Bespoke Gas CHP Policy– Cost curves and Analysis of Impacts on Deployment

Report for DECC

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Executive summary

1. Ricardo-AEA's Bottom-Up (BU) economic model and DECC's energy price projections have been used to estimate the impact of the following range of possible bespoke policies on UK CHP technical potential and projected (commercially cost-effective) deployment over a range of incentive levels.

    I. **Capital grants**: grants for investment in new natural gas CHP.

    II. **Premium Feed in Tariffs**: a payment per MWh of electricity generated by new natural gas CHP capacity.

    III. **Primary energy saving incentive**: a payment per MWh primary energy saving from new natural gas CHP.

    IV. **Primary energy saving obligation**: a regulatory obligation on energy suppliers, or business/public sector energy consumers, to achieve primary energy saving targets. Certificates would be issued to CHP operators per MWh of primary energy saving achieved which could then be traded with obligated parties and used to demonstrate compliance with their obligation.

    V. **Quality Index (QI) weighted heat incentive**: a payment per MWh of heat supplied from new gas CHP, weighted according to the plant's QI (CHPQA's measure of its overall efficiency).

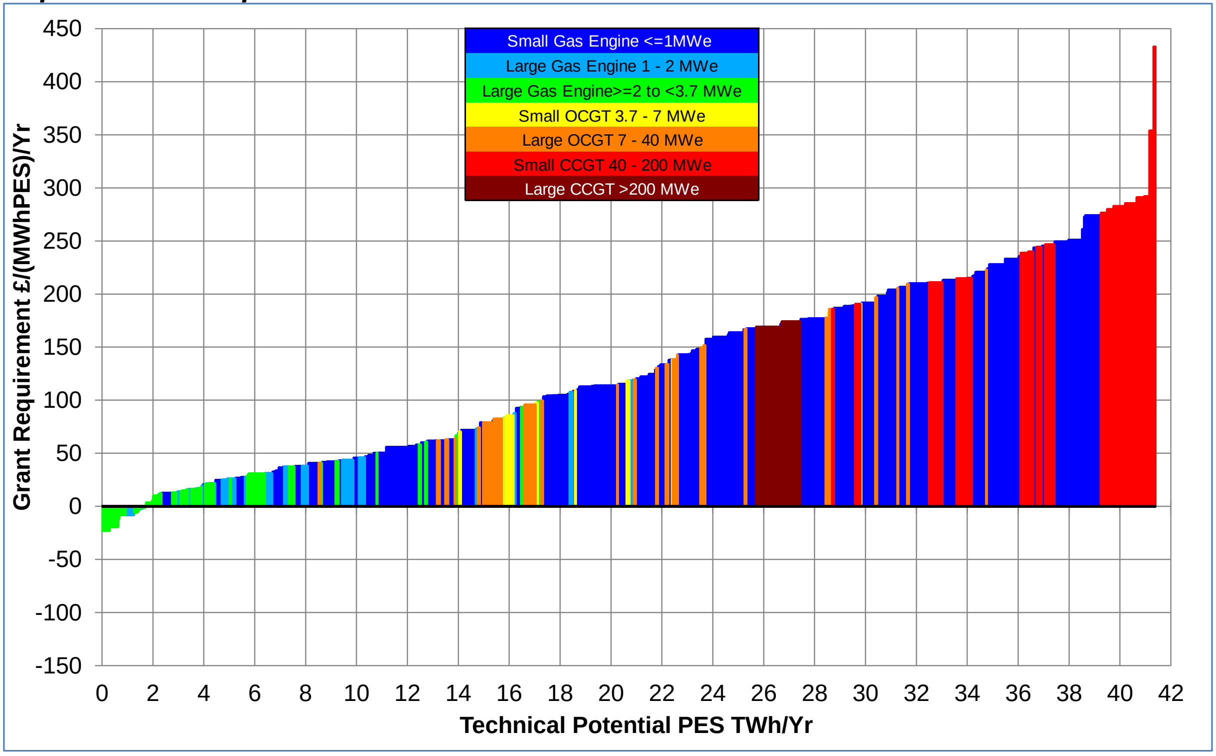
    VI. **Quality Index weighted capacity incentive**: payment per MW of new, gas CHP electrical capacity weighted according to the plant's QI (CHPQA's measure of its overall efficiency).

2. The support levels were each designed to bring forward an equal quantity of Primary Energy Saving (PES)[1] on the basis of the simple cost-effectiveness of CHP sized in the most energy efficient manner. These savings will not, however, be identical due to differences in probability and sizing strategy across the spectrum of potential sites and some types of schemes benefit more from one type of policy than another.

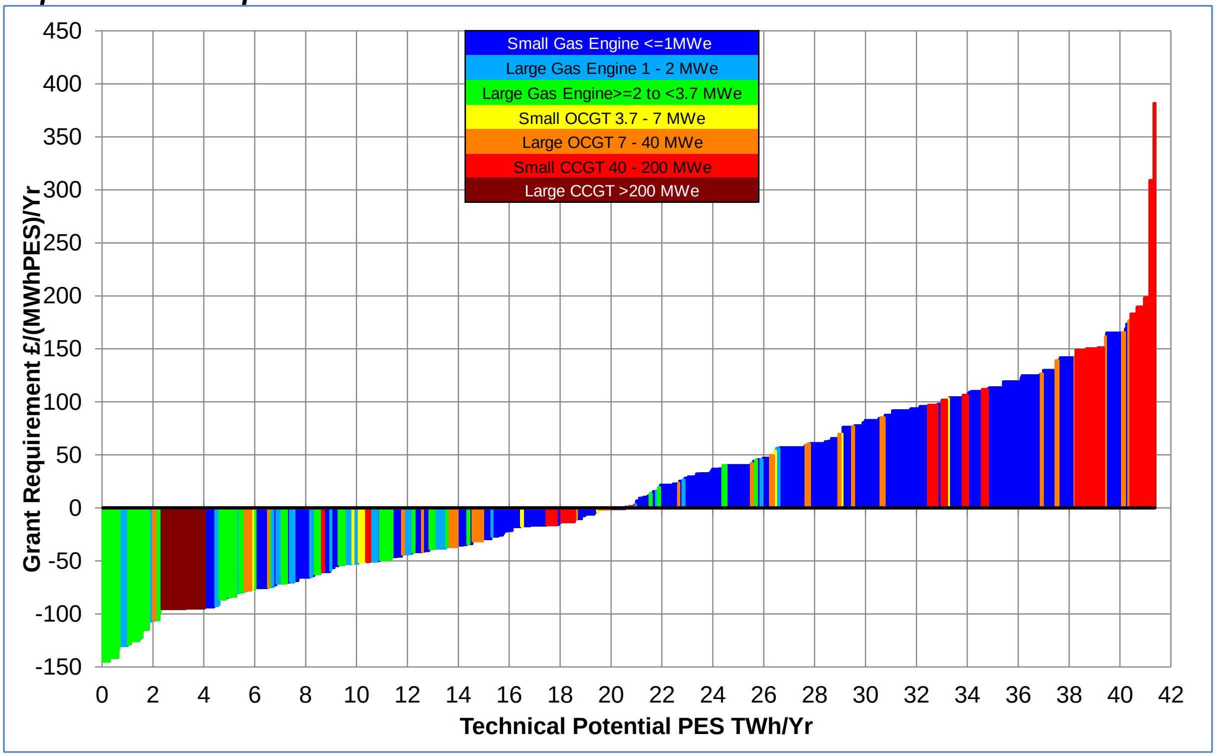
3. Cost supply curves were first produced for each policy using data generated by the BU model. These showed the level of support required for a given category of CHP (sized in an energy efficient manner based on heat load) to be cost-effective at commercial rates of return. The cost supply curves for the capital grant option in 2012 and 2020 are shown below. Costs on the y-axis are expressed in terms of £s of grant required per MWh of annual primary energy saving projected from the plant. This unit is used as it is presumed that support would be competitively allocated to projects with the greatest potential energy saving per £ of grant. These curves show that, at 2012 energy prices, most potential CHP capacity would require bespoke policy support to become cost-effective, but nearly half would become commercially cost-effective without any support by 2020 at projected energy prices[2]. This is principally due to retail electricity prices being projected to rise much more sharply than gas prices (54% as opposed to 21%) between 2012 and 2020.

[1] The Primary Energy Saving is the reduction in total fuel needed to produce a given quantity of heat and electricity.
[2] The fuel price categories for gas-fired and renewable CHP and the basic retail/export values are as shown in table 5 in section 3.5 below and are based on UEP 2013, the latest projection at the time the modelling was conducted and exclude policy additions payable by CHP.

Capital Grant Requirement in 2012



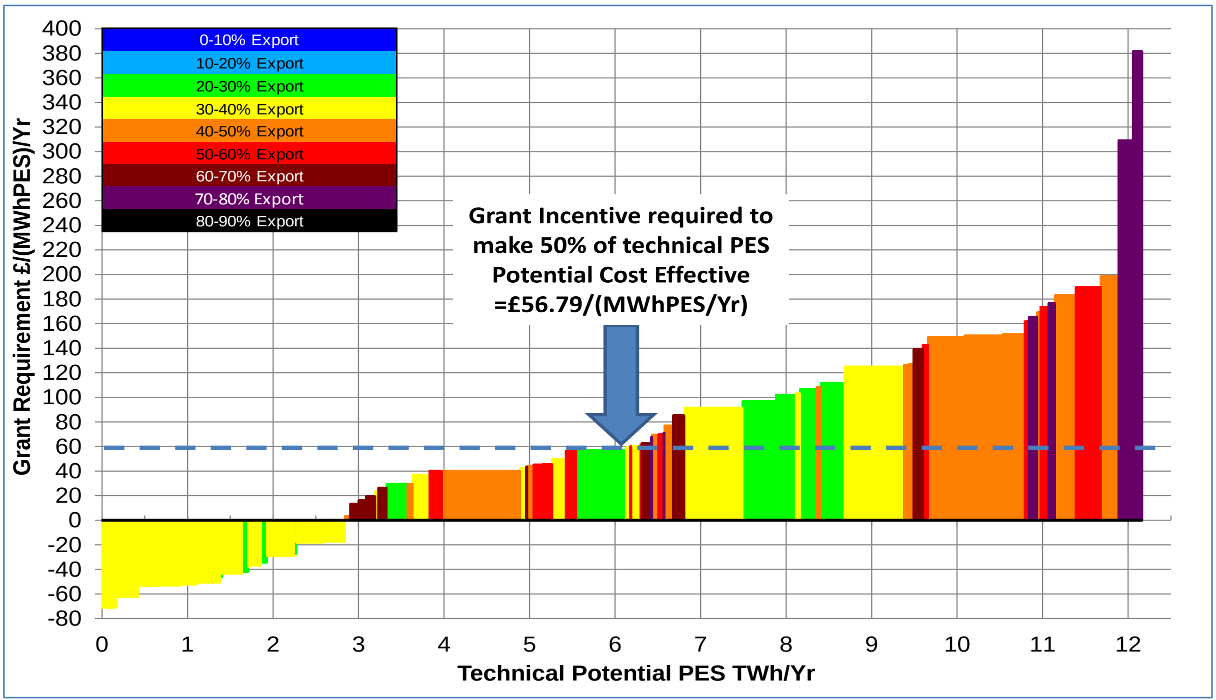
Capital Grant Requirement in 2020



4. Thus an attempt was made to devise eligibility criteria (based on measurable technical parameters of a scheme) to target bespoke support to the schemes which would be likely to require it in 2020.
5. Due to the variety of economic conditions faced by different schemes, there are no technical parameters which exactly align with the requirement for support, the best indicator being the proportion of electricity exported.

6. Whilst schemes exporting a high proportion of electricity generated tend to require more support, the relationship is not exact. Restricting support levels to schemes exporting above a certain minimum proportion inevitably means some schemes which export a higher proportion would be supported despite being cost-effective (policy deadweight) whilst others with a lower export proportion would be ineligible for support despite requiring it to become cost-effective.
7. A minimum export proportion threshold of 20% was proposed as the best compromise between maximising impact on CHP uptake and minimising deadweight. The tariff levels used in modelling the policy options were set to support 50% of technical Primary Energy Saving (PES) potential. The 50th percentile approach is in line with that used for RHI tariff setting and assists in ensuring that our approach does not give rise to overcompensation, in accordance with the EU State Aid requirements that prohibit support being provided to all potential projects. However, it should be noted that the 50th percentile level is arbitrary. For sensitivity purposes a 75th percentile based support level has also been modelled in the case of the Capital Grants option. The resulting cost curve for the capital grant and the tariffs for all policies are shown below.

Capital Grant Supply Curve 2020



Modelled Support Levels (2013 real)

	Capital grant	PES incentive / obligation	Premium FiT	QI weighted heat incentive	QI weighted capacity incentive
Support level	£56.79/(MWh/Yr)[3] PES (£124.79/MWh PES 75th percentile sensitivity case)	£19.30/MWh PES	£17.55/MWhe	£12.31/(MWh heat x QI/100)	£89.48/(kWe x QI/100)

[3] The capital grant is a one off up-front payment based on anticipated annual Primary Energy Savings. All other tariffs would be provided over 5 years based on annual performance. These tariffs are equivalent, each giving the level of support required to make 50% of technical PES potential cost-effective.

8. Having determined bespoke policy support tariffs, the technical potential (sized to meet heat or electrical load depending on economics) and projected uptake for CHP with and without bespoke policy support were modelled in Ricardo-AEA's Bottom Up model, DECC's Monte-Carlo model and via off-model calculations for Oil & Gas and District Heating sectors, which are less amenable to being assessed within the standard models. The sizing criteria for CHP in refineries, LNG and oil terminals is very different to that typical for other industrial sites and for District Heating, where the CHP potential depends on network potential, which is outside the scope of the BU model.
9. The modelled impact of bespoke policy support options was only a few hundred MW as shown in the tables below. This is due mainly to the following:-

   i) The high proportion of deadweight of eligible schemes (exporting >20%),

   ii) The exclusion of schemes which export less than 20% but would require policy support to become cost-effective,

   iii) The impact of the Monte-Carlo modelling of uncertainty in investment decisions and of non-financial barriers.

Projected Gas-Fired CHP capacity for modelled sectors in MWe

	Baseline	Capital Grant	PES Incentive / obligation	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant
2020 Total	2,613	2,769	2,783	2,783	2,777	2,788	3,045
2025 Total	2,127	2,294	2,279	2,288	2,325	2,298	2,574

Projected Gas-Fired CHP capacity Increase for modelled sectors resulting from bespoke policies in MWe

	Capital Grant	PES Incentive / obligation	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant
2020 Total	156	170	171	164	175	432
2025 Total	167	152	161	198	171	447

Economic Potential for Non-Modelled Sectors in MWe

	Baseline	Capital Grant	PES Incentive	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant
2020 Oil & Gas	177	177	177	177	177	177	177
2025 Oil & Gas	0	177	177	177	177	177	177
2020 DH	1,975	1,975	1,975	1,975	1,975	1,975	1,975
2025 DH	2,718	2,718	2,718	2,718	2,718	2,718	2,718

Increased Economic Potential Capacity Resulting from Bespoke policies in MWe for Non-Modelled Sectors

	Capital Grant	PES Incentive / obligation	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant
2020 Oil & Gas	0	0	0	0	0	0
2025 Oil & Gas	177	177	177	177	177	177
2020 DH	0	0	0	0	0	0
2025 DH	0	0	0	0	0	0

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1 Introduction

1. The EU Energy Efficiency Directive (as did the previous Cogeneration Directive) seeks to promote the use of high efficiency Combined Heat & Power (CHP) where there is an economically justifiable demand for heat, thereby saving energy and reducing CO_2 emissions.

2. In the 2013 Heat Strategy document, '*The Future of Heating: Meeting the challenge*'[4], DECC announced that it would develop a specific policy designed to bring forward new natural gas CHP generation, subject to confirmation that this would not displace low carbon generation. To this end, required support levels and their impact on natural gas CHP uptake have been investigated for six policy options.

3. Ricardo-AEA's Bottom-Up (BU) model and DECC's Monte-Carlo (MC) model have been used to derive bespoke incentive levels which would enable a reasonable proportion of potential CHP schemes (sized in an energy efficient manner based on heat load) to become cost-effective and to project market response to such policies.

4. The support levels were each designed to bring forward an equal quantity of Primary Energy Saving (PES) on the basis of the simple cost-effectiveness of CHP sized in the most energy efficient manner. As a result each policy is predicted to deliver a similar quantity of PES when sizing decisions with and without policy support are taken into account. However, these amounts are not identical due to differences in probability and sizing strategy across the spectrum of potential sites and the fact that some types of schemes benefit more from one type of policy than another (the tariffs being designed for an 'average' scheme).

5. As explained in section 2.1, modelling the techno-economic CHP potential for every one of around 2 million potential sites individually is impractical. Thus sites were grouped into 298 segments, each representing a number of sites in a size range within a sector and their performance assessed over 6 different seasonal/diurnal time periods. This data resolution is the same in the BU and MC models.

6. The BU model firstly calculated the potential in 2020 for natural gas CHP when sized to meet the heat demand for a range of sector/ size segments and the cost-effectiveness (NPV and IRR) under current policies but with no new bespoke policy support. This showed the segments that would require bespoke policy support (negative NPV) in order to meet the required rate of return and the tariff required for each proposed policy was then calculated (see section 2.3). The BU model was then rerun to assess the CHP sizing decisions and the resulting potential capacity in 2020 and 2025 after sizing. Sizing was on the basis of heat load if this was economic (required rate of return met) or if not, electrical or heat load whichever has the highest IRR over a 10 year period for <25MWe CHP schemes or 15 years for larger schemes. The model was run to determine potential after sizing for a baseline scenario, with no bespoke policy, and for scenarios with each of the proposed policies applied in 2020 and 2025.

