	31.0	91.4	0.0	23.5
H2 Turbine	27.7	44.8	0.0	0.0
Existing CCGT	31.8	0.0	26.6	30.7
New CCGT	79.0	15.4	63.3	71.8
Existing OCGT	0.1	0.0	0.0	0.0
Load factor (%)				
CCGT CCS	82%	79%	0% *	74%
H2 Turbine	72%	61%	0%*	0%*
Existing CCGT	26%	0%*	16%	21%
New CCGT	75%	29%	59%	61%
Existing OCGT	1%	0%	0%	0%

**The installed capacity is 0, so the load factor is 0%*

Comparison of GB price duration curves

GB (day-ahead wholesale station gate basis) power price in 2030 and 2040 (real 2016 basis)

- The comparison of the price duration curves for GB in 2030 and 2040 is shown below. Higher carbon price and tighter margin in scenario 3 lead to higher prices than the Baringa RC
- The much higher carbon price in scenario 3 leads to significant decarbonisation by 2040, whereas it remains at a similar level in the Baringa RC from 2030 to 2040

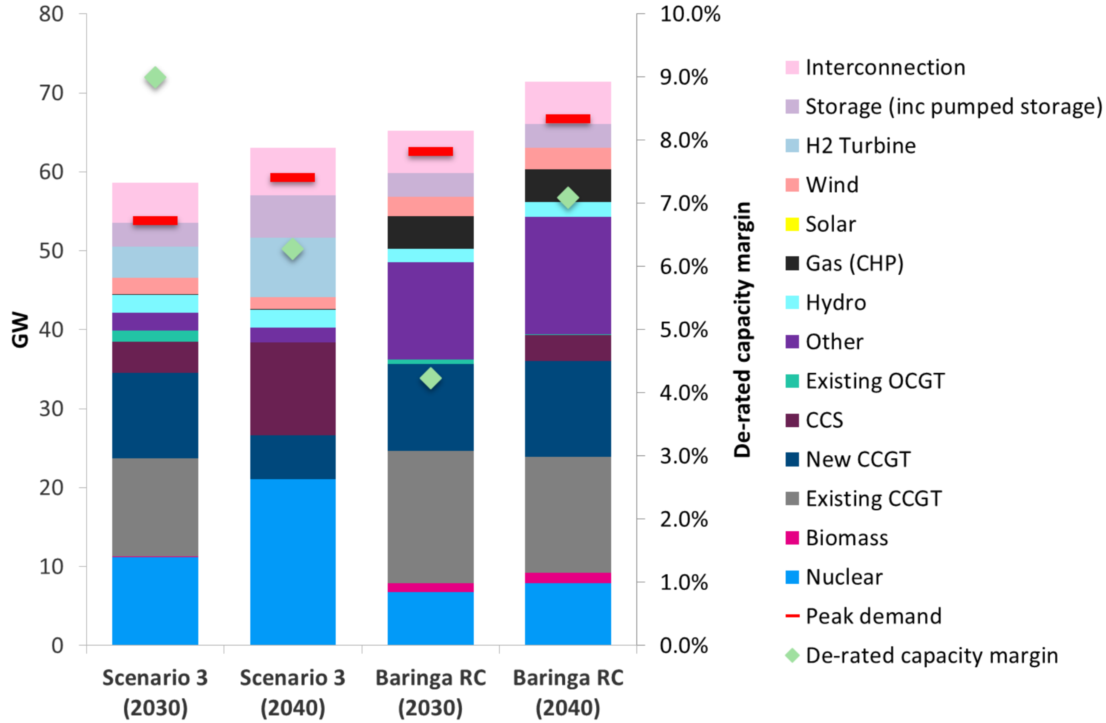


Scenarios	GB time weighted price (£/MWh)	Carbon intensity of power generation (g CO2/kWh)
Scenario 3 (2030)	87.7	105.8
Scenario 3 (2040)	104.8	20.1
Baringa RC (2030)	61.9	147.9
Baringa RC (2040)	73.4	143.3

Capacity market analysis – Scenario 3

The capacity margin is less tighter in scenario 3 compared to Baringa RC in both years

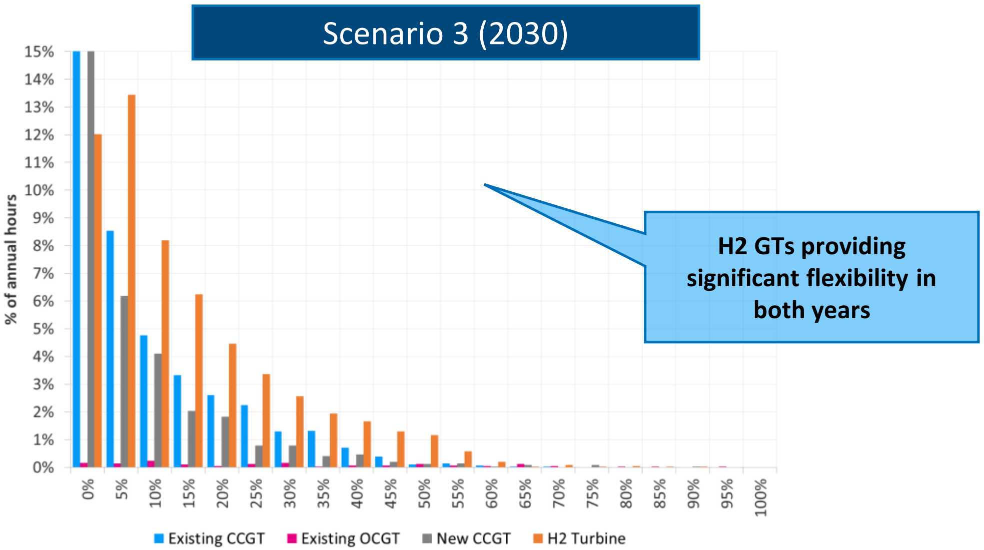
- The capacity margin is higher in scenario 3 compared to Baringa RC as shown below for 2030 and 2040
- Based on a targeted level of 3.4% domestic margin (excluding interconnectors), we have done capacity market simulation for scenario 3, which resulted in a clearing price of **23.6 £/kW** (de-rated) in 2030 and **13.1 £/kW** (de-rated) in 2040
- The simulated clearing prices for years 2030 and 2040 in the Baringa Reference Case are **19.4 £/kW** (de-rated) and **14.3 £/kW** (de-rated), respectively. The plant costs and technical assumptions are different between Baringa RC and Scenario 3 along with the auction prices and clearing plant (new/existing CCGT in the Baringa RC, OCGT/storage in scenario 3)