7. For the baseline and bespoke policy scenarios, the results of the BU model were then used as input to DECC's Monte-Carlo (MC) model to project the probability of the BU potential in each segment being installed based on economic performance in 2020 and 2025. Probability of investment is an increasing function of IRR with specific relationships

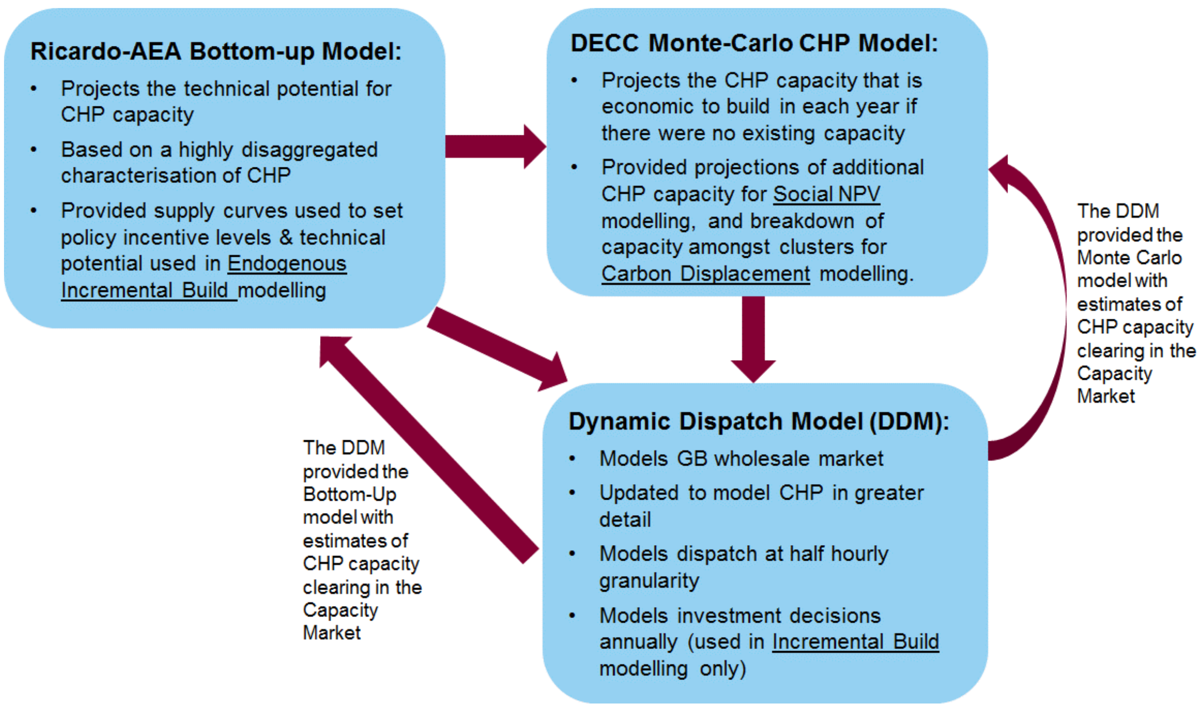
[4] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECC-The_Future_of_Heating_Accessible-10.pdf

for each economic sector. The model calculates a low probability for segments which have an IRR<assumed sectoral hurdle rate.

8. The results of the policy scenarios were compared with the baseline to assess the impact of each policy on projected capacity.

9. The impacts were also modelled externally by Lane Clark & Peacock using an upgraded version of DECC's Dynamic Despatch Model to analyse operation and carbon savings of the CHP capacity projected by DECC's MC model. This was based on much greater time detail (half hourly operation) and in order to make the modelling more manageable, the resolution of site segmentation was reduced into 38 clusters). Investment decisions were also modelled by LCP on an annual basis to enable the success of schemes in Capacity Market auctions to be predicted, and the results fed back into the BU and MC models, and as an independent comparison with the MC results. This interaction between the BU, MC and DDM models is summarised in Figure 1 below.

Figure 1 Interaction between BU, MC and DDM models.



10. The policy options analysed are as outlined below

I. **Capital grants**: grants for investment in new natural gas CHP. These would be competitively awarded to plant with the greatest projected primary energy saving per £ of grant, based on the plant's design and heat load, as certified by DECC's CHP Quality Assurance (CHPQA) programme[5]. Payment would be per MWh of anticipated annual primary energy saving.

[5] https://www.gov.uk/combined-heat-power-quality-assurance-programme

II. **Premium Feed in Tariffs**: a payment per MWh of good quality electricity generated, also referred to as Qualifying Power Output (QPO), by new natural gas CHP capacity.

III. **Primary energy saving incentive**: a payment per MWh primary energy saving from new natural gas CHP based on their annual performance as assessed by CHPQA using a standard EU methodology[6].

IV. **Primary energy saving obligation**: a regulatory obligation on energy suppliers, or business/public sector energy consumers, to achieve primary energy saving targets. Tradable certificates would be issued to new gas CHP per MWh primary energy saving delivered and surrendered by obligated parties to demonstrate compliance with their obligation. NB in the context of this modelling, option (iii) and (iv) have been considered as identical.

V. **Quality Index (QI) weighted heat incentive**: a payment per MWh of heat supplied from new gas CHP, weighted according to the plant's QI (CHPQA's measure of its overall efficiency).

VI. **Quality Index weighted capacity incentive**: payment per MW of new, gas CHP electrical capacity weighted according to the plant's QI

11. All policy options are assumed to support the installation of new gas CHP capacity up until 2025 only, with the non-grant policies (ii-vi) only payable for the first 5 years of operation. Later deployment is assumed to be undesirable due to declining carbon saving benefits against the backdrop of a decarbonising grid.

2 Bespoke Gas CHP Modelling Procedure

12. The procedure followed involved the 4 steps outlined below.

i) Generating Supply curves and setting bespoke policy tariff levels
ii) Modelling the Bottom Up CHP potential for various sectors with and without policies
iii) Modelling the probable uptake of Bottom-Up CHP potential for same sectors with and without policies
iv) Calculating the economic CHP potential for Oil & Gas and DH Sectors off-model with and without bespoke policy support. These sectors represent approximately 23% of all modelled technical potential but a much smaller proportion of projected capacity.

13. The first two required the use of Ricardo-AEA's BU model which was revised and considerably extended for the purposes of this analysis[7]. The BU model was used firstly to calculate the incentive levels required to make specified percentiles of the supply curve (assuming CHP is sized based on heat load) cost-effective. For this part of the analysis sizing was assumed to be based on heat load as this is the most energy efficient way to size CHP. The BU model was then used to assess the UK potential of CHP, taking

[6] Assessing gas CHP v separate gas fired generation at 52.5% electrical and 90% heat efficiency (Lower Calorific Value basis) plus 0-14% correction for avoided grid loss (depending on the voltage of network to which the plant is connected and whether power is exported or used onsite).
[7] In line with the recommendations of the Macpherson report on the quality of modelling in Government, in 2013 DECC commissioned a quality assurance review of the Ricardo-AEA Bottom-up model of CHP used to support them in predicting future potential for CHP. The review concluded that the model had been providing DECC with reasonably robust results to date, but that the software implementation was is in need of significant upgrade. Subsequently, significant improvements were made to documentation, QA checking and logging processes and the functionality of the model was extended for the purposes of this study.

account of whether CHP would be sized based on heat or electrical load, with and without policy support for sectors included within the model.

2.1 Ricardo-AEA Bottom-Up CHP Model Overview

14. Ricardo-AEA's BU model is used annually to assess the potential of CHP for various industrial and building sectors and scales of energy demand, representing potential sites in the UK.

2.1.1 Site Segmentation

15. There are approximately 2 million non-domestic sites in the UK, but assessing each individually would be very data intensive and inappropriate for smaller sites where energy data is unavailable individually (thus 298 examples used representing sector and size range). Sites are classified as belonging to one of 35 sectors, with each sector divided into 2 groups (within and outside the EU-ETS). Sites within each grouping are then ranked in descending order of annual heat demand and allocated to 6 size ranges (tranches), each with approximately the same total thermal demand, allocating the largest x sites whose total annual heat demand is approximately 1/6th of the sector total to tranche 6 and the next y sites to tranche 5 etc. The table below shows examples of this segmentation for 3 sector/EU-ETS status groupings. The examples in the table below illustrate that whilst sites in the education sector outside the EU-ETS can be allocated to size ranges with approximately equal total annual heat demand, this is not possible for Inorganic chemicals and Synthetic Fibres within the EU-ETS due to the relatively small number of sites (less than 6 sites in the latter group). Thus tranche 1 contains a large number of small sites and tranche 6 a few large sites (often just one). There are in fact 420 (i.e. 35 x 2 x 6) model segments, but many sectors have less than 6 EU-ETS sites, so only 298 are populated.

Segmentation Examples

EUETS Status	Sector	Sub-Sector	Sector Size Range	No of sites in segment	Total Segment heat demand (TJpa)	Average site heat demand (TJpa)
EUETS	Chemicals	Inorganic Chemicals	1	7	2,148	306.8
EUETS	Chemicals	Inorganic Chemicals	2	2	3,087	1,543.4
EUETS	Chemicals	Inorganic Chemicals	3	1	1,820	1,820.0
EUETS	Chemicals	Inorganic Chemicals	4	1	2,417	2,417.1
EUETS	Chemicals	Inorganic Chemicals	5	1	3,214	3,214.0
EUETS	Chemicals	Inorganic Chemicals	6	1	8,612	8,612.1
EUETS	Chemicals	Synthetic Fibres	1	0	0	-
EUETS	Chemicals	Synthetic Fibres	2	0	0	-
EUETS	Chemicals	Synthetic Fibres	3	1	126	125.6
EUETS	Chemicals	Synthetic Fibres	4	1	885	884.9
EUETS	Chemicals	Synthetic Fibres	5	1	1,661	1,660.8
EUETS	Chemicals	Synthetic Fibres	6	1	5,146	5,145.6
Non-EUETS	Services	Education	1	7,389	4,959	0.7
Non-EUETS	Services	Education	2	5,292	4,860	0.9
Non-EUETS	Services	Education	3	3,832	4,896	1.3
Non-EUETS	Services	Education	4	2,659	4,822	1.8
Non-EUETS	Services	Education	5	1,706	4,988	2.9
Non-EUETS	Services	Education	6	692	4,639	6.7

2.1.2 Time Segmentation

16. For each notional average site in the 298 segments, average energy demands are calculated for the following six equal time segments based on energy profile indices developed for each sector as detailed in section 3 and Annex A.

i) Winter Daytime (Nov-Apr 08:00 to 16:00)
ii) Winter Evening (Nov-Apr 6 16:00 to 00:00)
iii) Winter Night (Nov-Apr 00:00 to 08:00)
iv) Summer Daytime (May-Oct 08:00 to 16:00)
v) Summer Evening (May-Oct 08:00 to 16:00)
vi) Summer Night (May-Oct 08:00 to 16:00)

17. Each time segment covers 1,461 hours of the year in total (8,766/6), but the number of hours of site operation (when either heat or electricity will be consumed) may be reduced to reflect times when processes cease operation or buildings are unoccupied, for example in holiday shutdowns. The number of hours of CHP operation cannot be greater than site operating hours, but may be lower to reflect reduced output at times of low energy demand, price and/or maintenance.

18. The model sizes the CHP to match the average heat load for the time period chosen by the user and selects the appropriate technology. It also calculates the alternative size and technology required to match the electrical load in the same time period.

19. It then calculates the average annual cash flow[8] and the discounted whole life cost for each of these two CHP sizing options (discounted at a sector-specific hurdle rate specified) and the IRR implied, and then selects the more favourable size based on the techno-economic criteria option selected by the user. The options are:-

I. Select heat match option regardless
II. Select electricity match option regardless
III. Select the option with the larger electrical capacity
IV. Select the option with higher NPV at user specified discount rates
V. Select the option with higher IRR
VI. Select heat match option if IRR>hurdle rate (i.e. NPV>0), otherwise select the option with the higher IRR

20. Sizing CHP based on heat load is generally more energy efficient than sizing on electricity load, but it is not always the more economic option.

21. For sites where the heat to power (HPR) demand ratio is lower than the output HPR capability of the appropriate CHP technology, sizing based on heat load results in a smaller CHP unit than sizing based on electricity demand and avoids the need to dump heat (unless this can be exported to another site, which is not an option for many sites). For sites with a demand HPR higher than the output HPR capability of CHP, it is the larger option which maximises the amount of energy saving with excess electricity exported. In general demand HPR exceeds the output HPR of the CHP and maximising energy savings involves sizing the CHP to meet site heat demands and export surplus power.

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[8] The annual average cash flow is used rather than analysing the annual fluctuation in order to allow the model to operate more quickly.

22. For the purposes of setting policy support tariffs, the model was run with option 1 selected, the NPV information extracted and policy levels set to enable a certain percentile of the supply curve to become cost-effective. For subsequent modelling of the policy impact on actual outcome, option 6 was selected as being the most likely sizing strategy a site would adopt. Thus the tariff setting methodology reflects the policy objective to encourage CHP to be sized on heat load rather than electrical load, and hence maximise energy savings. However, unless tariff levels are set very high based on the least economic segment, some segments would always be sized on electrical load, even with policy support.

23. For each segment, the technical CHP potential is the capacity selected multiplied by the number of sites in the segment and the total national technical potential for modelled sectors is the total for all 298 segments.

24. The economic screening is carried out by the MC probability model operated by DECC. This calculates the IRR in greater detail as it accounts for fluctuations in annual cash flows for technical potential in the segments supplied by Ricardo-AEA, before calculating the probability of investment based on their IRR.

2.2 Estimating Energy Demands

25. Current thermal demands for industrial sites and service sector buildings were derived from estimated heat loads underlying the UK CHP development map data[9] as detailed below.

26. Electrical demands were estimated using Energy Consumption in the UK (ECUK), fuel and electricity data[10] to estimate the heat to power demand ratio for each sector. This was then used, in conjunction with heat loads derived from the UK CHP development map, to estimate site electrical demand.

2.2.1 Estimating Heat Demands – UK CHP Development Map

27. Estimates of heat consumption for sites in chemical, engineering, food & drink, paper, textiles, other manufacturing and service sectors were made using the following approaches:

1. Non-Domestic Sites with individual energy data

   i) For CHPQA-registered CHP schemes, annual heat demands were equated with measured useful heat output and fuel input noted.

   ii) A list of sites underlying the National Atmospheric Emission Inventory (NAEI)[11] was obtained and sites in sectors where fuel is mainly used for power generation, high temperature processes (direct dry heat) and non-combustion processes were excluded.

   iii) Historic annual fuel data underlying the NAEI was obtained for each the remaining sites.

[9] The UK CHP development map can currently be found on the DECC website at http://chp.decc.gov.uk/developmentmap/
[10] The Energy Consumption in the UK Statistics (ECUK) can currently be found on the DECC website at https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

[11] http://naei.defra.gov.uk/

iv) Registered CHP schemes were mapped to NAEI sites, fuel input to heat only boilers calculated by subtracting CHP fuel from NAEI fuel where applicable, non-CHP heat calculated assuming a standard boiler efficiency and CHP heat added where applicable to calculate the total heat demand for each site.

2. Other Non-Domestic Sites

i) A first estimate average national fossil fuel use per employee (fuel intensity) was calculated for each Standard Industrial Classification (SIC)[12] sector using DECC's Energy consumption in the UK (ECUK)[13] data and dividing by the total number of employees obtained from Inter-Departmental Business Register (IDBR)[14] to produce a first estimate of total fuel use per employee per business sector.

ii) For various geographical areas (Office for National Statistics Output Areas[15]) the total non-domestic fuel use was calculated using a combination of the following sources;

- DECC gas consumption data at Medium Layer Super Output Area (MSOA) level. Super output areas were designed to improve the reporting of small area statistics and are built up from groups of output areas[16].
- Northern Ireland gas consumption data from Phoenix Gas,
- a 1 square km domestic gas grid map and a map of Smoke Control Areas created by combination of a digital picture of Smoke Control Area available from Defra and
- Urban area boundaries and used to assign the locations of coal and oil consumption.

iii) The fuel intensity calculated in step i was multiplied by number of employees in each MSOA area, compared with high level fuel estimates from step ii and the fuel intensities for all sectors scaled to give the correct fuel total for the MSOA.

iv) For each square km and Lower Layer Super Output Area (LSOA) for each SIC code, the fuel consumption was estimated for each sector by multiplying the calibrated fuel intensity by the number of employees to obtain the fuel consumption. This process took account of fuel demand for sites with individual energy consumption data to ensure there was no double counting.

v) Fuel consumptions were converted to heat demand assuming a standard boiler efficiency of 81% (Gross Calorific Value basis).

vi) For the purposes of CHP modelling, the heat load was calculated for each individual site before grouping into segments as described in section 2.1.1.

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[12] http://www.ons.gov.uk/ons/guide-method/classifications/current-standard-classifications/standard-industrial-classification/index.html
[13] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk
[14] http://www.ons.gov.uk/ons/about-ons/products-and-services/idbr/index.html
[15] http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/output-area--oas-/index.html
[16] http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/super-output-areas--soas-/index.html

2.3 Supply Curves and Bespoke Policy Tariffs

28. The BU model was set up to calculate the potential CHP capacity based on capacity in all segments being sized to match the heat demand (the most energy efficient sizing method) and the energy and policy[17] prices anticipated in 2020.

29. The marginal cost of CHP (discounted by hurdle rates ranging from 18-25% depending on sector over 10 years for <25MWe schemes and 15 years for larger schemes) versus heat supply from conventional boilers and electricity imported from the grid was then calculated for each segment.

30. The **tariff for the capital grant policy option** was calculated by dividing the marginal discounted whole life cost of CHP by the annual Primary Energy Saving (PES). For the **other policy options,** the marginal discounted whole life cost of CHP was annualised over 5 years (the period over which the policies would be paid), and divided by the technical parameter appropriate to the policy in question, in order to calculate the required policy tariff as follows:-

- Grant Requirement = Marginal discounted whole life cost of CHP (£) / Annual PES (MWh)
- PES Incentive Requirement = Marginal discounted whole life cost of CHP Annualised over 5 years (£) / Annual PES (MWh)
- Premium FiT Incentive Requirement = Marginal discounted whole life cost of CHP Annualised over 5 years (£) / Annual QPO (MWh)[18]
- QI Weighted Heat Incentive Requirement = Marginal discounted whole life cost of CHP Annualised over 5 years (£) / [QI/100 x Annual QHO (MWh)]
- QI Weighted Capacity Incentive Requirement = Marginal discounted whole life cost of CHP Annualised over 5 years (£) / [QI/100 x TPC (MWe)]

31. Discounting used the sector-specific commercial hurdle rates relevant for each segment as shown in the table below. The resulting tariff level shown for each segment in the curve therefore represents the tariff required in order for CHP projects in that segment to just meet the sectoral hurdle rate.

Sector	Hurdle rate (%)
Chemicals	18%
Engineering	20%
Food & drink	25%
Other Industry	20%
Paper	25%
Textiles	25%
Services	20%

32. Segments which are cost-effective without support have a positive NPV and show as negative support level requirements (i.e. no support required).

[17] Existing and future announced policies including CCL, CCA, EUETS, CRC and CPS but not CM which will not apply where bespoke incentives are received.
[18] Under CHPQA, QPO (Qualifying Power Output) is the annual power generation from a CHP scheme that qualifies as Good Quality CHP, QHO (Qualifying Heat Output is the amount of 'useful' heat supplied annually from a CHP scheme; TPC (Total Power Capacity) its maximum power generation capacity and QI (Quality Index) an indicator of the energy efficiency and environmental performance of a CHP scheme [see CHPQA Standard at https://www.gov.uk/combined-heat-power-quality-assurance-programme]

33. For each of the policies, the segments were plotted as curves with segments requiring least policy support to the left and those requiring the most support to the right with height representing the required support level and width representing PES.