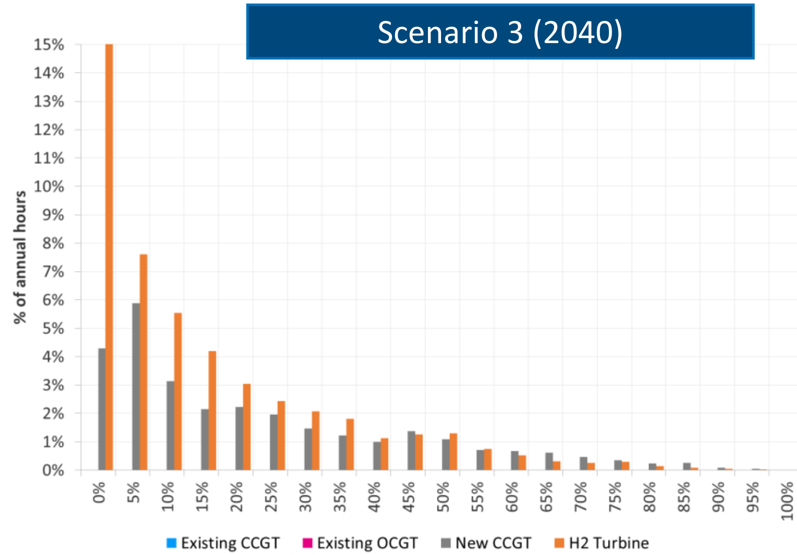


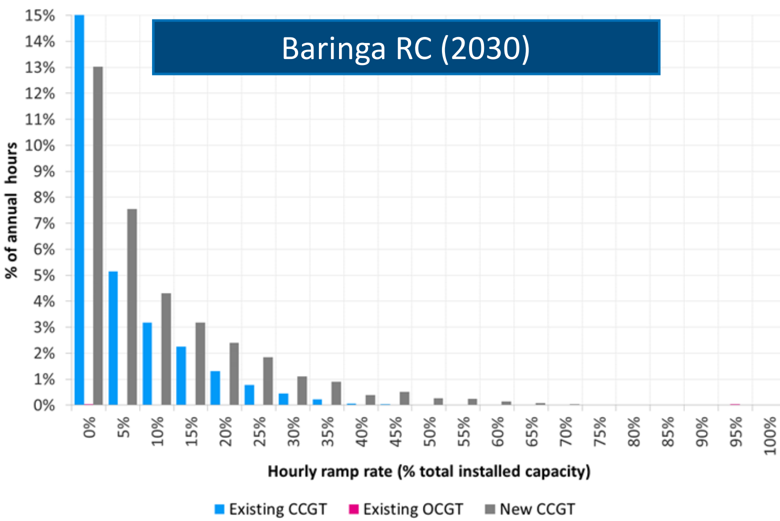
Technology	GB CM de-rating factors
Nuclear	90.0%
Biomass	86.9%
Existing CCGT	90.0%
CCS	90.0%
Existing OCGT	94.2%
Other	86.9%
Hydro	86.2%
Gas (CHP)	90.0%
Solar	0.0%
Wind	10.0%
Pumped storage	96.6%
Interconnection	60%