34. In order to derive tariffs focussed on new capacity, the existing gas-fired CHP capacity was estimated for each segment based on 2012 capacity data from DUKES 2013 and subtracted from total potential. As many segments represent a number of sites each with the same notional energy demand, this is assumed to make no difference to the marginal discounted whole life cost of remaining potential in each segment and thus the required support level (height) of each segment. The impact is to reduce the PES potential (width) of segments, removing some altogether.

35. Example curves for deriving the capital grant tariff are shown in Figures 2 and 3 below, based on 2020 energy prices and policy costs. Existing CHP capacity was excluded so the curves represent the required incentive level to bring forward new capacity only.

Figure 2 Capital Grant Requirement in 2020 Banded by Technology & Size

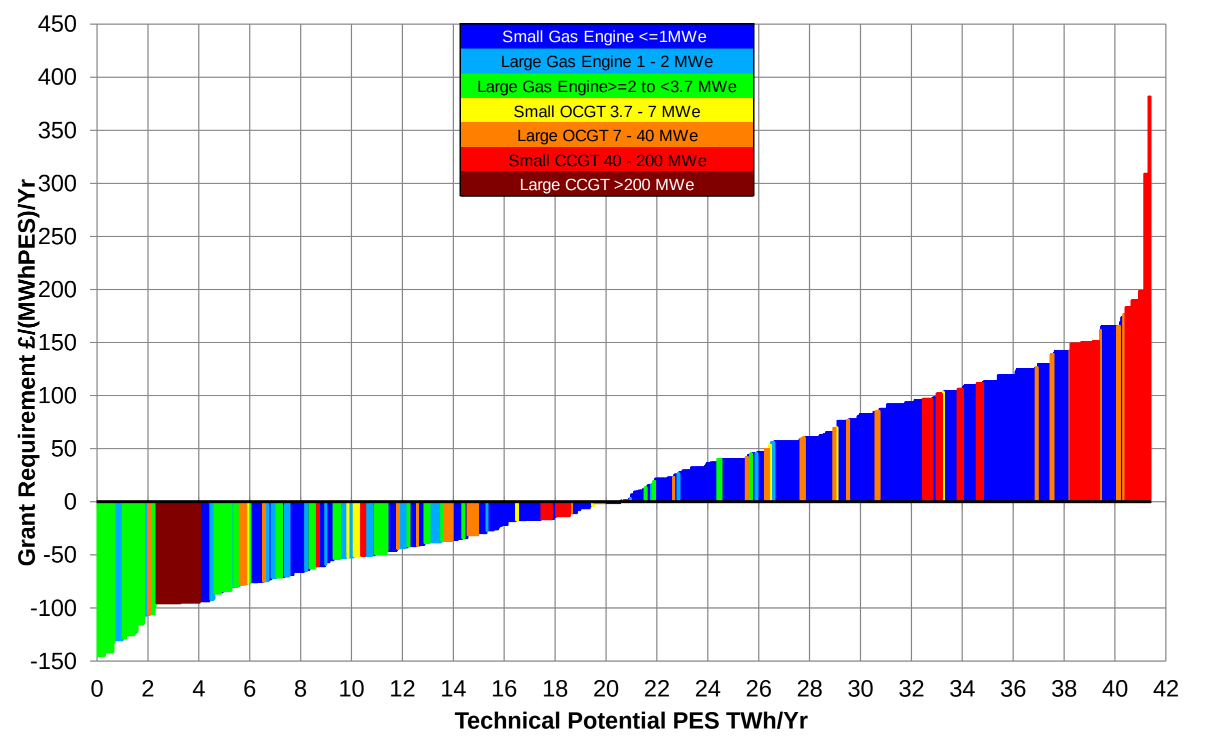
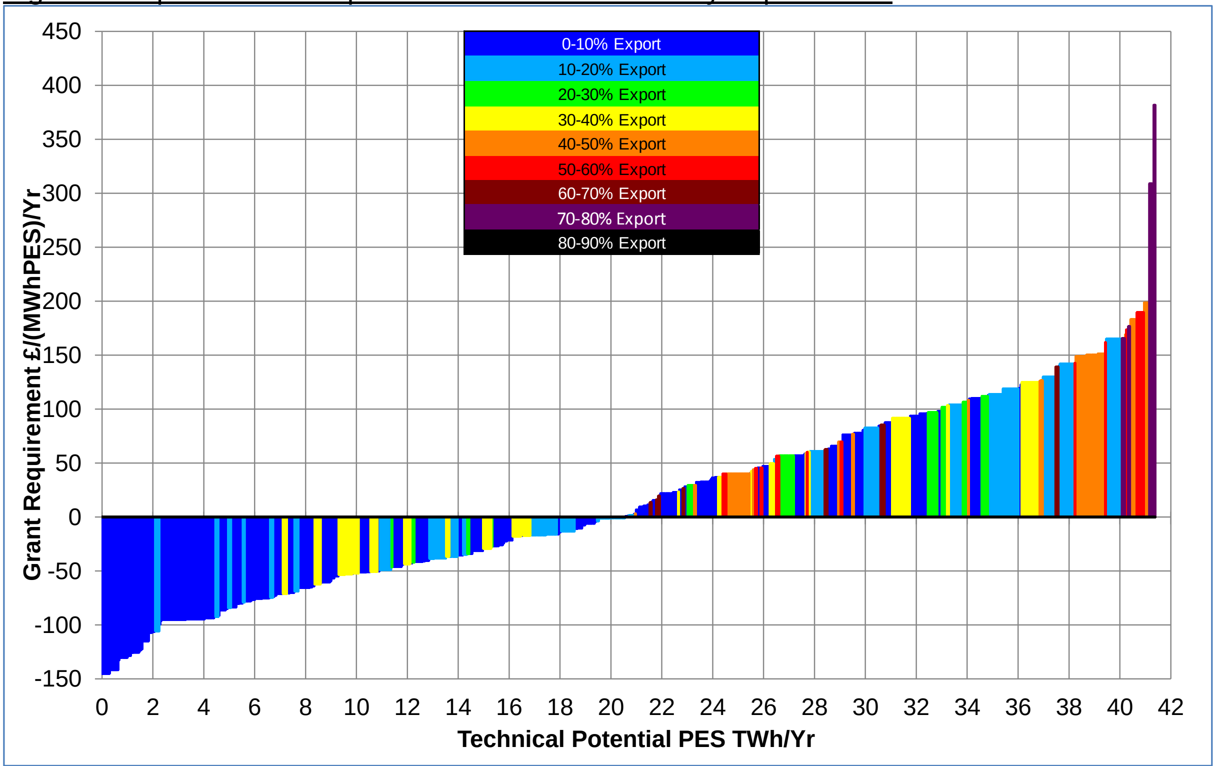


Figure 3 Capital Grant Requirement in 2020 Banded by Export Level



36. Segments with positive values on the right hand side of the curve require support to be commercially cost-effective but those with negative values on the left do not. Thus if all segments were eligible for policy support, this would lead to schemes which the supply curve suggests would be financially viable in any case, being able to claim support i.e. a “deadweight” cost.

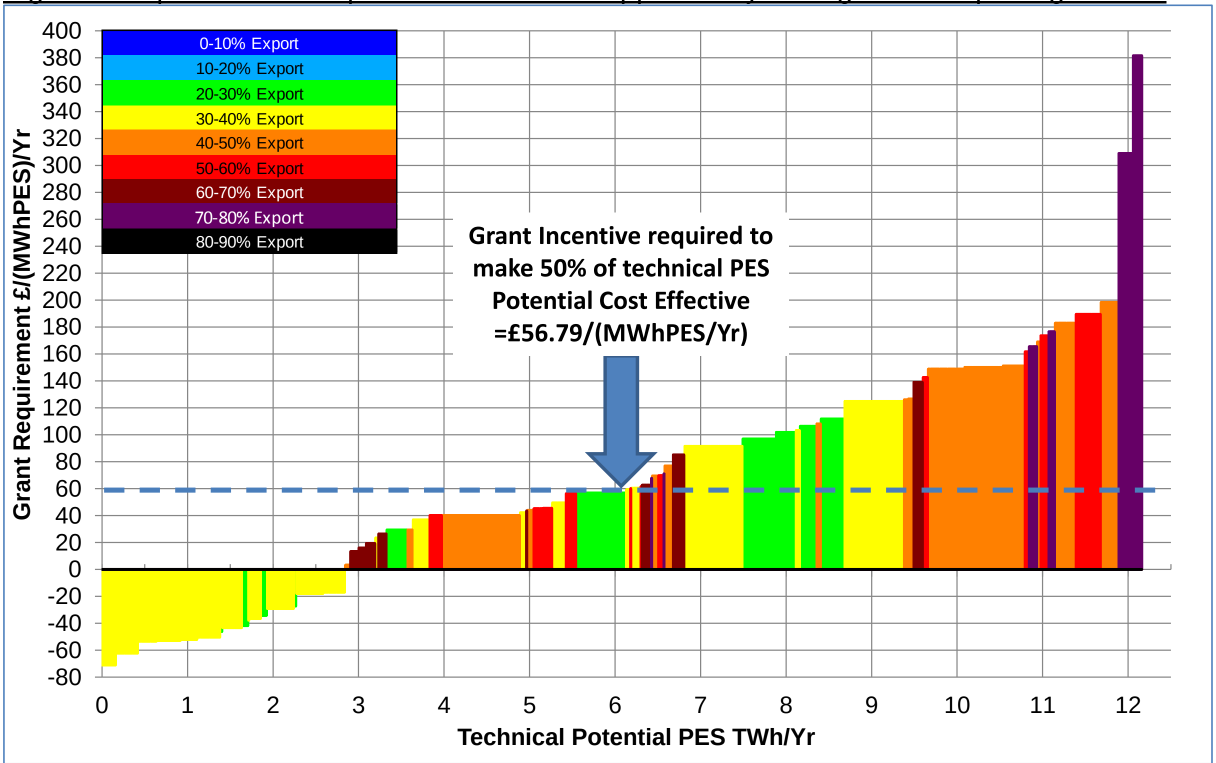
37. This does not consider the fact that the probability of cost-effective schemes being built is not 100% and would increase with policy support so the curve above does not give the full picture of policy impact only an approximate one.

38. From Figure 3, it can also be seen that schemes which export a high proportion of electricity generally require more support than those exporting a small proportion, with all potential exporting more than 40% of electrical output requiring support.

39. A minimum export threshold of 20% was selected for policy eligibility with support levels set to support the average scheme exporting 20% or more. A lower export % threshold would require lower support tariffs and bring forward more capacity (i.e. some of the positive light green and, if <10%, some blue segments) but this would increase the overall policy costs and deadweight. Conversely, a higher threshold would increase tariffs but reduce overall policy cost and would bring forward less capacity.

40. 20% was selected as the best overall compromise. Segments exporting less than 20% were then excluded from the cost curves and tariffs derived which would make CHP amounting to 50% of eligible technical PES potential cost-effective as shown in Figure 4 below.

Figure 4 Capital Grant Requirement in 2020 if applied only to Segments Exporting >=20%



2.4 Modelling Technical Potential with and without Policy Support

41. Having determined the required support tariff levels for the policies, the BU model was used to assess the 2020 and 2025 technical potential for gas-fired CHP in the baseline scenario (no bespoke policy support) and for each of the bespoke gas CHP policies and separately for renewable CHP (baseline scenario only with anticipated energy prices and policies).

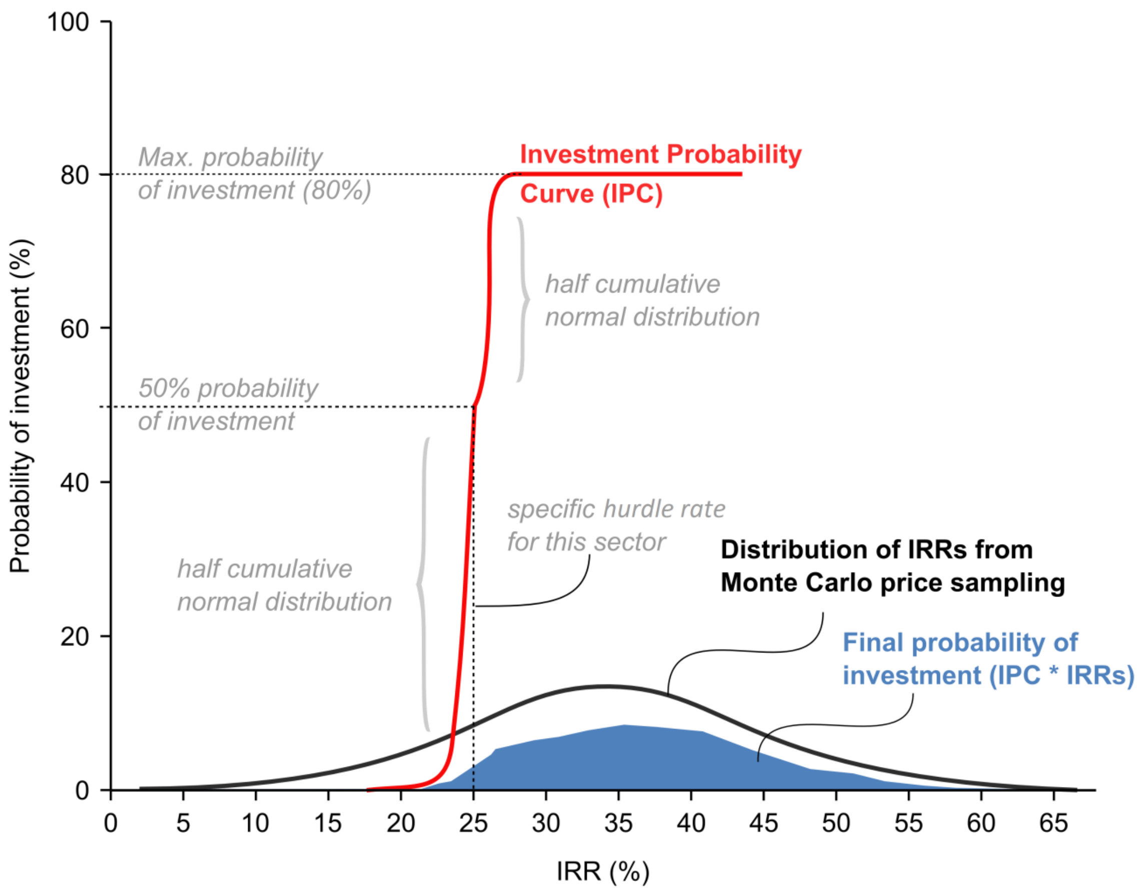
42. For gas-fired CHP, sizing is based on heat load if economic, otherwise electrical/heat load whichever has the higher IRR. For renewable CHP, all capacity is assumed to be sized on heat load as RHI tariffs were designed to encourage this.

43. The results were then used by DECC as input to the MC model.

2.5 Monte-Carlo Modelling

44. The investment model (the 'Monte Carlo', MC, simulation model), operated by DECC, takes into account the commercial investment criteria. It was established in 2008 in discussion with a number of companies operating and developing CHP in the UK and reviewed with CHPA members as part of this project. It is used to assess the likelihood of investment in the identified sector/size categories. It contains the same sector/size segmentation as the BU model and calculates the IRR of the technical potential in each segment and the probability of it being built. This is based on a sector-specific formula of probability versus the IRR achieved and a hurdle rate appropriate for the sector which has been developed in consultation with industry. The model uses an investment probability curve approach which models non-financial constraints by capping the maximum probability of investment and setting the probability of investment to 50% at the nominal hurdle rate. This means that the model never builds 100% of technical potential, irrespective of the economics. Figure 5 below shows an example of how investment probability varies with IRR for a particular sector with a nominal 25% hurdle rate. The nature of non-financial barriers to CHP investment is explored in *Factors affecting the uptake of gas CHP*, published alongside this report.

Figure 5. Example Investment Probability Curve



45. Whilst the BU model assesses the technical potential of gas-fired and renewable CHP separately, these will compete for the same applications. In some cases gas-fired CHP is more cost-effective and vice versa.

46. The decision between gas-fired and renewable CHP is made within the Monte Carlo model. Factors reflecting future growth or reduction in energy demands were also applied based on the assumptions of expansion or contraction in industrial and service sectors used in DECC's annual Updated Energy Projections.

47. Policies influencing investment decisions differ between gas-fired and renewable CHP because of the differing effects on fuel prices, investment and operating costs, etc. The combined energy price forecasts and policies appropriate to the years being modelled were also thus required to run the investment model.

48. The technical potential and associated technical data for CHP (capacity and appropriate technology) for each segment were provided using the BU model:

- Total Power Capacity (TPC),
- Annual Qualifying Heat Output (QHO) which is usefully used not dumped,
- Annual Total Power Output (TPO),

- How much power is surplus to site requirements and thus exported to the grid,
- Annual Total Fuel Input (TFI),
- Primary Energy Savings (PES) and
- CHPQA Quality Index (QI).

49. The MC modelling also uses technology-specific cost functions from the BU model to calculate capex and opex for each segment.

50. The Model calculates the probability of investment for both gas-fired and renewable (biomass/biodiesel) projects. A further adjustment is applied to the renewables probability to take account of the fact that not all sites are suited to renewables, by multiplying the probability by a Suitability Factor (100%, 75%, 50%, 25% or 0%) assumed for each segment. The latter represents the proportion of sites in each size and tranche suited to renewable technologies. These were supplied by us to DECC's modelling team based on a judgement for each segment given the number of sites, CHP technology and size potential and the perceived ability to host such a scheme considering spatial constraints on plant and fuel deliveries etc.

51. Once both probabilities are known the model calculates how much of each is likely to be built. This is done by comparing the two probabilities. If for example there is a 75% probability for renewable CHP and only 50% for gas-fired CHP in a segment, a larger proportion of renewable CHP is likely to be installed.

52. The MC model was then run for the required policy / input scenarios and a composite summary spread-sheet to include the probabilities of investments for both renewable CHP and gas-fired CHP generated. This task provided forecasts of renewable and gas-fired CHP up to 2025.

2.6 Non-Modelled Sectors

53. A number of sectors cannot be readily modelled including Refineries, LNG and Oil Terminals (sizing criteria is very different to more typical sizing for industrial sites) and District Heating (depends on DH network potential scenarios involving extensive work outside the scope of the BU model).

54. The BU and MC models therefore exclude CHP in Oil & Gas or District Heating (DH) sectors and separate off-model assessments of economic capacity in these two sectors has been produced. These assessments use input assumptions consistent with the MC model, but a simpler investment decision methodology (modelling all projects with IRRs above the sector hurdle rate as being built) that does not include the investment probability element of the MC model (representing behavioural and non-financial factors).

55. We have thus calculated cost-effective potential outside the BU model based on a combination of data on current CHP schemes supplying DH drawn from CHPQA data, market knowledge, and results of Redpoint Energy System Optimisation Modelling (RESOM) for *The Future of Heating: Meeting the challenge* publication which was supplied to us by DECC and which predicted future DH capacity in the UK.

56. The technical CHP potential supplying DH schemes in sectors modelled in the BU model would compete with potential for CHP in individual buildings. The results of the RESOM model indicate the proportion which would serve residential heat load only (not included in the BU model) so this formed the basis of the DH potential calculations.

57. Other sectors such as Anaerobic Digestion (AD), sewage treatment works, high temperature industries and domestic CHP are likely to have relatively little natural gas-fired CHP potential so were not considered. Further details of the approach and key assumptions are given in Section 3.

3 Key Technical and Cost Assumptions

3.1 Energy Demands and assumed Capacity Market Participation

58. Segmented annual energy demands for various chemical sites in the EUETS and service sectors outside the EUETS are shown below as examples. Capacity Market participation was modelled externally by Lane Clark & Peacock (LCP) using an upgraded version of DECC's Dynamic Dispatch Model. Segments which form part of the clusters which LCP modelled as being successful in Capacity Market auctions, and hence receiving the Capacity auction clearing price, are shown here. Assumptions for all sectors are shown in Annex A.

Table 1 Segmented Annual Energy Demand and Assumed participation in the Capacity Mechanism for Example Segments

EUETS Status	Sector	Sub-Sector	Sector Size Range	No of sites in segment	Average site power demand (TJpa)	Average site heat demand (TJpa)	Expected to be Successful in Capacity Market Auction
EUETS	Chemicals	Inorganic Chemicals	1	7	202	307	Yes
EUETS	Chemicals	Inorganic Chemicals	2	2	1,018	1,543	Yes
EUETS	Chemicals	Inorganic Chemicals	3	1	1,200	1,820	Yes
EUETS	Chemicals	Inorganic Chemicals	4	1	1,593	2,417	Yes
EUETS	Chemicals	Inorganic Chemicals	5	1	2,119	3,214	Yes
EUETS	Chemicals	Inorganic Chemicals	6	1	5,678	8,612	Yes
EUETS	Chemicals	Other Chemicals	1	11	273	259	Yes
EUETS	Chemicals	Other Chemicals	2	1	579	550	Yes
EUETS	Chemicals	Other Chemicals	3	1	1,151	1,094	Yes
EUETS	Chemicals	Other Chemicals	4	1	1,612	1,533	Yes
EUETS	Chemicals	Other Chemicals	5	1	3,790	3,603	Yes
EUETS	Chemicals	Other Chemicals	6	1	8,947	8,505	No
EUETS	Chemicals	Organic chemicals	1	8	168	155	Yes
EUETS	Chemicals	Organic chemicals	2	1	903	832	Yes
EUETS	Chemicals	Organic chemicals	3	1	950	875	Yes
EUETS	Chemicals	Organic chemicals	4	1	1,679	1,547	Yes
EUETS	Chemicals	Organic chemicals	5	1	3,143	2,896	Yes
EUETS	Chemicals	Organic chemicals	6	1	4,025	3,708	Yes
Non-EUETS	Services	Education	1	7,389	0	1	No
Non-EUETS	Services	Education	2	5,292	0	1	No
Non-EUETS	Services	Education	3	3,832	1	1	No
Non-EUETS	Services	Education	4	2,659	1	2	No
Non-EUETS	Services	Education	5	1,706	1	3	No
Non-EUETS	Services	Education	6	692	3	7	No
Non-EUETS	Services	Health	1	667	1	2	No
Non-EUETS	Services	Health	2	487	1	3	No
Non-EUETS	Services	Health	3	385	1	4	No
Non-EUETS	Services	Health	4	294	2	5	No
Non-EUETS	Services	Health	5	185	3	7	No
Non-EUETS	Services	Health	6	103	6	14	No
Non-EUETS	Services	Hotels	1	6,229	1	1	No
Non-EUETS	Services	Hotels	2	5,378	1	1	No
Non-EUETS	Services	Hotels	3	4,292	1	1	No
Non-EUETS	Services	Hotels	4	3,275	1	1	No
Non-EUETS	Services	Hotels	5	2,102	2	2	No
Non-EUETS	Services	Hotels	6	829	4	4	No
Non-EUETS	Services	Offices	1	1,318	0	0	No
Non-EUETS	Services	Offices	2	1,089	0	0	No
Non-EUETS	Services	Offices	3	800	1	1	No
Non-EUETS	Services	Offices	4	540	1	1	No
Non-EUETS	Services	Offices	5	327	1	1	No
Non-EUETS	Services	Offices	6	139	3	3	No
Non-EUETS	Services	Retail	1	2,684	1	0	No
Non-EUETS	Services	Retail	2	2,254	2	0	No
Non-EUETS	Services	Retail	3	1,771	2	1	No

Non-EUETS	Services	Retail	4	1,313	3	1	No
Non-EUETS	Services	Retail	5	940	4	1	No
Non-EUETS	Services	Retail	6	349	10	3	No

59. The number of hours of annual site operation (i.e. the hours for which there is at least some heat or electricity load) was assumed to be 8,094 for all sectors (8,766 minus 4 weeks when processes would cease and buildings would be unoccupied due to holidays). The model splits these equally across time periods so each is assumed to comprise a total of 1,349 hours of site operation.

60. The average energy loads in other periods are expressed as a percentage of the winter daytime load whose index is 100.

61. For each site the annual site demand is a product of the loads and time duration of each period. As the annual site demand and the ratio of loads in the different periods are known, the loads can be calculated as follows:-

Annual Demand (MWh) = Σ [Period Index/100 * Winter Day Load (MW) * Time Period Length (Hours)]

As all six time period lengths = 8,094/6 = 1,349 and Winter Day Load is a constant:-

Annual Site Demand (MWh) = Winter Day Load (MW) * 1,349 * Σ Period Index/100 :-

Winter Day Load (MW) = Annual Site Demand (MWh) / (1,349 * Σ Period Index/100))

For Example, for Inorganic Chemicals Tranche 1,

Annual Site Heat Demand = 307TJ / 3600 * 1,000,000 = 85,277MWh

So Winter Day Heat Load = 85,277 / (1,349 * (1+0.9+0.85+0.8+0.75+0.7)) = 12.6MW

Winter Evening heat load = 12.6 x 0.9 = 11.4MW etc.

62. Assumed energy load profiles for various chemical and service sectors are shown in Table 2 below as examples. Assumptions for all sectors are shown in Annex A.

Table 2 Assumed Site Operating Hours and Load Profiles for Example Segments

Sector	Sub-Sector	Sector Size Range	Assumed Site Operating Hours	Heat load index winter day	Heat load index winter eve	Heat load index winter night	Heat load index summer day	Heat load index summer eve	Heat load index summer night	Elec load index winter day	Elec load index winter eve	Elec load index winter night	Elec load index summer day	Elec load index summer eve	Elec load index summer night
Chemicals	Inorganic Chemicals	1	8,094	100	90	85	80	75	70	100	90	85	90	85	80
Chemicals	Inorganic Chemicals	2	8,094	100	95	90	80	75	70	100	90	85	90	85	80
Chemicals	Inorganic Chemicals	3	8,094	100	95	90	85	80	75	100	90	90	95	85	85
Chemicals	Inorganic Chemicals	4	8,094	100	95	90	85	85	80	100	95	90	95	90	85
Chemicals	Inorganic Chemicals	5	8,094	100	95	90	90	85	80	100	95	90	95	90	85
Chemicals	Inorganic Chemicals	6	8,094	100	95	90	90	90	85	100	95	90	95	90	85
Chemicals	Other Chemicals	1	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	2	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	3	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	4	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	5	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	6	8,094	100	100	100	65	85	65	100	100	100	95	95	95
Chemicals	Organic chemicals	1	8,094	100	90	85	80	75	70	100	95	85	95	90	80
Chemicals	Organic chemicals	2	8,094	100	90	85	80	75	70	100	95	85	95	90	80
Chemicals	Organic chemicals	3	8,094	100	95	90	85	80	75	100	95	90	95	90	85
Chemicals	Organic chemicals	4	8,094	100	95	90	85	80	75	100	95	90	95	90	85
Chemicals	Organic chemicals	5	8,094	100	95	90	85	80	75	100	95	90	95	95	90
Chemicals	Organic chemicals	6	8,094	100	95	90	90	85	80	100	95	90	95	95	90
Services	Education	1	8,094	100	105	28	54	60	15	100	114	55	91	100	47
Services	Education	2	8,094	100	105	28	54	60	15	100	114	55	91	100	47
Services	Education	3	8,094	100	60	50	54	15	15	100	15	15	91	15	15
Services	Education	4	8,094	100	100	50	54	54	15	100	100	15	91	91	15
Services	Education	5	8,094	100	60	50	54	15	15	100	15	15	91	15	15
Services	Education	6	8,094	100	60	50	54	15	15	100	15	15	91	15	15
Services	Health	1	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	2	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	3	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	4	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	5	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	6	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Hotels	1	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	2	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	3	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	4	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	5	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	6	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Offices	1	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	2	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	3	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	4	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	5	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	6	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Retail	1	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	2	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	3	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	4	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	5	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	6	8,094	100	40	20	30	20	10	100	40	20	100	40	20

Winter Daytime (Nov-Apr 08:00 to 16:00)
Winter Evening (Nov-Apr 6 16:00 to 00:00)
Winter Night (Nov-Apr 00:00 to 08:00)
Summer Daytime (May-Oct 08:00 to 16:00)
Summer Evening (May-Oct 08:00 to 16:00)
Summer Night (May-Oct 08:00 to 16:00)

3.2 Time Segment Sizing Strategy

63. The summer day period was selected for CHP sizing as this generally has the 4th highest heat demand out of the six options and is usually the most cost-effective allowing CHP to run at full output for up to 5,800 hours/yr. without dumping heat.

3.3 Gas-Fired CHP Technologies

64. Three gas-fired CHP technologies were considered:-

1. Reciprocating Gas Engines
2. Open Cycle Gas Turbines (OCGT)
3. Combined Cycle Gas Turbines (CCGT)

65. Their properties are summarised in Annex D:

66. Table 3 below shows the assumed technologies for different capacities of CHP and their assumed efficiencies. These are based on CHP market experience, verified by industry consultation

67. Table 4 shows the assumed number of hours of CHP operation in each of the six time periods. It was assumed that CHP would operate for a total of 6,500 hours per year in industrial sectors based typical operation of new industrial CHP schemes and 5,600 hours/Yr for service sectors based on typical operation of 17 hours per day with 90% availability and timed to coincide with maximum energy demand.

Table 3 Techno-economic CHP assumptions for Gas-Fired CHP

CHP Type	Fully Condensing electrical efficiency - GCV (%)	Z Ratio (heat/ power drop	H:P ratio	electrical efficiency in CHP Mode (%)	Overall CHP efficiency (%)	Capex - A multiplier (£/kWe)**	Capex - n exponent**	Maintenance cost factor (£/MWhe)	Technology Investment Period (Years)	Engine/ Turbine Replacement Project Year	Engine/ Turbine Replacement Cost % of CHP Capex
Small Gas Engine <0.1 MWe	31.7%	-	1.5	31.7%	79.4%	961.29	-0.15	12.86	10	10	0.0%****
Small Gas Engine>=0.1 to <0.2 MWe	33.8%	-	1.3	33.8%	78.0%	961.29	-0.15	12.86	10	10	0.0%****
Small Gas Engine>=0.2 to <1 MWe	38.0%	-	1.2	38.0%	83.6%	961.29	-0.15	12.86	10	10	0.0%****
Large Gas Engine>=1 to <3.7 MWe	38.0%	-	1.2	38.0%	83.6%	961.29	-0.15	10.20	10	10	0.0%****
Small OCGT>=3.7 to <7 MWe	30.0%	-	1.6	30.0%	78.0%	1,720.10	-0.23	9.61	10	10	0.0%****
Large OCGT>=7 to <25 MWe	35.0%	-	1.2	35.0%	77.0%	1,720.10	-0.23	8.54	10	10	0.0%****
Large OCGT>=25 to <40 MWe	35.0%	-	1.2	35.0%	77.0%	1,720.10	-0.23	8.54	15	10	50.0%
Small CCGT>=40 to <200 MWe	45.1%	4.5	0.76*	38.6%	67.9%	1,345.81***	-0.10	6.41***	15	10	33.3%
Large CCGT>=200 MWe	45.1%	4.5	0.76*	38.6%	67.9%	790.40***	0.00	6.41***	15	10	33.3%

* A H:P of 0.76 is assumed for CCGT as this is the minimum required by a >500MWe CHP size with the assumed condensing efficiency and Z ratio to achieve a QI of 100.

** Capex Formula £/kWe = A x MWe^n

*** Capex and Opex formulas for CCGT are in terms of capacity/electricity which would be generated in fully condensing mode. The costs in terms of the actual electrical generation in CHP mode are higher by a factor equal to the ratio of electrical efficiency in fully condensing mode / electrical efficiency in CHP mode, i.e. 45.1/38.6.

**** The decision whether to replace the engine is assumed to occur at the end of the investment period and is therefore a separate investment decision.

Table 4 Assumed Hours of CHP Operation

Sector	CHP Operating hours winter day	CHP Operating hours winter evening	CHP Operating hours winter night	CHP Operating hours summer day	CHP Operating hours summer evening	CHP Operating hours summer night
Chemicals	1,349	1,349	1,349	1,349	1,104	0
Engineering	1,349	1,349	1,349	1,349	1,104	0
Food & drink	1,349	1,349	1,349	1,349	1,104	0
Other Industry	1,349	1,349	1,349	1,349	1,104	0
Paper	1,349	1,349	1,349	1,349	1,104	0
Services	1,349	1,349	1,349	1,349	204	0
Textiles	1,349	1,349	1,349	1,349	1,104	0

3.4 Design and Operating Heat to Power Ratio

68. For **reciprocating engines** and open cycle gas turbines, the level of available useful heat, electricity and fuel input all increase or decrease in tandem and the ratio of useful heat available to the amount of power that is generated (heat to power ratio) is determined by the CHP design, but is fairly constant in operation, with relatively little variation between CHP units of similar size. The CHP size is usually selected either to match the typical heat load or the electrical load and can then be modulated to match either the heat load or electrical load when this is less than the maximum the CHP can deliver.

69. When the ratio of site heat to power demand is lower than the output ratio of the CHP, sizing and modulating to match the heat load will result in a shortfall in electricity generation (which must be imported from the grid). Sizing and modulating to match the power demand leads to excess heat generation which must be dumped unless it can be exported to an adjacent site (often not possible). If the CHP follows the electrical load and wastes heat, it may not fully qualify as Good Quality CHP so sizing and modulating to follow the heat load is best practice.

70. When the ratio of site heat to power demand is greater than the output ratio of the CHP, sizing and modulating to match the heat load will result in excess electricity output which can be exported to the grid or a private customer. Sizing and modulating to match the electricity demand leads to a shortfall in heat generation which must be supplied with conventional boilers. The former approach maximises co-generation and thus energy savings but is often less economic as the value of exported electricity is typically low in comparison to the value of electricity used on-site. Thus policies which encourage CHP to be sized and operated to follow heat load are beneficial.

71. With **steam turbines**, (including steam turbines used in CCGT), the useful heat is extracted in the form of steam diverted during the power generation process which reduces power output. The heat to power ratio can be tailored to match the site heat to power demand ratio more closely. There are two types of steam turbine used for CHP: **back pressure** and **condensing**.

72. **Back pressure steam turbines** (BPST) are designed such that all of the steam leaving the turbine is at a useful temperature so all the steam is used for process but as a consequence the steam leaves at a higher pressure and therefore generates less electricity than would be generated in a condensing turbine. With a back pressure turbine, the exit pressure can be designed to be high, which would give a high heat to power output ratio, or lower to suit the typical heat to power demand ratio of the site. However the CHP output ratio is essentially then fixed in operation so if following the site steam demand, excess electricity will be generated at times of above average heat to power demand ratio and top up electricity will be required when the demand heat to power ratio is low. Back pressure steam turbines always follow heat load so never dump heat.

73. **Condensing turbines** on the other hand maximise the amount of power generation with steam leaving the turbine at sub-atmospheric pressure and condensed to enable it to be pumped back to the boiler. The temperature of the low pressure steam leaving the turbine is very low (around 50 ºC) which is not useful for most applications, thus in CHP, the turbine is designed to allow steam to be extracted from an intermediate stage of the turbine. This is at a usefully high temperature but also at a higher pressure so removing this steam results in a reduction in power generation. This type of design is called a '**Pass-Out Condensing Steam Turbine** (POCST). The volume of steam extracted can be controlled from a level where heat extraction is maximised down to zero heat extraction

(i.e. fully-condensing) where power generation is maximised. POCSTs are thus more flexible than BPSTs.

74. The ratio of heat extracted from a POCST to its resulting reduction in power output is defined as the Z ratio. Steam extracted at lower pressures will be lower in temperature but will result in a smaller reduction in power production.

75. The higher the heat to power ratio, the higher the CHP's overall efficiency and maximising useful heat to power ratio will mean sizing and modulating the CHP to suit the site's heat load.

3.5 DECC Energy Price Projections, £/MWh (2013 Real)

Table 5 Basic energy price projections

Price scenario	Year	Natural Gas	Electricity Imported	Electricity Exported by >=25MWe Schemes (=wholesale value)	Electricity Exported by <25MWe Schemes (=80% of wholesale value)[19]
Central	2012	25.46	67.22	49.61	39.69
	2020	30.77	103.50	63.49	50.79
	2025	31.14	112.81	71.71	57.37
High	2012	25.46	67.22	49.61	39.69
	2020	42.09	121.30	80.50	64.40
	2025	43.31	133.20	91.44	73.15
Low	2012	25.46	67.22	49.61	39.69
	2020	18.61	83.32	42.62	34.09
	2025	18.98	90.99	49.96	39.97

76. The fuel price categories for gas-fired and renewable CHP and the basic retail/export values are given in table 5 above. These are based on UEP 2013, the latest projection at the time the modelling was conducted and exclude policy additions payable by CHP Operators for CCL and Carbon and to CHP operators participating in the Capacity Market which are shown in table 6 below.

77. Gas and electricity prices are used in the calculation of the IRR of potential projects together with the financial values of extant and proposed policies. For each segment for each of the two sizing options, the economic performance (used only to determine the best sizing option) was calculated on the basis of the central energy prices in the year of installation continuing through the life of the scheme. However, in the modelling of CHP investment decisions in the Monte Carlo model, costs and revenues during the lifetime of plant were calculated using the prices and policies for designated years and interpolated prices and policies for intermediate years. The value that sites can achieve for exported electricity is assumed to be equal to the wholesale value for large sites, but lower for smaller CHP units selling smaller quantities of electricity through Power Purchase Agreements. This is modelled as a 20% discount to the value of exported power for units below 25MW capacity. The upper and lower price values shown in Table 5 are used to define the limits of the energy price distributions used in the Monte Carlo modelling to model fuel price uncertainty.