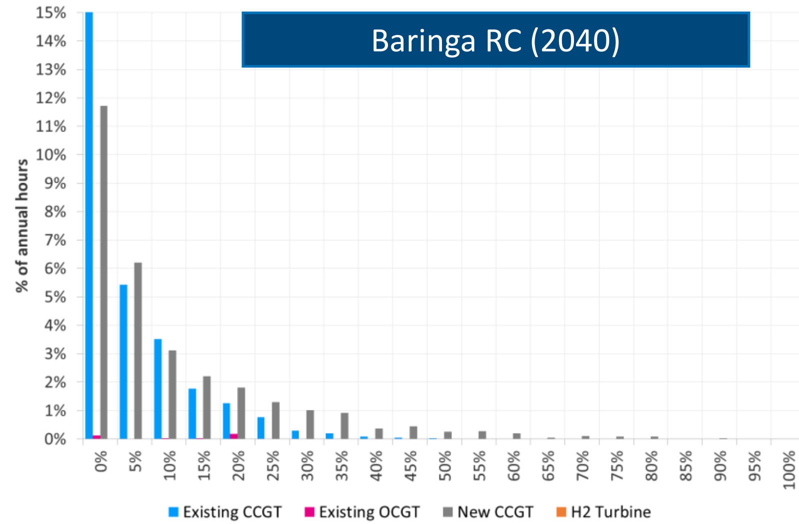
Ramping of flexible gas generation

Ramping as a percentage of installed capacity for flexible generation



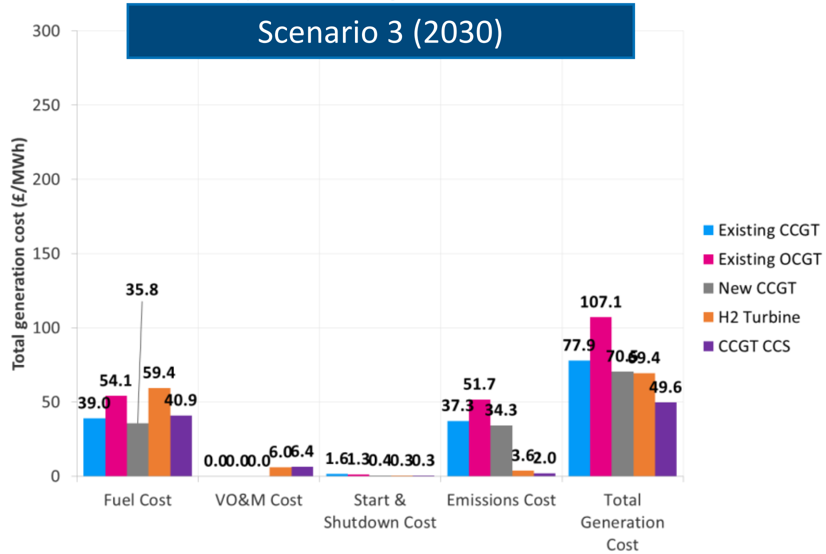


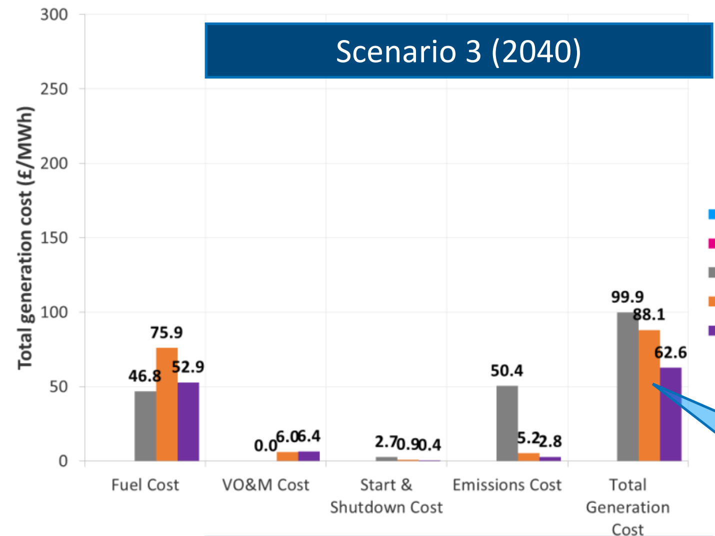




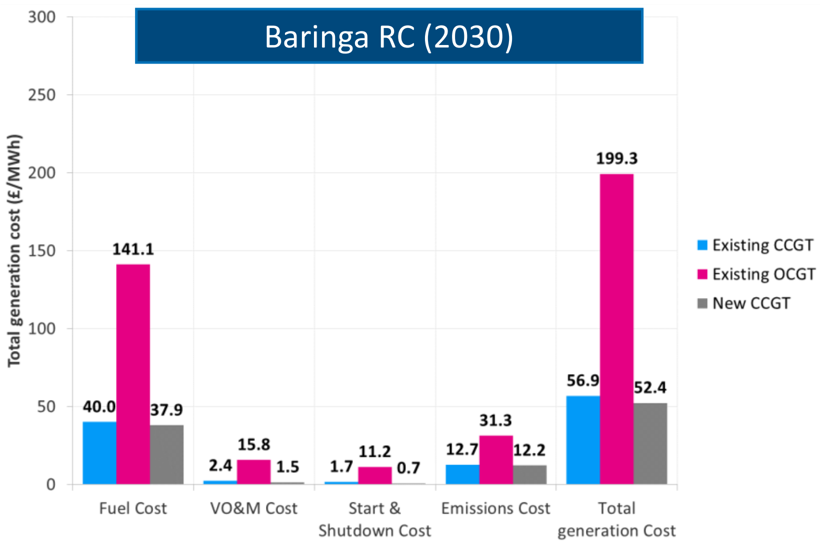
Plant operating costs

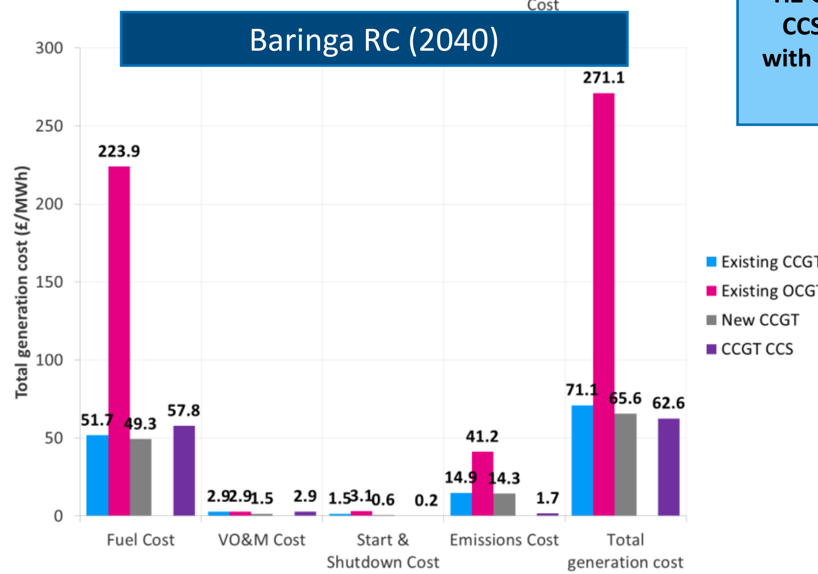
Breakdown of operating costs





High carbon costs in scenario 3 makes H2 GTs and CCGT CCS compatible with CCGTs in 2030 and 2040

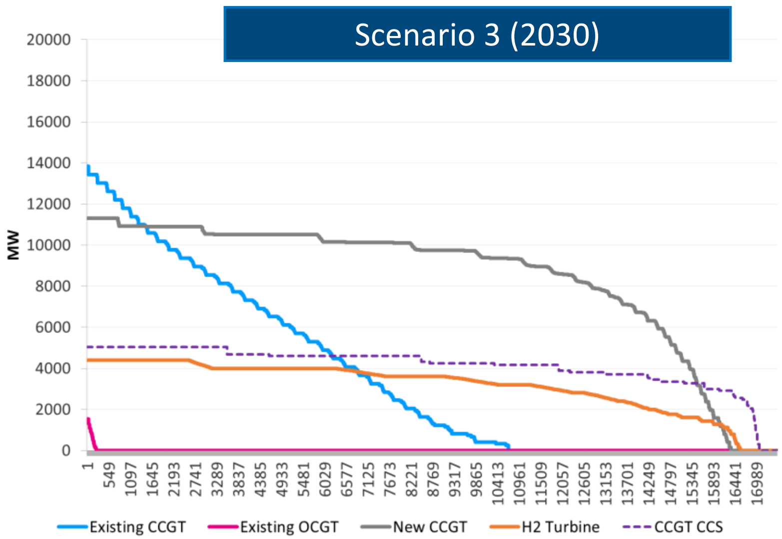


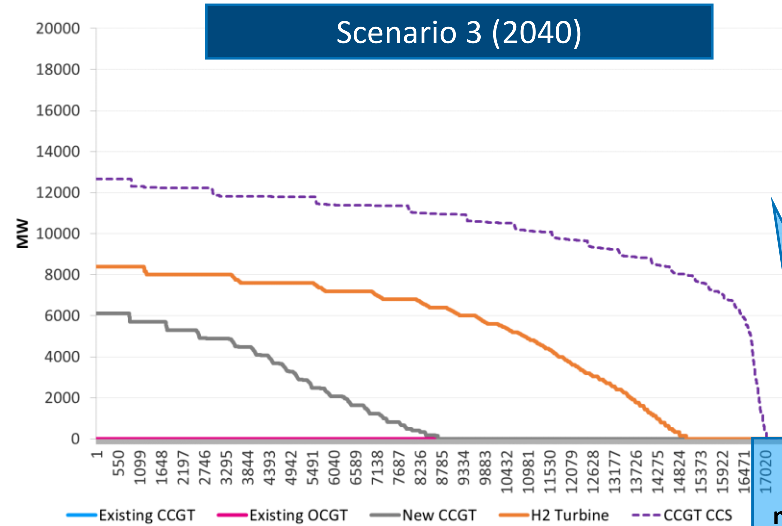


Duration curves for flexible gas generation

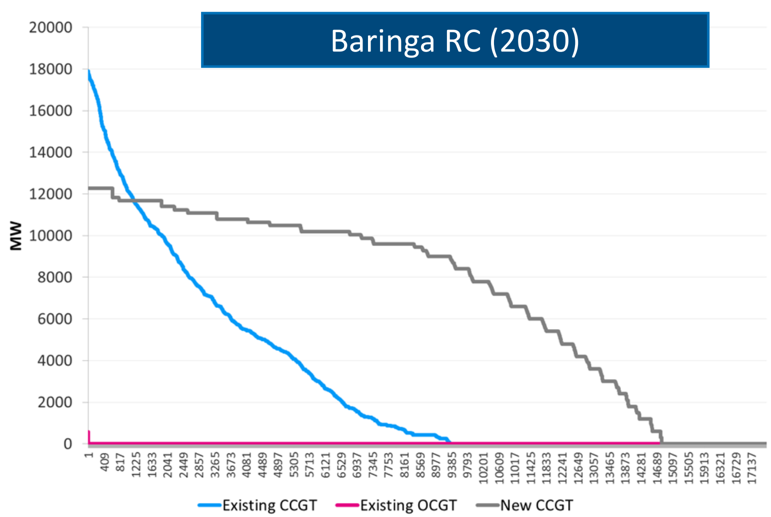
Baringa

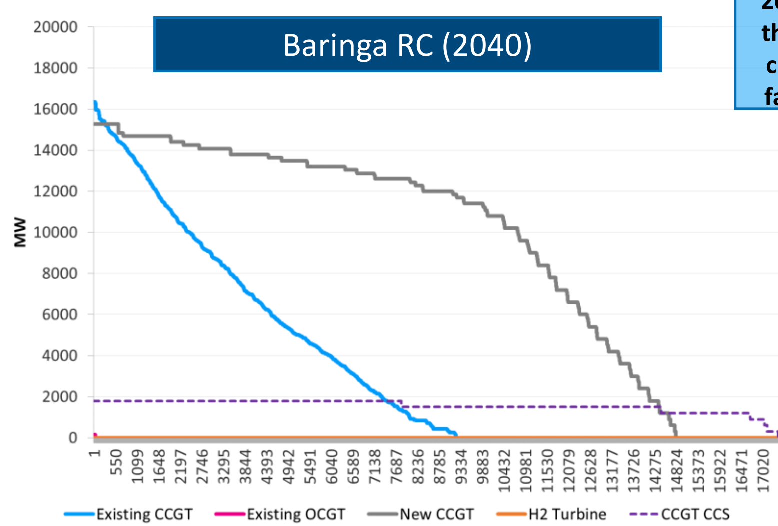
Generation duration curve of flexible gas generation in 2030





H2 GTs and CCGT CCS generating significantly more in 2040 compared to 2030 mainly as a result of the significant increase in carbon price (H2 GT load factor decreases in 2040)

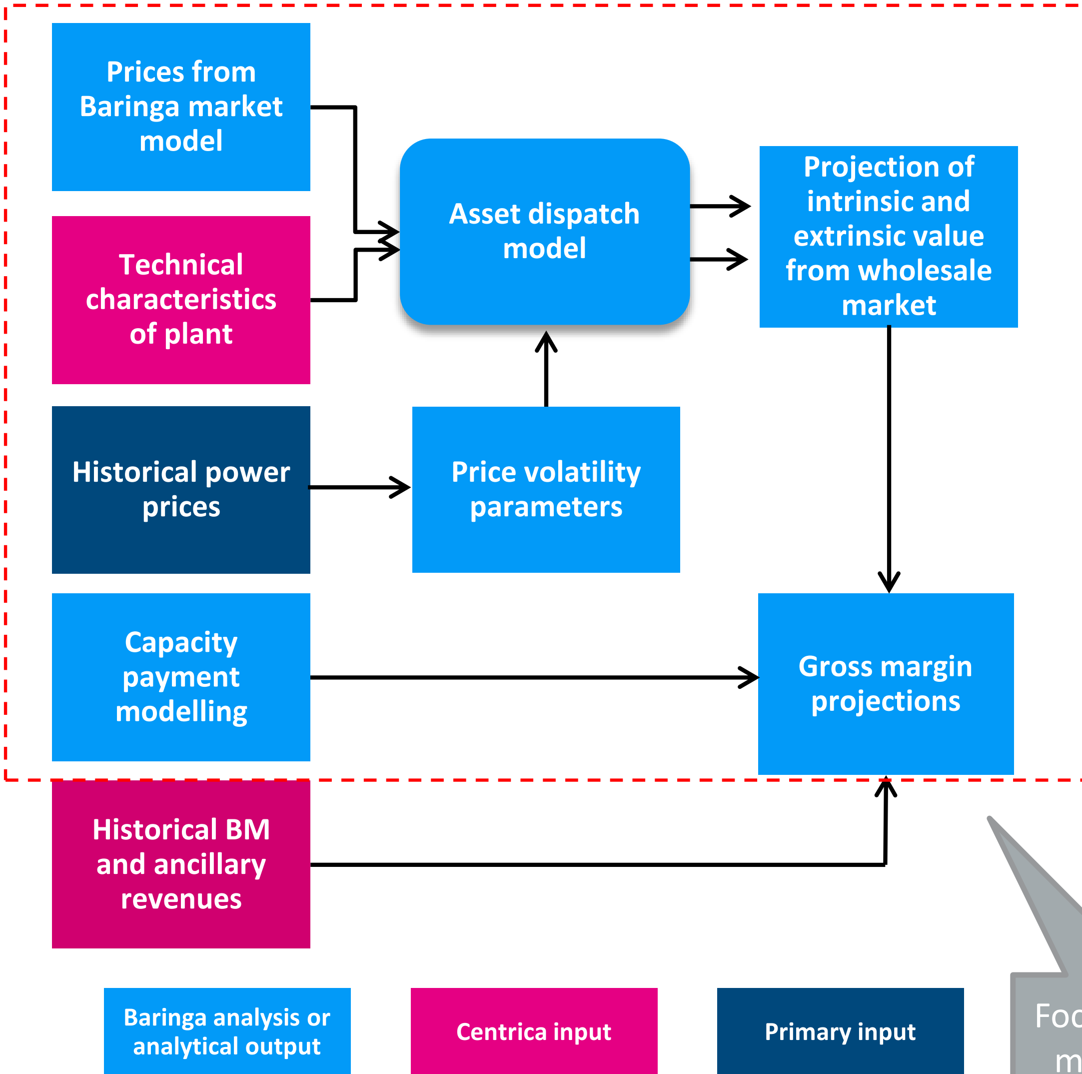




Overview of methodology for asset valuation

Baringa

Final gross margin accounts for energy market income and additional revenues streams like capacity payments