78. Both models used the single unit prices shown here, regardless of the size of the CHP plant being modelled. This was because an investigation of price with consumption,

[19] Based on Ricardo-AEA's market knowledge and direct discussions with industry.

sourced from DECC's Quarterly Fuels Inquiry (QFI) survey, a quarterly panel survey of approximately 600 establishments within manufacturing industry conducted by the Office for National Statistics (ONS) on behalf of DECC, showed no clear distinction between the prices paid by different sizes of plant. The dataset used for this review included information from around 600 industrial consumers in 2012. Their usage spanned the range 400 kWh – 1,700 GWh for gas and 13 MWh - 462 GWh for electricity.

3.6 Energy Policy Additions/Support and Assumed Hurdle Rates

79. Tables 6 shows the present (2013) and predicted 2020 and 2025 policy values which affect gas-fired CHP, taking account of Budget 2014 Carbon Price Support announcements. Table 7 shows how sector-specific policies are assumed to apply and also the hurdle rates assumed in deriving policy supply curves and also in DECC's Monte-Carlo model.

Table 6 Energy policy costs, relief and carbon intensities relevant to CHP (2013 Real)

Year	EU-ETS CO2 Price Forecast (£/tCO2)[20]	Carbon Floor Price Forecast (£/tCO2)[21]	CRC CO_2 Price Forecast (£/tCO2)[22]	CCL rate gas (£/MWh)[23]	CCL rate electricity (£/MWh)[24]	Carbon factor EUETS/CRC gas (tCO2/MWh)[25]	CCA rebate level - gas (%)[26]	CCA rebate level - electricity (%)[27]	Capacity Market Payment (£/kWe)[28]	EUETS Heat Allowance "At Risk" Carbon Leakage Factor (CLEF)	EUETS Heat Allowance "Not At Risk" Carbon Leakage Factor (CLEF)	EUETS Heat Allowance Linear Reduction Factor (LRF)
2013	3.49	3.49	12.25	1.82	5.24	0.1836	65%	90%	0.00	100%	80.00%	100.00%
2020	4.87	20.60	16.34	1.88	5.41	0.1836	65%	90%	21.24	100%	30.00%	87.82%
2025	40.55	54.49	16.34	1.88	5.41	0.1836	65%	90%	30.83	100%	8.57%	79.12%

Table 7 Assumed CCA and Carbon Leakage Risk Status and Hurdle rates for sectors

Sector	In a CCA	At Risk of Carbon Leakage	Hurdle rate (%)
Chemicals	Yes	Yes	18%
Engineering	Yes	Yes	20%
Food & drink	Yes	Yes	25%
Other Industry	Yes	Yes	20%
Paper	Yes	Yes	25%
Textiles	Yes	Yes	25%
Services	No	No	20%

[20] Traded Carbon prices in Table 3 of the IAG toolkit Updated 19 September 2013 https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
[21] Supplied by DECC to R-AEA 02/04/2014
[22] Supplied by DECC to R-AEA 09/10/2013
[23] Supplied by DECC to R-AEA 09/10/2013
[24] Supplied by DECC to R-AEA 09/10/2013
[25] Supplied by DECC to R-AEA 20/11/2013
[26] CCL relief rates as set out in Government Guideline https://www.gov.uk/climate-change-agreements--2
[27] CCL relief rates as set out in Government Guideline https://www.gov.uk/climate-change-agreements--2
[28] Supplied by DECC to R-AEA 28/04/2012

80. All schemes outside the EU-ETS were assumed to be covered by CRC.

81. CCA relief on CCL for applicable industrial sectors is as set out in UK Government Guidelines https://www.gov.uk/climate-change-agreements--2. It is applicable from 2013 to 2023 but assumed to continue beyond 2023. All modelled industrial sectors are assumed to be in a CCA as shown in table 7.

82. As confirmed by DECC[29], under EUETS Phase 3, free Heat Allocation Allowances for CHP schemes under EU-ETS Phase 3 will be:-

=CHP heat output/Assumed Displaced Boiler Efficiency of 81% GCV * Carbon Factor for Gas (0.1836TCO2/MWh GCV) * Carbon Leakage Exposure Factor (CLEF) * Linear Reduction Factor (LRF).

83. and the free Heat Allocation Allowances for boilers (CHP top up and counterfactual) will be:-

=Boiler Heat output/Assumed Boiler Efficiency of 81% GCV * Carbon Factor for Gas (0.1836TCO2/MWh GCV) * CLEF * LRF.

84. Carbon leakage is the phenomenon where, rather than implementing carbon reduction in the UK, an industry simply moves its emissions abroad. The alternative, the purchase of emission allowances is mitigated somewhat for CHP by a free allowance whose value is affected by the CLEF and the LRF. For sectors with no significant risk of carbon leakage (assumed to apply to the modelled service sectors as per table 7) the CLEF is 0.8 in 2013, gradually falling to 0 in 2027 as shown in table 6. However the CLEF is 1.0 in all years for sectors deemed to be at risk (assumed to apply to all modelled industrial sectors). The linear reduction factor is described in the EUETS Directive and applies to all sectors. This factor falls by 1.74% per annum from the reference year of 2013 as shown in the final column of Table 6.

85. Guidance Document no. 1 on the harmonized free allocation methodology for the EU-ETS, post 2012[30], and Guidance document no.5 on carbon leakage)[31] explain in more detail.

86. Thus with time the free heat allowance will reduce (most rapidly for sectors not at risk of carbon leakage) so EUETS will be payable on an increasing proportion of carbon emitted in generating heat. This is true for emissions from boilers as well as from CHP so the relative treatment of CHP compared to the gas boiler alternative will remain constant. Renewable CHP on the other hand will avoid an increasing EUETS burden on the gas boiler alternative.

87. As explained in Section 2.5, assumed hurdle rates were developed in consultation with industry.

[29] Methodology Supplied by DECC to R-AEA 22/02/2013
[30] http://ec.europa.eu/clima/policies/ets/cap/allocation/docs/gd1_general_guidance_en.pdf
[31] http://ec.europa.eu/clima/policies/ets/cap/allocation/docs/gd5_carbon_leakage_en.pdf

3.7 Primary Energy Saving Assumptions

88. EU Directive 2012/27/EU 25 October 2012,[32] Annex II sets out the standard EU methodology for calculating the Primary Energy Saving (PES) of CHP based on standard assumed reference efficiencies for conventional heat and power generation. The basic formula for calculating the PES as a percentage of conventional fuel input for separate heat and power generation is as shown below:-

$$\mathrm{PES} = 1 - \frac{1}{\frac{\mathrm{CHP\ H\eta}}{\mathrm{Ref\ H\eta}} + \frac{\mathrm{CHP\ E\eta}}{\mathrm{Ref\ E\eta}}}$$

Where:

CHP Hη is the actual heat efficiency

Ref Hη is the reference heat efficiency

CHP Eη is the actual electrical efficiency

Ref Eη is the reference electrical efficiency

89. The Commission implementing decision of 19 December 2011 established the harmonised reference efficiencies currently in force across the EU[33]. This specifies the reference efficiencies for different fuels and ages of plant and a method for adjusting to account for differences in transmission losses in the electricity transmission system, depending on the voltage at which electricity is either consumed on-site or exported.

90. In the CHP models the PES was calculated on the basis of the EU reference efficiencies for natural gas installed in 2012-15 (shown in table 8 below) which are on the basis of Net Calorific Value. There were converted to a Gross CV basis to facilitate a PES calculation based on the modelled CHP efficiencies shown in Table 3 (with reduced heat efficiency where excess heat is generated) which are on a Gross CV basis in line with energy prices and Quality Index. This was done by multiplying by the Net/Gross CV ratio for natural gas obtained from the 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting Annex 11[34].

Table 8 Assumed Reference Values

CHP Fuel Type	EU Reference Value Heff NCV	EU Reference Value Peff NCV	NCV/GCV Conversion Factor
Natural Gas	90.0%	52.5%	0.900

[32] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:EN:PDF

[33] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:343:0091:0096:EN:PDF

[34] 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting Annex 11, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69554/pb13773-ghg-conversion-factors-2012.pdf

91. The voltage at which electricity from CHP in the different size ranges would be consumed on-site or exported was assumed based on experience and the corresponding embedding factors as shown in table 9 below

Table 9 Assumed Grid Correction Factors

CHP Size Range MWe	Assumed Connection Voltage Range	Correction factors for avoided grid losses (Electricity used on-site)	Correction factors for avoided grid losses (Electricity exported)
>0 to <1	<0.4kVA	0.860	0.925
>=1 to <10	0.4kV-50kV	0.925	0.945
>=10 to <25	50kV-100kV	0.945	0.965
>=25 to <50	50kV-100kV	0.945	0.965
>=50 to <100	100kV-200kV	0.965	0.985
>=100 to <200	>200kV	0.985	1.000
>=200 to <500	>200kV	0.985	1.000
>=500	>200kV	0.985	1.000

3.8 Key Approach and Assumptions for Off-Model Sectors

3.8.1 Oil & Gas Sector

The general approach taken to model projected capacity in off-model sectors was as follows:

Technical potential

i) Annual Heat output (QHO), Power Generation (TPO), export and import, TFI and fuel split (all in MWh) were obtained from the CHPQA database for each oil refinery, LNG terminal and oil terminal with existing certified CHP.
ii) Heat demand assumed = QHO
iii) Electrical demand calculated = TPO – export + import.
iv) Annual QHO, TPO export and import and hence electrical demands for sites with no existing CHPQA certified capacity were estimated based on published data on the sites (e.g. existing or planned capacity) and data for similar CHPQA certified schemes.
v) Existing Annual QHO and TPO for recently installed LNG capacity was based on anticipated full capacity operation.
vi) Flat heat demand profiles were assumed.
vii) Average heat load (MWt) was calculated for each scheme.
viii) Appropriate technology selected based on heat load (all CCGT).
ix) Technical potential TPC (MWe) was calculated for each scheme.

92. Table 10 below summarises the technical potential based on heat load. For clarity, this omits existing schemes designed primarily as large power stations which already provide all of the heat requirement for refineries and LNG stations.

Table 10 Technical Potential Summary

Sector	no. of sites	Qualifying Heat Output (QHO)	Existing Total Power Capacity (TPC)	Average Existing Power capacity Per Site	Existing Technology	Total Technical Potential (TPC)	Technical Potential per site	Assumed Potential Technology based on size	Proportion of Electricity Exported
		TWh/Yr	MWe	MWe		MWe	MWe		%
Refineries	5	8.50	757	151	CCGT	1,720	344	CCGT	75%
LNG	2	2.23	48	24	CCGT	856	428	CCGT	97%
Σ	**7**	**10.72**	**805**	**115**		**2,576**	**368**		**82%**

Economic Potential

i) Annual Power Generated TPO was calculated based on TPC x Assumed Full Load Hours of CHP Operation (6,500 as assumed for modelled industrial sectors)
ii) Annual electricity import or export MWh calculated based on Potential TPO and site electricity demand.
iii) Annual Fuel Input TFI (MWh) = TPO / Electrical efficiency for selected technology.
iv) Cost-effective potential for baseline and bespoke policy support scenarios calculated based on a hurdle rate of 18% (post tax real) and otherwise the same assumptions as for modelled industrial sectors with following exceptions:

- Power Efficiency = 48% for LNG terminals in condensing mode with no reduction in CHP modes as low grade heat is taken from the condenser
- HPR = 0.4 for LNG terminals
- Wholesale Gas price was assumed for CHP at LNG terminals (£25.18/MWh for 2020 & 2025 based on DECC Updated Energy & Emissions Projections - September 2013 Annex F)
- A proportion of refinery fuel was assumed to be supplied by refinery off-gas (assumed to be free) based on the existing quantity of refinery off-gas use at sites with any increase due to increased CHP capacity assumed to be met by natural gas
- No CCL was applied on either fuel or imported electricity

93. Results on Oil & Gas sector economic potential are listed in section 4.4.

3.8.2 Residential District Heating

94. The general approach taken to model projected CHP capacity in the District Heating sector was as follows:

DH Technical potential

i) 50 Existing DH schemes with CHP certified by the CHP Quality Assurance Programme –(CHPQA) were identified and used to define archetypal DH CHP schemes for the analysis.
ii) For each of these existing schemes, the Annual CHP Qualifying Heat output (QHO), Total Power Generation (TPO)[35], electricity export and import (all MWh) were obtained from the CHPQA database.

[35] Under CHPQA, QHO is the amount of 'useful' heat supplied annually from a CHP scheme; TPO is its total annual power generation and TPC its maximum power generation capacity [see CHPQA Standard at https://www.gov.uk/combined-heat-power-quality-assurance-programme]

iii) Their Annual CHP Heat demand (including losses) was assumed = QHO.
iv) Their Electrical demand was calculated = TPO - export + import.
v) Ordered by QHO and grouped into 6 tranches based on similar total QHO and/or prime mover technology (the same process as used for the modelled sectors)
vi) Average QHO and electrical demand calculated for each scheme in each tranche.
vii) A flat heat demand profile was assumed on the basis that thermal storage would be used.
viii) Average heat load (MWt) was calculated for each scheme in each tranche based on CHP running hours of 4,500, the un-weighted average for the 50 existing DH schemes)
ix) Appropriate technology was selected based on scheme size, with tranches 1-4 assumed to have one or more gas engines and tranches 5 and 6 assumed to be large OCGT.
x) The technical potential (MWe), was calculated for the average scheme in each tranche based on average heat load / HPR for selected technology i.e. matching the CHP size to the heat demand.
xi) Total residential DH network heat input potential was based on results from Redpoint Energy System Optimisation Model (RESOM) modelling produced for *The Future of Heating: Meeting the challenge*[36]. DH potential was estimated as 17.2TWh/Yr for 2020 and 23.7TWh/Yr for 2025. For example in 2020, the RESOM model estimated a potential for 14.3 and 4.5 TWh/Yr of heat to be delivered by DH to dwellings and the services sector respectively, with a total input to the DH networks of 23.8TWh/Yr. On this basis the input to DH networks serving domestic heat demands was estimated at 17.2TWh/Yr[37].
xii) Total technical potential was calculated based on technical potential per scheme x number of existing schemes x total technical DH heat potential (17.2TWh) / QHO from existing schemes (1.12TWh/Yr.) as shown in Table 11.

[36] https://www.gov.uk/government/publications/the-future-of-heating-meeting-the-challenge
[37] Domestic heat demand was estimated at 17.2TWh/yr, i.e. 23.8 x 14.3/(14.3+4.5).

Table 11 Segmented Technical Potential Illustrating approach

Tranche	Existing no. of sites in each tranche	Existing CHP QHO per site in the tranche	Existing Total CHP QHO	DH Heat output potential 2020 (Based on RESOM model)	DH Heat output potential 2025 (Based on RESOM model)	Existing TPC per site	Existing TPC per tranche	Existing Technology	Proportion of Electricity Exported	Technical Potential per site	Assumed Potential Technology based on size	Total Technical Potential 2020	Total Technical Potential 2025
		GWh	TWh	TWh	TWh	MWe	MWe		%	MWe		MWe	MWe
DH_1	29	5.17	0.15	2.32	3.19	0.78	23	All Gas Engines	21%	0.96	Gas Engines	429	590
DH_2	7	23.25	0.16	2.51	3.46	2.02	14	All Gas Engines	22%	4.31	Gas Engines	466	641
DH_3	6	32.66	0.20	3.03	4.17	6.06	36	One OCGT and rest Gas Engines	32%	6.05	Gas Engines	560	771
DH_4	4	45.46	0.18	2.81	3.87	4.47	18	All Gas Engines	52%	8.42	Gas Engines	520	716
DH_5	2	73.17	0.15	2.26	3.11	3.54	7	All Gas Engines	71%	13.55	Large OCGT	419	576
DH_6	2	139.40	0.28	4.31	5.93	16.70	33	Steam Turbines	90%	25.81	Large OCGT	797	1098
Σ	**50**	**319.10**	**1.12**	**17.23**	**23.72**		**132**					**3,191**	**4,392**

95. Note, the total DH Projection was based on residential proportion of the total RESOM potential to remove double counting of CHP potentials for individual non-domestic sites modelled elsewhere and DH covering these same sites. However, for the purposes of the projection, the distribution of RESOM based potential across different sizes of DH network was built up from examples of CHPQA certified schemes, many of which included non-domestic customers as the sample of CHPQA certified domestic only examples was very small. Export levels for tranches 1-4 were therefore possibly lower than would be typical for residential only schemes.

DH Economic Potential

i) Annual Power Generated TPO calculation was based on assumed hours of CHP operation (4,500 as explained above)
ii) Annual electricity import or export MWh calculation was based on Potential TPO and local electrical demand
iii) Annual Fuel Input TFI (MWh) = TPO / Electrical efficiency for selected technology as per Table 3
iv) Cost-effective potential for the baseline and bespoke policy support scenarios calculated based on a hurdle rate of 12% and otherwise the same energy price and policy assumptions as for modelled service sectors with the exception of CCL as new schemes were assumed to serve mainly residential customers.

96. Results are shown in section 4.4

4 Modelling Results

4.1 Policy Incentive Tariff Levels

97. Supply curves of potential gas CHP capacity, excluding existing capacity, resulting from the modelling described in section 2.3 are shown in Figures 6-10 below for all bespoke policies option under 2020 energy prices. These curves show the level of support required (y-axis) for a given category of CHP to be cost-effective at commercial rates of return. The x-axis shows the cumulative primary energy saving delivered by the CHP potential. Additional capacity is banded according to the proportion of electrical output exported rather than used to meet power demands on-site.

98. The curves were used to generate indicative support levels for the purpose of modelling CHP policies. As the primary policy objective is to deliver CO_2 savings, via primary energy savings, the supply curves have been generated assuming that CHP is optimally sized to meet site heat demand, with surplus electricity exported, rather than sized to meet site power demand. This generally results in larger plant and greater primary energy savings. The supply curves all contain the same total CHP potential (c.7.3GWe which would achieve 41.4 TWh of primary energy savings per annum) and the same cost-effective potential (c.3.3GWe which would achieve 20.6TWh/Yr of PES/Yr). However the order of CHP potential in the curves (in ascending order of required policy support) differs between the different incentive options for the following reasons.