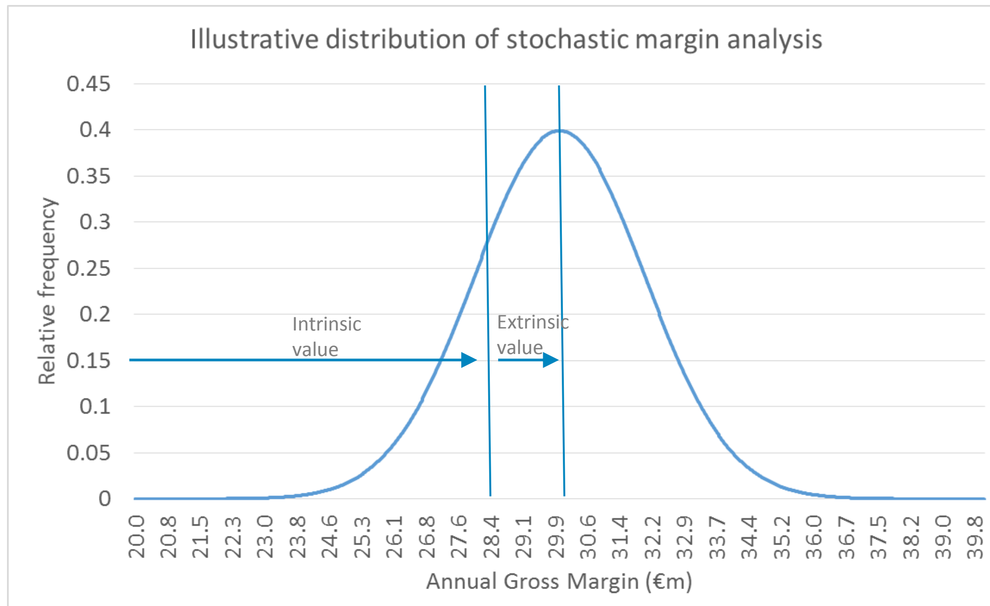
Focus of this asset modelling work

- The most material inputs to our gross margin modelling are the plant technical parameters, and our projected wholesale electricity prices
- The technical plant parameters are based on ESME dataset and we have layered in additional assumptions from our Baringa Reference Case where required (fuel offtake at start and VOM for CCGT/OCGT)
- Intrinsic value has been projected using a deterministic approach
- Extrinsic value has been projected using a stochastic approach with calculated price volatility, mean reversion and gas price correlation based upon historical price data
- Our dispatch model has been run against a large number of price simulations (Monte-Carlo simulation), constructed using these calibrated parameters
- Our asset dispatch model utilises PLEXOS power system optimisation software
- PLEXOS optimises the dispatch of the plant against the input prices, taking account of technical constraints

Extrinsic gross margin (Option value)

Baringa asset modelling with stochastic treatment of commodities determines option value

- Intrinsic value captures all of the value inherent in liquid and granular traded markets. Our hourly PLEXOS scenario projections represent the full intrinsic value of the asset, capturing hour-by-hour variations in demand, intermittent generation and the availability of plant capacity in the market
- However, there is extra *time value* available to flexible assets which are able to respond to random fluctuations in conditions over time: although these fluctuations might be positive or negative, the asset can respond selectively so that the value of positive fluctuations is captured but negative fluctuations are avoided
- Baringa's Price Simulation Engine is used to generate a statistically consistent set of spot time series for power and fuel prices, calibrated to historic price dynamics. This will include parameters representing the volatility, mean reversion and correlation for and between the price series
- The mean of the simulated price series is set to match the deterministic prices used in the intrinsic scenario analysis
- For each of the simulated price series, the PLEXOS model determines how the plant would dispatch to maximize gross margin; a probability distribution of gross margin outcomes is then produced for the complete set of simulations
- Some of these outcomes will display lower gross margins than the deterministic outcome, but most of the outcomes will display higher gross margins; the asymmetry reflects the flexibility/controllability of the asset
- The mean (expected) value of the distribution is the expected total (intrinsic + extrinsic) value of the asset
- Extrinsic value is then determined as the difference between this expected value and the deterministic (intrinsic) outcome
- This is likely to represent an upper bound on the extrinsic value and a hair-cut is likely to be required in reality to reflect lack of perfect foresight and cost of adjusting trading strategy (e.g. day-ahead and intraday)
- In addition, if the asset is often at the margin setting the price, then there will be less potential for extrinsic margin



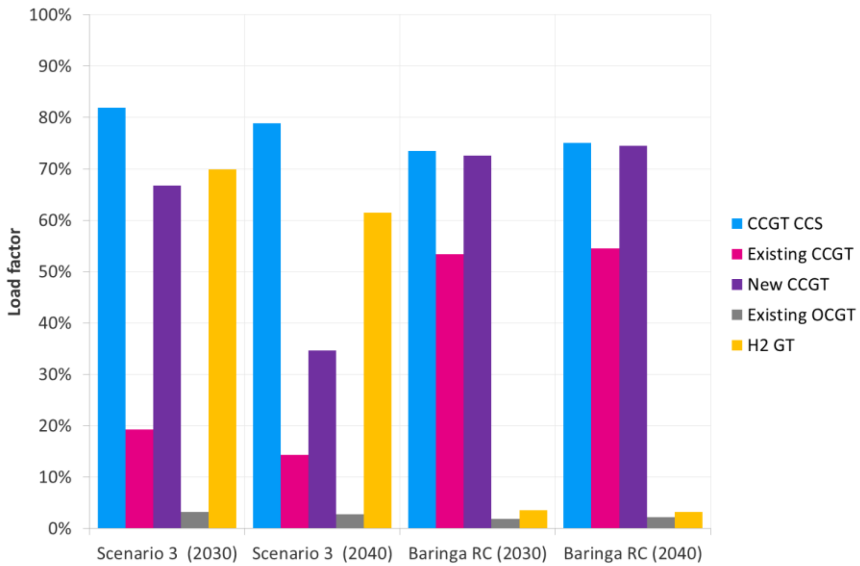
Gross margin drivers

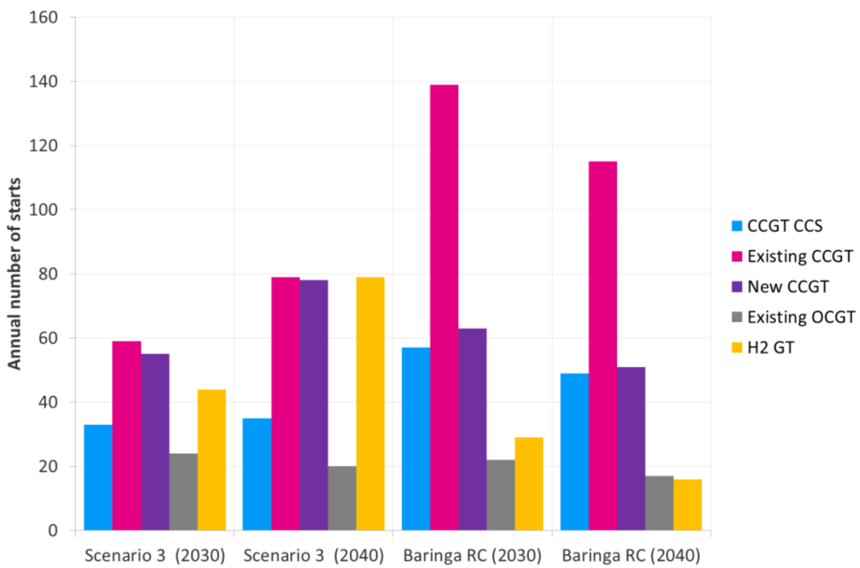
CCGT in the GB market can expect to receive a diverse range of earnings streams, depending on flexibility, plant operation and contracting strategy

GM driver	Indicative contribution to the plant gross margin (£m, real 2017): 2017	2020	2030	Description of GM driver	Relevance to CCGTs
Intrinsic Value	16	21	25	Intrinsic value is the gross margin associated with 'expected' hourly price shape. It comprises two main components: infra-marginal rent (IMR) and scarcity rent. IMR is the margin between the generation costs of the price-setting power plant and those of the asset in question. Scarcity rent is additional value which emerges in periods of tight capacity margin.	IMR increases as the merit order position of a CCGT improves and more expensive plants operate at the margin. IMR may increase as coal plants retire and as carbon prices rise, increasing the competitiveness of gas versus coal-fired generation. New plants commissioning with lower generation costs will reduce IMR. A tightening capacity margin in coming years is forecast to put upward pressure on scarcity rent.
Extrinsic value	4	4	3	The extrinsic value of the power plant is the option value that can be realised when that plant is able to run to capture upward movements in spark spread away from the average. It is the additional option value associated with hourly price volatility at the day-ahead and within-day stage.	The ability to realise extrinsic value is dependent on plant flexibility. Flexible CCGTs are well-placed to capture the option value associated with price volatility. The level of extrinsic value captured by a plant will also depend on efficiency, and the risk-appetite of owners.
Capacity payments	1	16	25	The first auction for capacity under the Capacity Mechanism (CM) was held in December 2014, with the first payments under the CM being made during winter 2017/18.	Existing plants will be subject to rolling one year contract whereas this is fifteen years for a new plant. The level of capacity payment in any one year will depend on the capacity auction clearing price.
Ancillary services & Balancing Mechanism	7	7	7	Revenues from providing ancillary services and the plant operation in the Balancing Mechanism.	Some CCGTs can get these extra revenues if they are eligible to provide these services.

Load factor and number of starts

Plant load factor decreases overtime in scenario 3

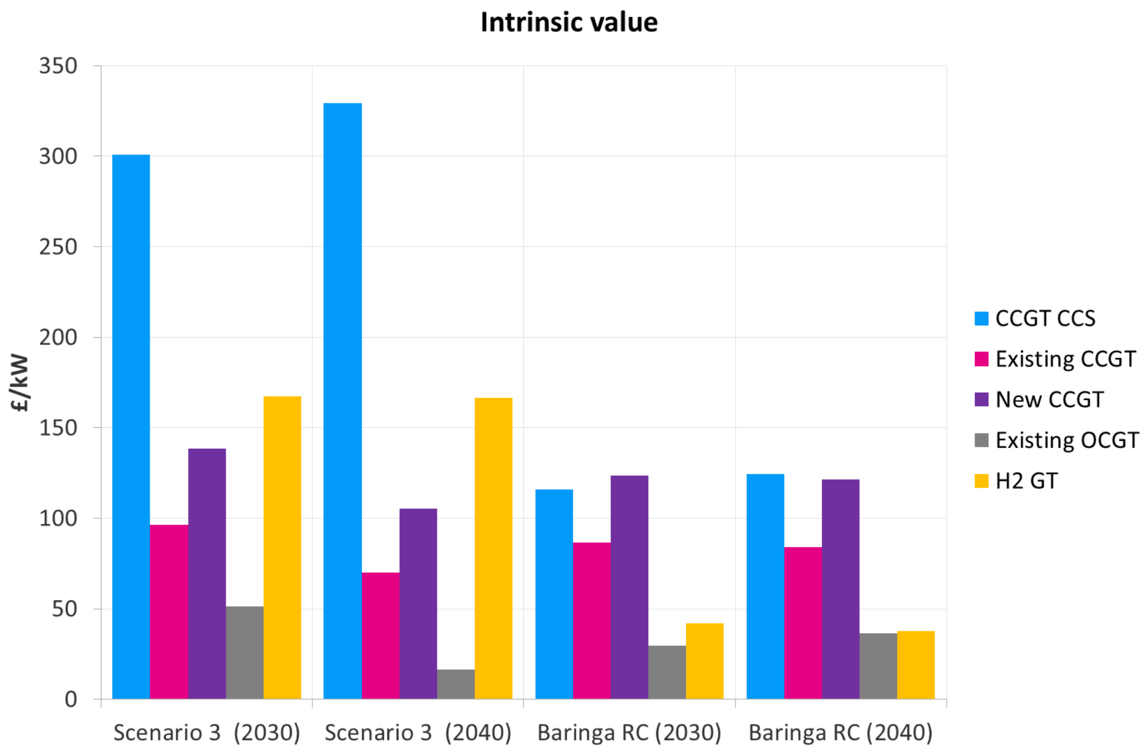




- The load factor for unabated plant decreases sharply in scenario 3 form 2030 to 2040 due to significantly increasing carbon price
- For low carbon generation, the load factor decreases slightly due to significant expansion of nuclear
- Much lower carbon price in the Baringa RC mean that H2 GTs hardly ever dispatch