99. Firstly,

- The grant and PES incentives support schemes in proportion to PES. The segments with above average PES% tend to be those best suited to these policies and require the lowest tariffs.
- The PFiT supports schemes in proportion to QPO. The segments with above average qualifying power output per unit capacity tend to be those best suited to this policy and require the lowest tariffs.
- The QI weighted heat incentive supports schemes approximately in proportion to QHO. The segments with above average heat output per unit capacity output tend to be those best suited to this policy and require the lowest tariffs.
- The QI weighted capacity incentive supports schemes approximately in proportion to TPC. The segments with above average good quality CHP capacity tend to be those best suited to this policy and require the lowest tariffs.
- Thus the segments where the technical parameter which a policy supports is above average, tend to require the lowest tariffs for that policy and hence appear towards the central point on the curve where there is no support requirement.

These differences are largely CHP technology/size related, hence the reason the curves are plotted by technology/size bands. For example CHP in segments served by CCGT will usually generate more electricity for a given amount of useful heat than other segments. As a consequence, segments with CCGT which require support (i.e. positive on the y-axis) more frequently require lower levels of PFiT but higher levels of QI weighted heat incentive as compared to other segments. Conversely segments which are already cost-effective (negative on y-axis) more frequently require less negative PFiT and more negative QI weighted heat incentive levels. Thus segments with CCGT generally appear closer to the central segments requiring no support on the PFiT incentive curve (Figure 8) than on the QI weighted heat incentive curve (Figure 9).

100. Secondly, the grant and PES incentive curves are similar, as both incentivise annual PES, but not identical due to differences in hurdle rates for different sectors which leads to different ratios between the capital grant requirement and the PES incentive which equates to the grant requirement annualised over 5 years.

Figure 6. Gas CHP Potential 2020 Capital Grant Supply Curve Banded by Size Range

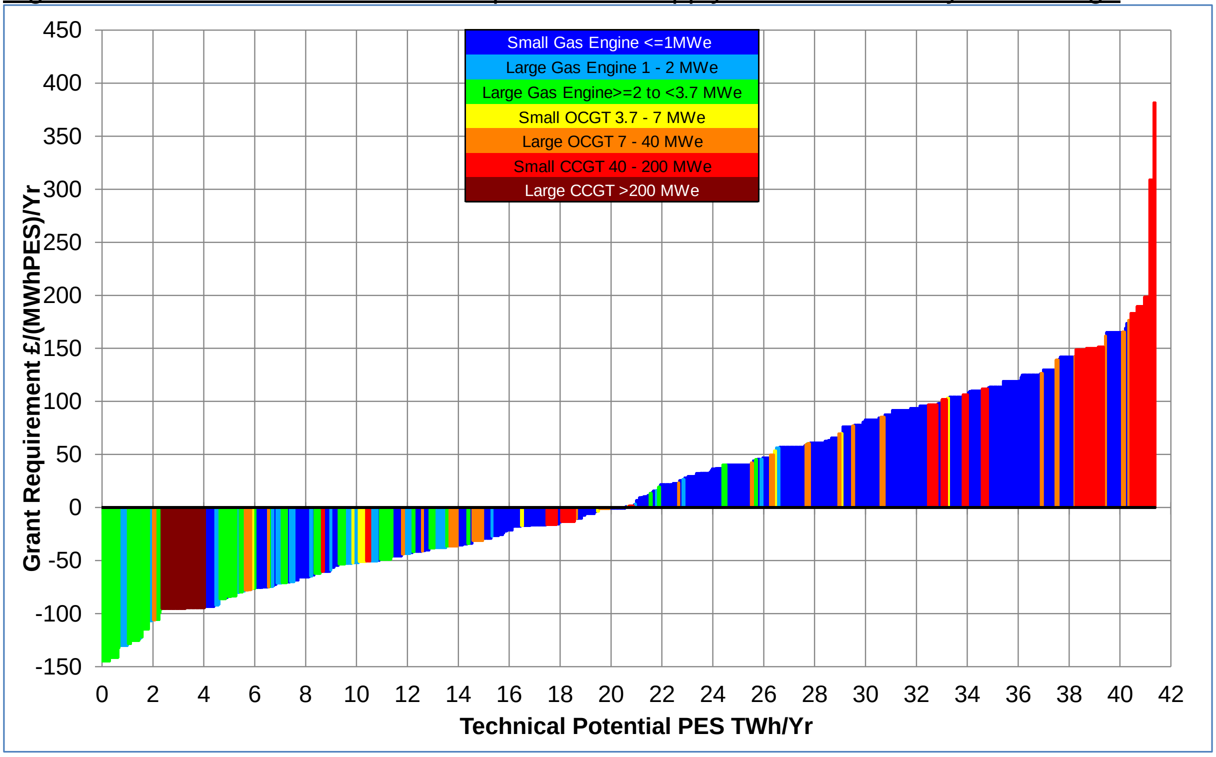


Figure 7. Gas CHP Potential 2020 PES Incentive Supply Curve Banded by Size Range

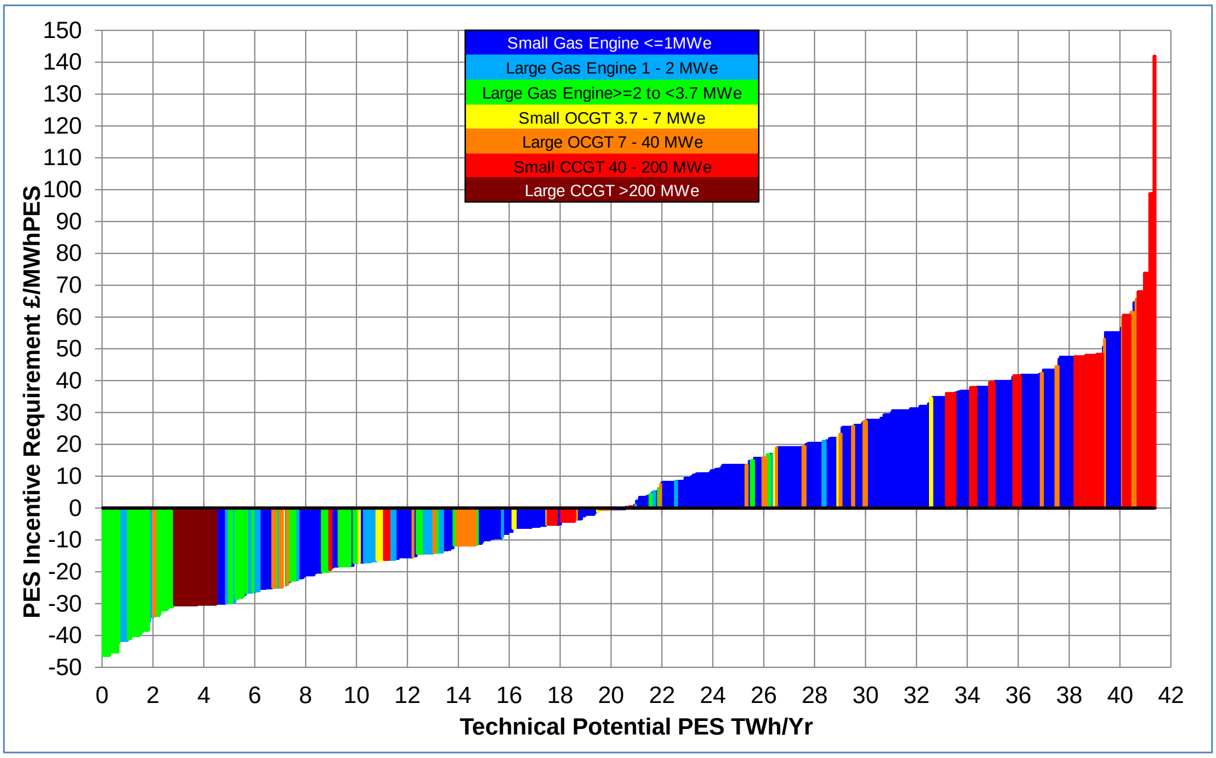


Figure 8. Gas CHP Potential 2020 PFiT Supply Curve Banded by Size Range

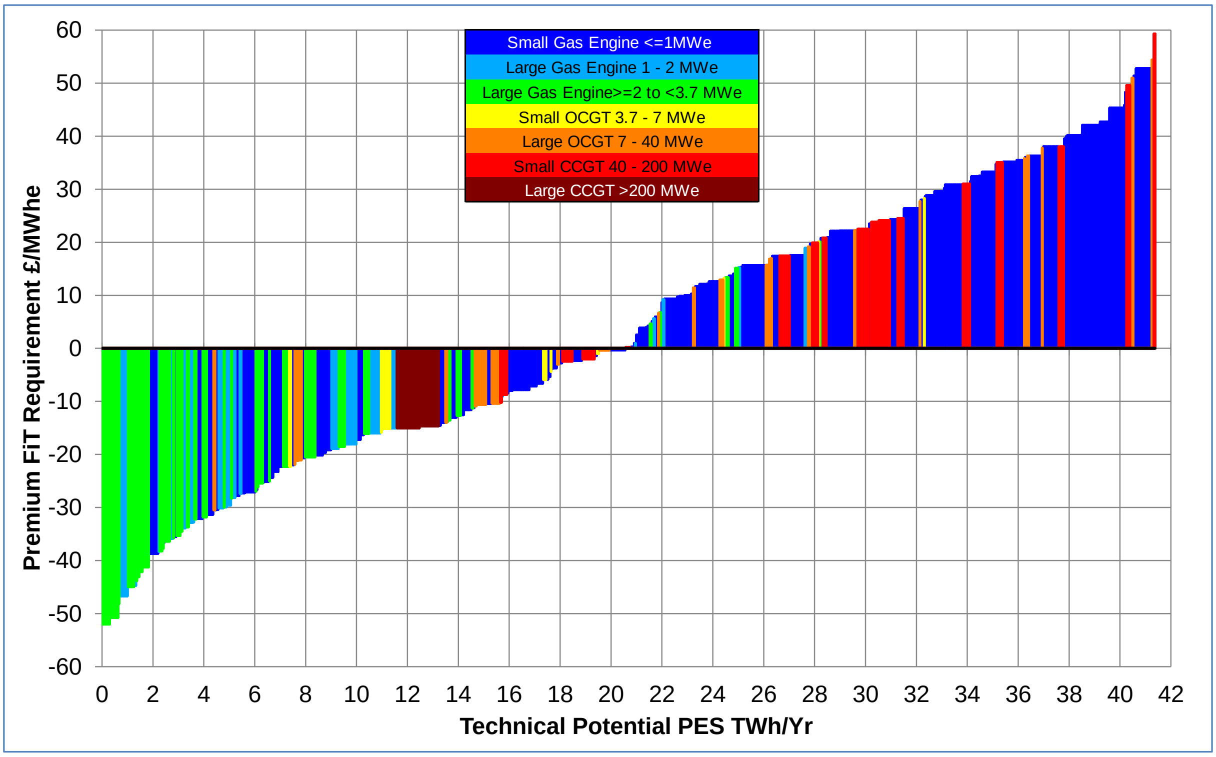


Figure 9. Gas CHP Potential 2020 QI Weighted Heat Incentive Supply Curve Banded by Size Range

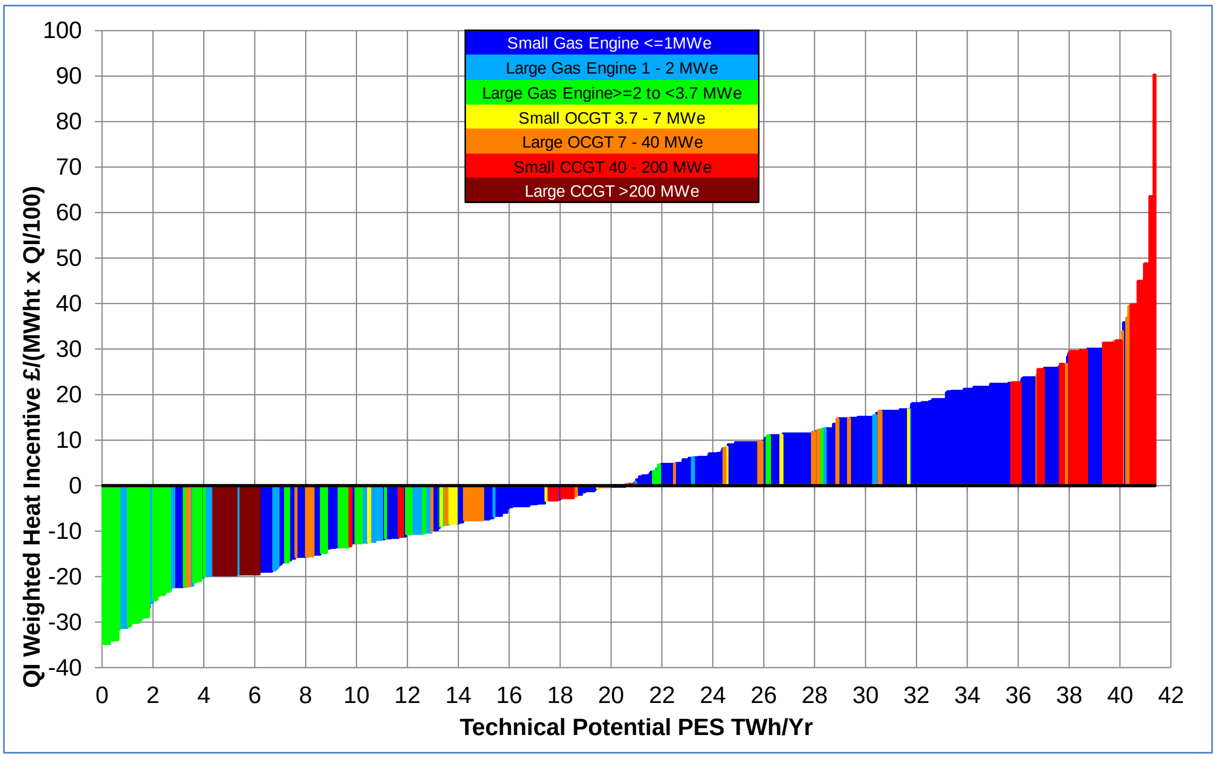
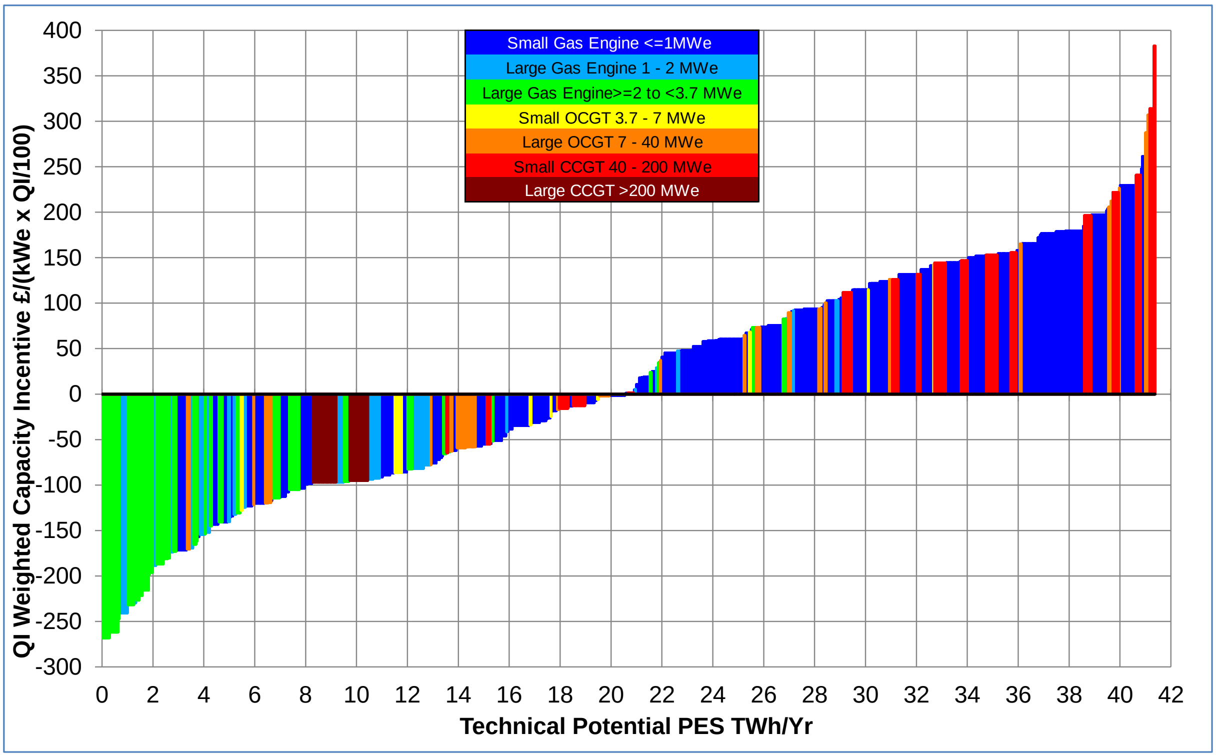
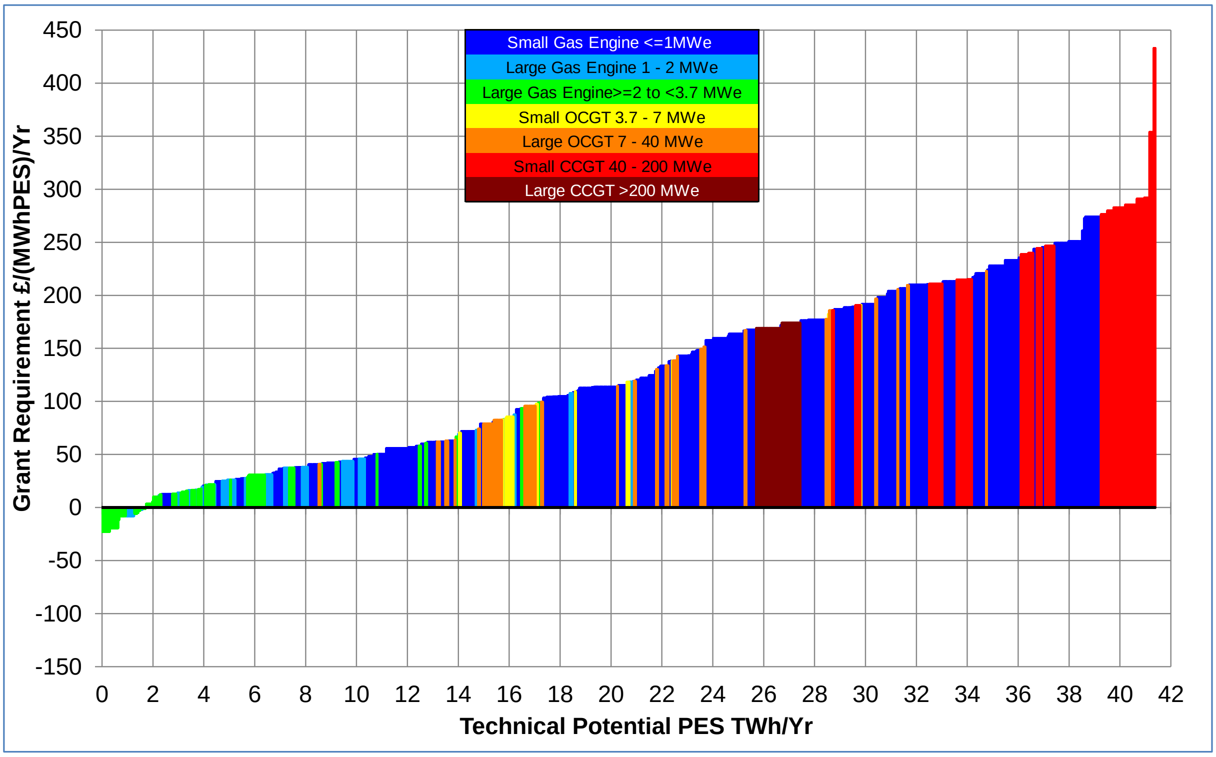