Intrinsic Value

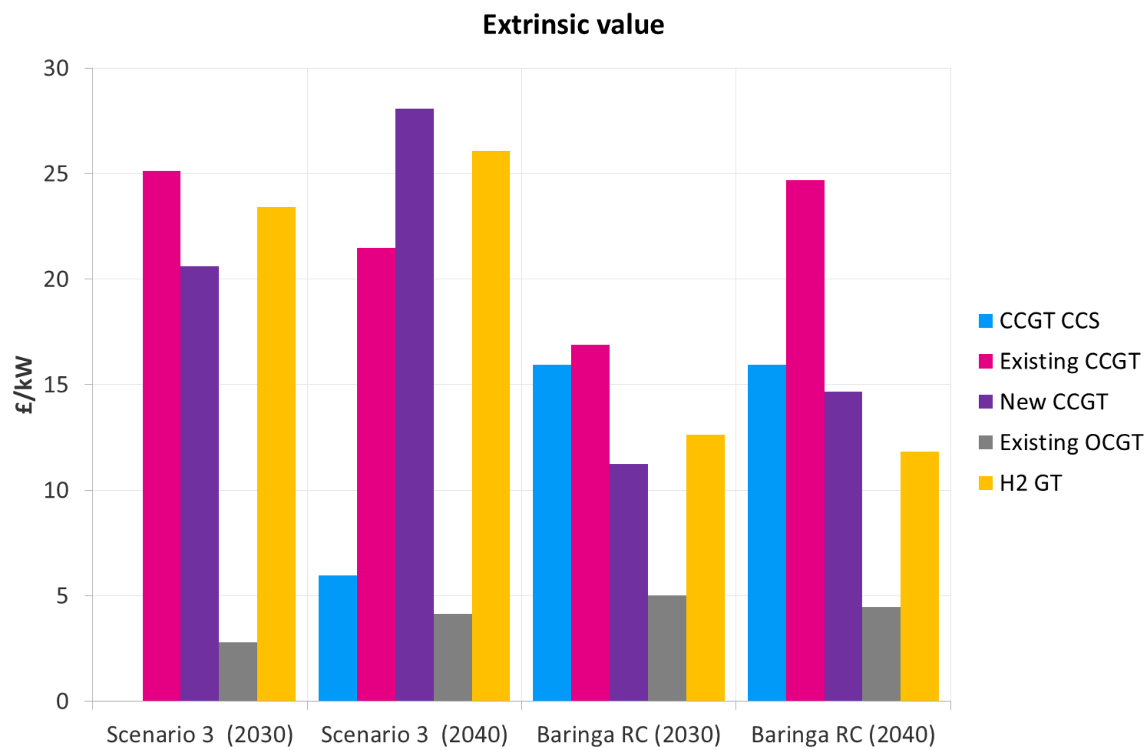
Carbon price drives significant value for mid-merit and baseload low carbon plant



- High carbon price in scenario 3 is the main contributor to the higher value for H2 GTs and CCGT CCS. This drives significantly higher price of largely unabated plant at the margin and allows low carbon baseload plant to capture high infra-marginal rent

Extrinsic Value

Short-term electricity price volatility could add a modest amount to the plant revenues

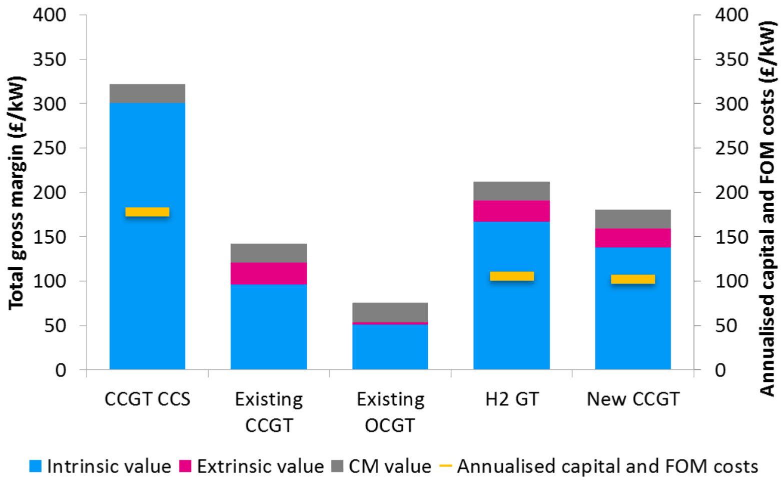


- The values on the left are likely to represent an upper bound on the extrinsic value and a hair-cut is likely to be required in reality to reflect lack of perfect foresight and cost of adjusting trading strategy (e.g. day-ahead and intraday)
- As an example from real world operators a CCGT is able to capture 30% of the potential value of extrinsic margin indicated by our stochastic modelling (which is a value we commonly use for CCGT valuation purposes)
- In addition, if the asset is often at the margin setting the price, then there will be less potential for extrinsic margin

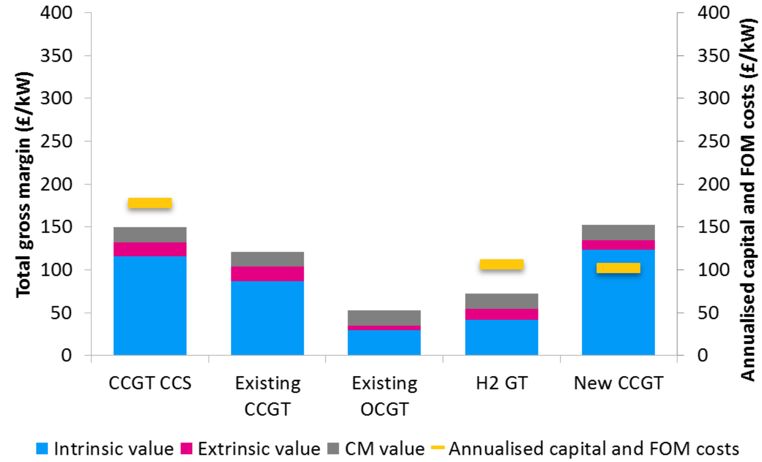
Total wholesale Value

The total revenue for an asset is a result of the combined wholesale and capacity market revenues (breakeven cost assuming WACC=12% and economic life=20 yrs)*

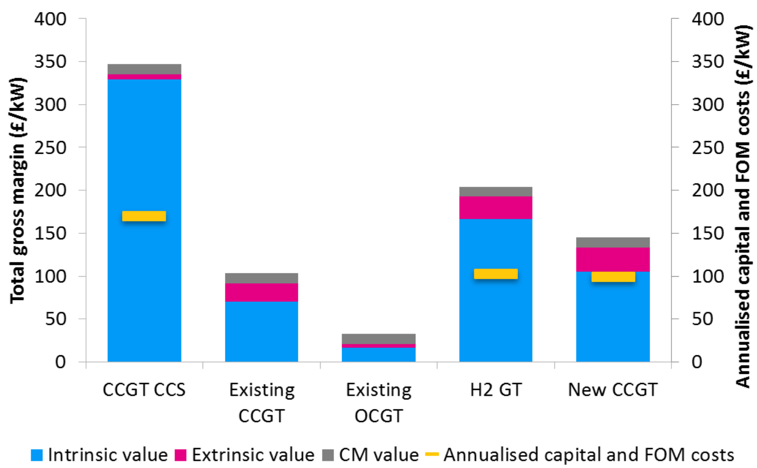
Scenario 3 (2030)