Figure 10. Gas CHP Potential 2020 QI Weighted Capacity Incentive Supply Curve Banded by Size Range



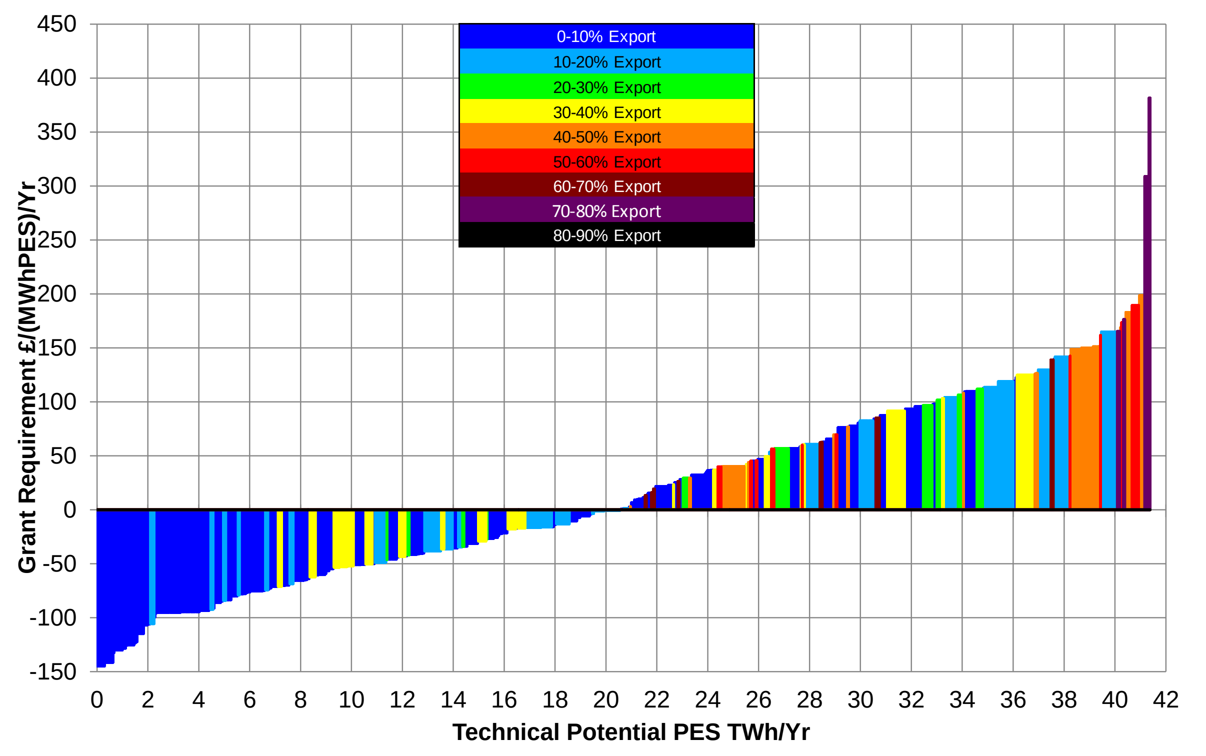
101. The supply curves show that nearly half of the potential CHP is commercially cost-effective without additional support i.e. the bars are below the x-axis. Figure 11 below shows the capital grant supply curve with 2012 energy prices. This shows higher levels of grant requirement and low cost-effective PES potential (c.2TWh/Yr) as compared with the 2020 supply curve (figure 4). This indicates that the large proportion of cost-effective capacity in 2020 is driven by DECC's central projection of future energy prices, rather than reflecting a large proportion of potential gas CHP being commercially viable at present.

Figure 11. Gas CHP Potential 2012 Capital Grant Supply Curve Banded by Size Range



102. As the supply curves indicate that such a large proportion of gas CHP potential would become cost-effective without any additional support by 2020 based on projected energy prices, trends in the relationship between different CHP parameters and required support levels were investigated to develop eligibility criteria designed to target the neediest schemes. Due to the variety of economic conditions faced by different schemes, no parameters were found to exactly align with the requirement for support, the best indicator being the proportion of electricity exported. Figure 12 shows the grant incentive supply curve banded by export % ranges rather than technology/size ranges.

Figure 12. Gas CHP Potential 2020 Capital Grant Supply Curve Banded by Export % Range



103. A minimum 20% power export threshold was developed as an eligibility criterion for the bespoke CHP policy options. This is intended to exclude capacity which will be cost-effective without additional support, and hence to minimise "deadweight" cost associated with the policies. This eligibility criterion does not completely eliminate deadweight cost and excludes some capacity which would need support to be cost-effective as can be seen in Figure 12 and quantified in Table 12 below. The eligibility criterion captures 2.4 GWe out of a total of 4 GWe potential CHP needing support but 0.4 of the 2.4 GWe is deadweight. However, alternative power export threshold values either increase deadweight or exclude a substantial proportion of capacity which would need support. Eligibility thresholds based on CHP size (MW electrical) have also been considered, but size shows a poorer correlation with cost-effectiveness than power export as can be seen by comparing figures 6 and 12.

104. Supply curves for all policies, banded by technology/size and export % ranges are shown in annex E.

Table 12 Supply curve potential additional electrical capacity and energy saving

	Potential additional capacity (MW electrical)	Potential additional CHP (TWh pa Primary Energy Saving)
Total	7,338	41.4
Not cost-effective without additional support	4,003	20.9
>20% exporting	2,437	12.2

105. Figures 13-17 show the 2020 supply curves for the bespoke policies with <20% exporting capacity excluded.

106. The 50th percentile of the resulting supply curves has been used to set illustrative incentive levels for modelling. The 50th percentile approach is in line with the approach used for RHI tariff setting and reflects the fact that EU State Aid rules prohibit support being provided to all potential projects.

Figure 13. Gas CHP Capital Grant Supply Curve excluding schemes exporting <20%

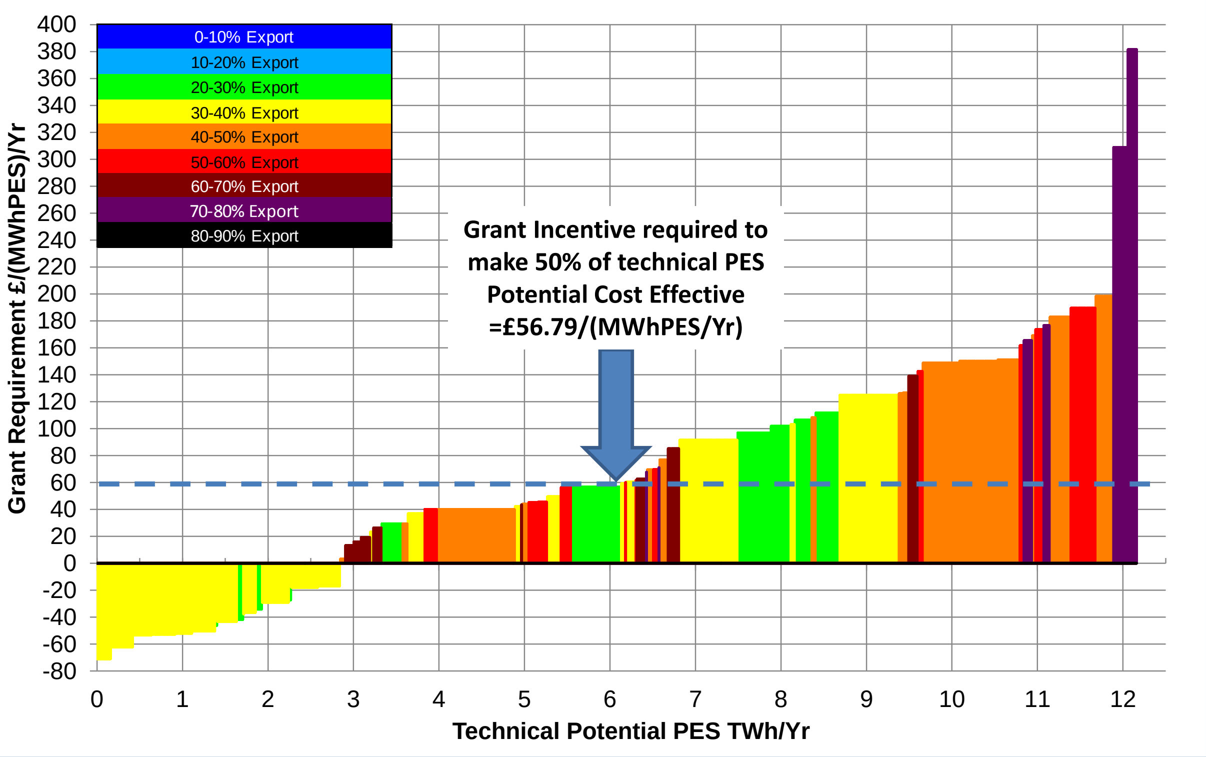


Figure 14. Gas CHP PES Incentive Supply Curve excluding schemes exporting <20%

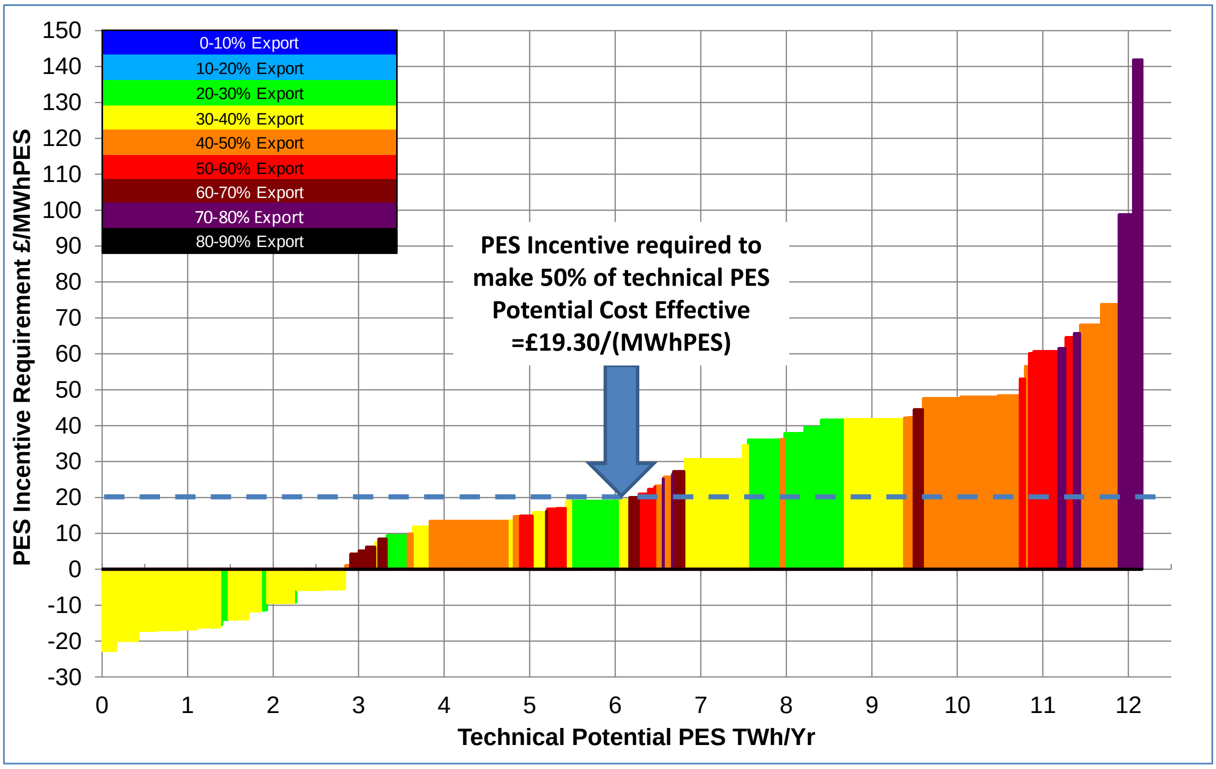


Figure 15. Gas CHP Premium Feed in Tariff Supply Curve excluding schemes exporting <20%

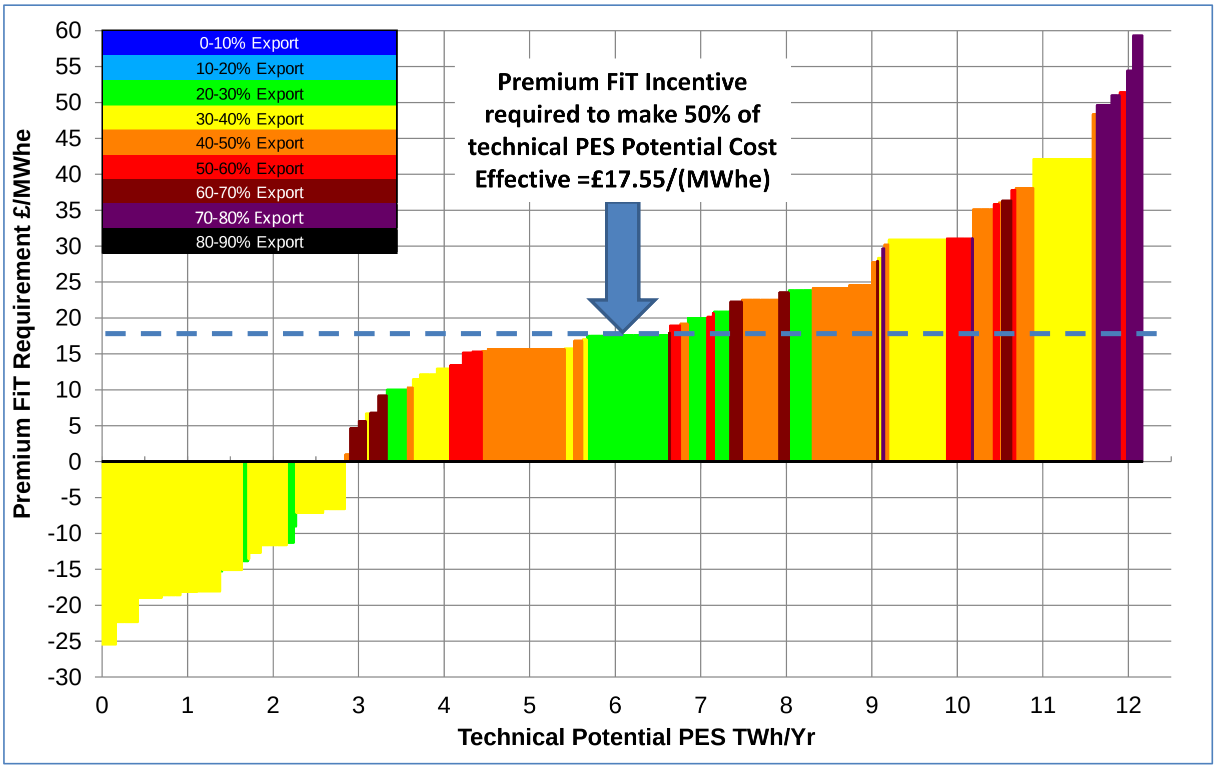


Figure 16. Gas CHP QI-Weighted Heat Incentive Supply Curve excluding schemes exporting <20%