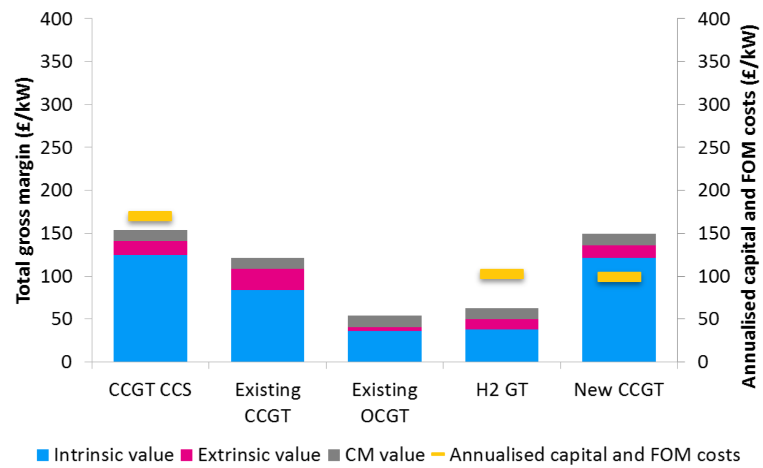
Baringa RC (2030)



Scenario 3 (2040)



Baringa RC (2040)



The Capex and FOM costs are just for illustration, in practice there will likely be additional costs that need to be reflected such as connection, insurance, use of system charges, etc

Key conclusions and next steps

Baringa

CCS and H2 assets appear profitable in high CO2 price world (particularly CCS), but would need significant support under a more "central market" scenario

- Recap of scenarios
  - Baringa RC is central market view of the world with increasing levels of wind/solar/CCGT and modestly rising carbon price, but which leads to limited further decarbonisation post 2030
  - Scenario 3 shows significant ongoing decarbonisation due to a far higher CO2 price (x3-4) and expansion of baseload CCS/Nuclear and H2 turbine as a low carbon replacement for CCGT (but with limited wind/solar)
- High carbon price in 2030 and 2040 is key value driver of CCS and H2 turbine in 2030 / 2040
  - In scenario 3 this pushes up price of marginal plant (primarily remaining unabated CCGT) and allows H2 turbines and CCGT with CCS to capture significant infra-marginal rent
  - CM and extrinsic value a relatively modest component of future value
- Significant nuclear expansion (to ~24GW from 2030-2040) impacts CCS / H2 load factors
  - 2-3 percentage point drop for CCS and ~10 for H2 turbine, but increasing prices mean GMs are maintained
- Next steps
  - Consolidate S3/4 material and excel results
  - Scenario 5 – two additional sensitivities around asset valuation analysis (e.g. gas / CO2 price)
  - ETI to use GM and CM results as part of more detailed internal financial model of new plants

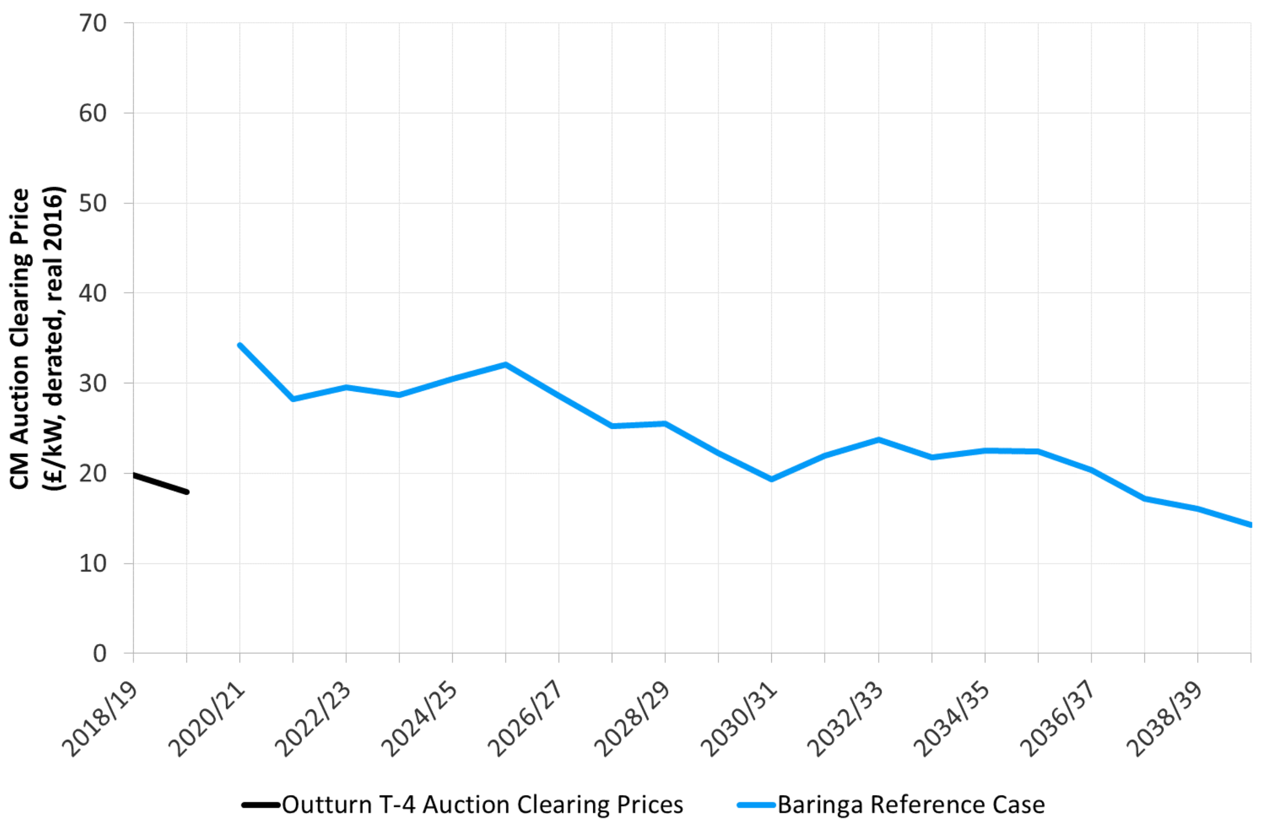
APPENDIX

Capacity market analysis – Baringa Reference Case

Auction clearing prices (rolling average)

Capacity Mechanism Auction Clearing Price

(£/kW, De-rated, Real 2016, All Scenarios)



CM Clearing Prices

- To date there have been two T-4 CM auctions for delivery in 2018/19 and 2019/20.
- The clearing prices for the first two auctions were 19.78 £/kW and 17.94 £/kW respectively, in real 2016 money
- This chart shows our future projections on a 5-year rolling average basis
- We expect more variability in the clearing price of future auctions depending on whether or not large new entrant plant are required or not
- Other factors affecting CM price projections include
  - long-term prospects for generator TNUoS charges, which are currently forecast to become negative in the 2020s
  - Ofgem's ongoing review of "Embedded Benefits" that could reduce the viability of small-scale gas engines. Such engines have secured large volumes of contracts in the first two auctions
- The simulated clearing prices for years 2030 and 2040 in the Baringa Reference Case are **19.4 £/kW** (de-rated) and **14.3 £/kW** (de-rated), respectively

Baringa