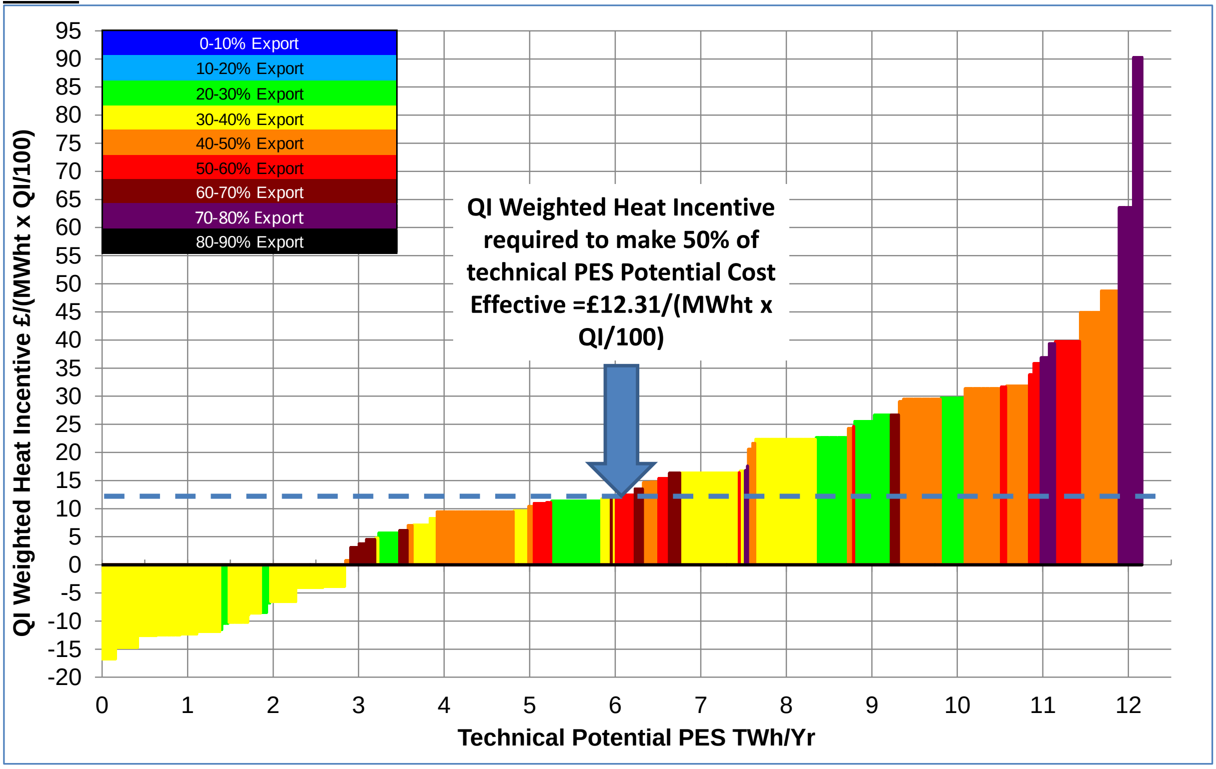
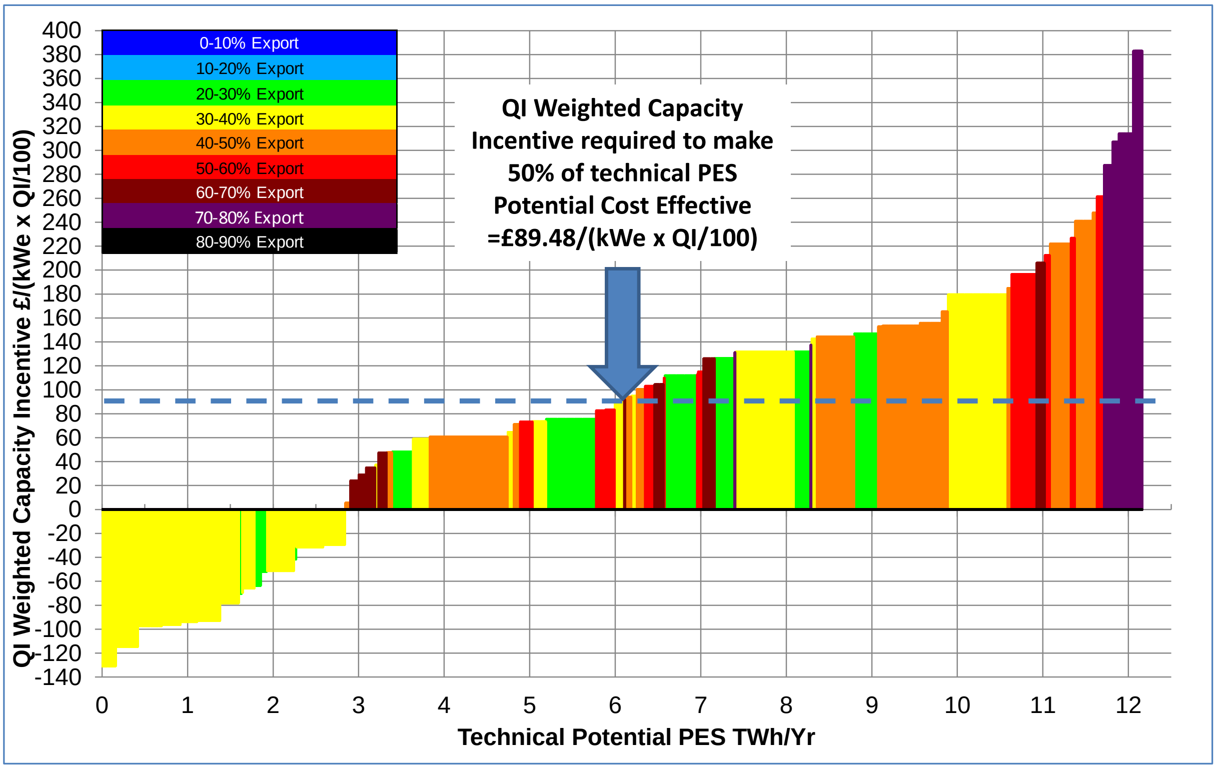


Figure 17. Gas CHP QI-Weighted Capacity Incentive Supply Curve excluding schemes exporting <20%

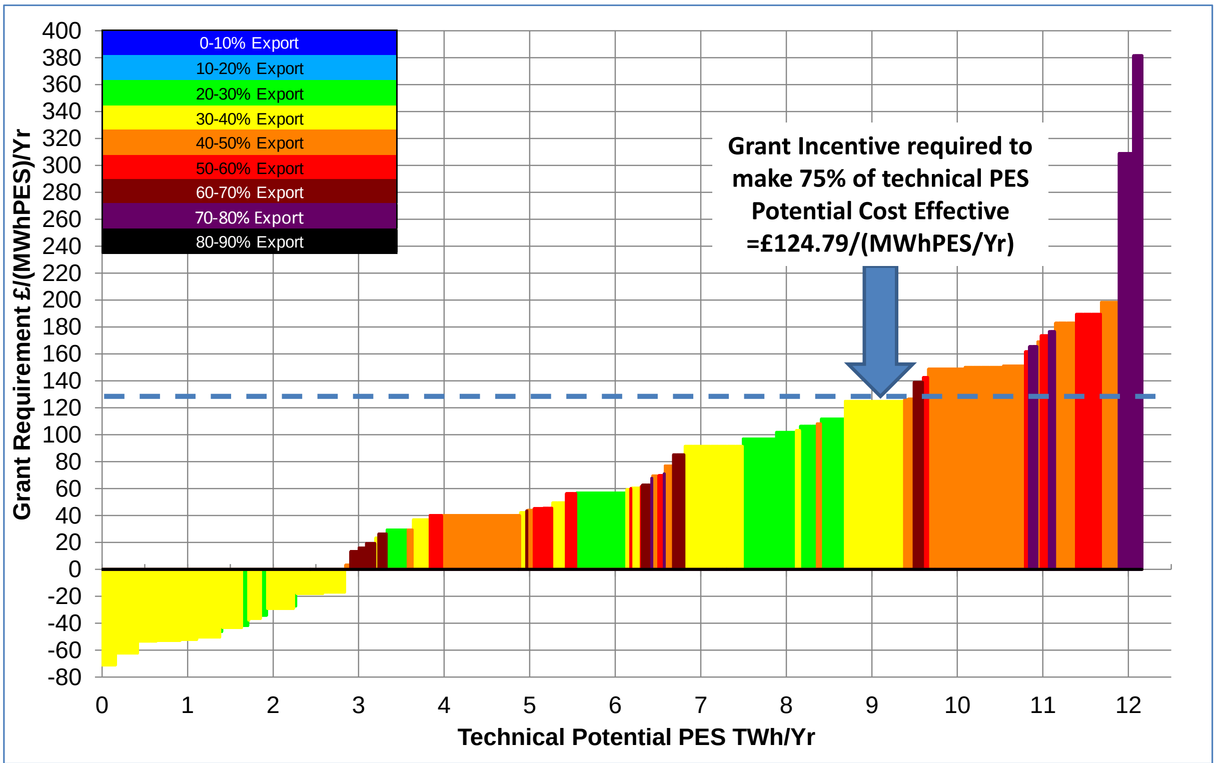


107. It should be noted that setting support levels at the 50th percentile of the supply curve is arbitrary. In addition, as discussed in section 2.5, the Monte Carlo investment modelling methodology inherently results in less capacity being built than appears cost-effective in

the supply curve. Increasing the incentive level to a higher percentile of the supply curve would increase the capacity built by the Monte Carlo model and increase the ratio of additionality to deadweight. There are therefore arguments for considering higher incentive levels.

108. For sensitivity purposes a 75th percentile based support level has therefore also been modelled in the case of the Capital Grants option (Figure 18 below). This will support additional segments which would not be cost effective with the 50th percentile based support level, increasing the amount of capacity which is made cost effective, but clearly this will be at a greater cost due to the increased support levels for all segments, including those which would be cost effective with a 50th percentile based support level. The same amount of deadweight capacity will exist in absolute terms, but will be supported to a higher level.

Figure 18. Gas CHP Capital Grant Supply Curve 75% sensitivity



109. These modelled support levels (summarised in Table 13 below) give an indication of likely support costs, budget and capacity that could be brought forward. In practice, any support would be competitively allocated (allocation mechanism design to be determined) to ensure value for money. The resulting modelled support levels applied in the Bottom Up and Monte Carlo modelling were as follows.

Table 13   Modelled Support Levels

	Capital grant	PES incentive / obligation	Premium FiT	QI weighted heat incentive	QI weighted capacity incentive
Support level	£56.79/MWh PES (£124.79/MWh PES 75th percentile sensitivity case)	£19.30/MWh PES	£17.55/MWhe	£12.31/(MWh heat x QI/100)	£89.48/(kWe x QI/100)

110. Limitations in the supply curve modelling include the fact that much of the underlying heat demand data dates back to 2008. Heat demand may have reduced since then due to energy efficiency measures and closure of some heat intensive industry. Consequently the analysis may overstate CHP potential in the modelled sectors. A further limitation is the fact that the BU model does not include CHP potential in Oil & Gas and District Heating sectors, as historically these sectors have not been found to be amenable to generic modelling. This may result in modelled incentive levels being set higher or lower than the 50th percentile which would be required to reflect the total CHP potential including Oil & Gas and District Heating CHP. This is because the average tariff required in these sectors may be above or below the average for modelled sectors.

4.2 Technical and Economic Potential for Modelled Sectors

111. The technical and economic potential for Gas-fired CHP is as per Tables 14 and 15 below. 50th percentile incentive levels are used in all cases, except the final column which shows the response to a more ambitious (75th percentile) Grant. The economic potential shown in table 15 below is the proportion of BU potential which would achieve the modelled hurdle rates. Table 16 shows the impact of bespoke policies on economic potential.

Table 14   Bottom-up Gas-Fired CHP potential for modelled sectors (MWe)

	Baseline	With Capital Grant	With PES Incentive	With Premium FiT	With QI Weighted Heat Incentive	With QI Weighted Capacity Incentive	75th percentile Capital Grant Sensitivity
2020 EUETS	3,678	3,715	3,715	3,805	3,728	3,714	3,930
2020 Non-EUETS	4,730	4,819	4,811	4,811	4,803	4,811	4,756
2025 EUETS	3,678	3,699	3,713	3,712	3,712	3,712	3,888
2025 Non-EUETS	4,799	4,840	4,840	4,837	4,839	4,837	4,769
2020 Total	**8,408**	**8,534**	**8,526**	**8,616**	**8,531**	**8,525**	**8,686**
2025 Total	**8,477**	**8,539**	**8,553**	**8,549**	**8,550**	**8,549**	**8,657**

112. Bottom Up potential results are based on current energy demands and sizing CHP to match summer daytime heat load where this is economic and if not, the summer electrical or heat load, whichever gives a higher IRR. This varies slightly across policy options due to the differing impacts policy would have on the sizing decisions in individual segments. The segmented data underlying these totals is then passed to DECC to calculate the probability of capacity being installed in the Monte Carlo modelling.

113. It should be noted that the Bottom Up potential is based on current energy demands regardless of any existing CHP capacity, reflecting the potential for new CHP on virgin

sites and also the capacity at sites with existing CHP were this to be redesigned based on the new market conditions. This is in contrast to the supply curves which omit the latter.

114. No account of investment probability or competition with renewable CHP is accounted for in the BU or economic potentials. These are accounted for in the Monte-Carlo model resulting in projected capacities which are much lower than the economic potentials.

Table 15 Economic Gas-Fired CHP potential for modelled sectors (MWe)

	Baseline	With Capital Grant	With PES Incentive	With Premium FiT	With QI Weighted Heat Incentive	With QI Weighted Capacity Incentive	75th percentile Capital Grant Sensitivity
2020 EUETS	3,333	3,385	3,394	3,506	3,414	3,384	3,888
2020 Non-EUETS	2,253	2,519	2,618	2,634	2,626	2,618	2,838
2025 EUETS	3,236	3,280	3,292	3,290	3,290	3,274	3,710
2025 Non-EUETS	2,662	3,097	3,097	3,082	3,222	3,209	3,293
2020 Total	**5,586**	**5,903**	**6,012**	**6,139**	**6,039**	**6,002**	**6,726**
2025 Total	**5,899**	**6,378**	**6,389**	**6,373**	**6,513**	**6,482**	**7,003**

Table 16 Increased Economic Potential Capacity Resulting from Bespoke policies (MWe)

	Capital Grant	PES Incentive	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant Sensitivity
2020 EUETS	52	61	173	81	51	555
2020 Non-EUETS	265	365	380	372	365	585
2025 EUETS	44	55	54	54	37	474
2025 Non-EUETS	435	435	420	560	546	631
2020 Total	**317**	**425**	**553**	**453**	**415**	**1,140**
2025 Total	**479**	**490**	**474**	**614**	**584**	**1,104**

4.3 Monte-Carlo Modelling Results – CHP Projections under Policy

115. The Monte Carlo potential results in Table 17 represent the total capacity in the modelled sectors which the model predicts would be built if there were no existing capacity under projected 2020 and 2025 market conditions with and without bespoke policy support[38]. Because the model does not consider existing capacity the absolute results need to be treated with caution as in some cases existing CHP plant may be retained rather than being replaced by new good quality CHP whose capacity may differ from that of existing plant. Our main interest is in the incremental impact the policy scenarios have on modelled capacity over and above that deployed in the baseline.

116. For context current UK good quality CHP capacity is 6.1 GWe, of which 2.6 GWe is natural gas CHP in the modelled sectors. 50th percentile incentive levels are used in all cases, except the final column which shows the response to a more ambitious (75th percentile) Grant.

[38]For sites with existing CHP, modelling the economic potential for new good quality CHP replacing existing CHP would require data on the outstanding lifetime for every existing CHP plant and would greatly increase the complexity of the CHP model. Thus the simplifying assumption is made that in the long term, the most likely comparison would be between a new good quality CHP scheme and a standard heat only boiler.

Table 17 Projected Gas-Fired CHP capacity for modelled sectors in MWe

	Baseline	Capital Grant	PES Incentive	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant Sensitivity
2020 EUETS	1, 631	1,658	1, 664	1,692	1,652	1,669	1,834
2020 Non-EUETS	982	1,111	1, 119	1,091	1,125	1,119	1,211
2025 EUETS	1,065	1,091	1,072	1,096	1,093	1,085	1,271
2025 Non-EUETS	1,062	1,203	1,207	1192	1,232	1,213	1,303
2020 Total	**2,613**	**2,769**	**2,783**	**2,783**	**2,777**	**2,788**	**3,045**
2025 Total	**2,127**	**2,294**	**2,279**	**2,288**	**2,325**	**2,298**	**2,574**

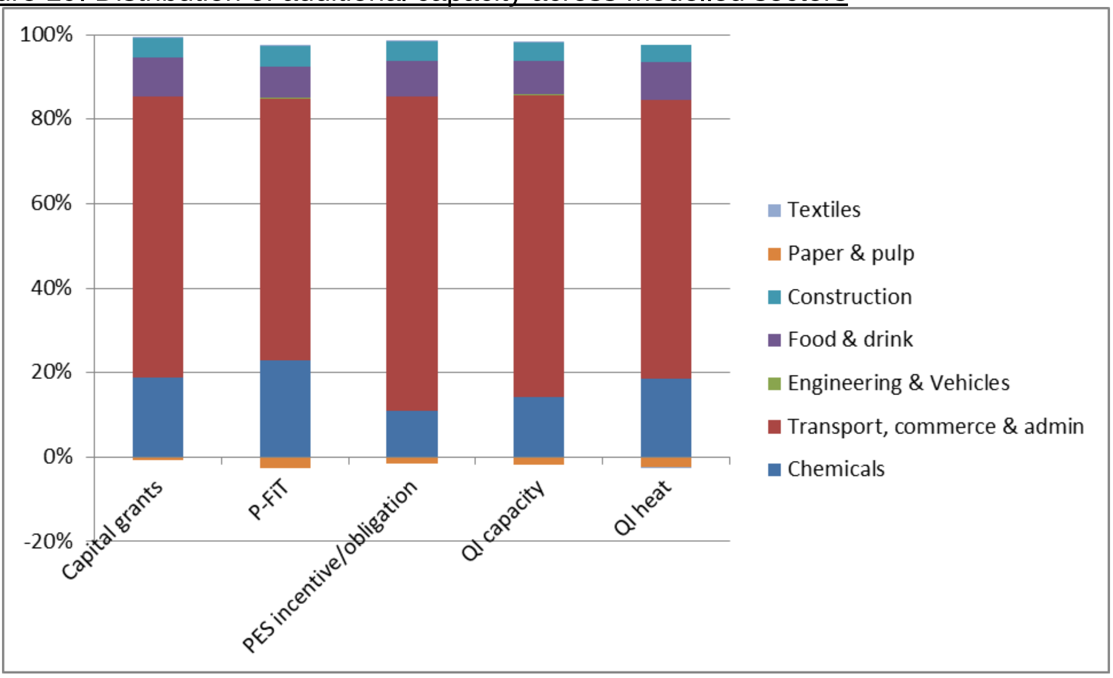
Table 18 Projected Gas-Fired CHP capacity Increase for modelled sectors resulting from bespoke policies in MWe

	Capital Grant	PES Incentive	Premium FiT	QI Weighted Heat Incentive	QI Weighted Capacity Incentive	75th percentile Capital Grant Sensitivity
2020 EUETS	27	33	61	21	38	203
2020 Non-EUETS	129	137	109	143	137	229
2025 EUETS	26	7	31	28	20	206
2025 Non-EUETS	141	145	130	170	151	241
2020 Total	**156**	**170**	**171**	**164**	**175**	**432**
2025 Total	**167**	**152**	**161**	**198**	**171**	**447**

117. **Total additional capacity brought forward in the modelled sectors is relatively small in all cases**, even under an ambitious Grant scenario. All policy options bring forward similar quantities of additional CHP capacity. This is as expected given that the incentive levels were all set based on the 50th percentile of the supply curve.

118. Figure 19 shows the additional capacity brought forward by 2025 by the policy options and its distribution across sectors. The 2025 year is shown as additional capacity peaks in this year (the final year for which the policies are assumed to offer support for new CHP).

Figure 19. Distribution of additional capacity across modelled sectors



119. The sectorial distribution of additional capacity is very similar across the different policies. Additional capacity comprises largely of small CHP in the Transport, commerce and admin sector (providing space and water heating for individual buildings/sites such as hospitals, universities, offices, hotels, leisure centres etc.). Overall the 150-200MW of additional capacity brought forward is very small in comparison to existing capacity (6.1 GWe of good quality CHP capacity in 2012). At first glance this appears counterintuitive considering that the full supply curve contains 7.3 GWe of potential additional gas CHP and just over half of this requires additional support to be commercially cost-effective. The small size of the incremental increase is the result of the following combination of factors:

- Almost 50% of the full supply curve is commercially cost-effective and likely to be built in the baseline.
- The >20% export eligibility criterion imperfectly targets support to the CHPs that need it, as discussed in section 4.1. This reflects the diverse nature and economics of gas CHP projects, covering as they do a range of sectors (including both public and private sector), technologies and power export proportions which makes it is impossible to define a perfect generic eligibility criterion. Although the majority of capacity which is commercially cost-effective without additional support is <20% exporting (see Figure 12), a significant proportion of capacity which does require additional support to be commercially cost-effective is also <20% exporting. The eligibility criterion therefore excludes around 40% of the potential capacity that might have been incentivised by a bespoke policy (see row 3 of Table 19 below).
- Some >20% exporting capacity is cost-effective under the improved modelling assumptions: see Figures 13-17 and Table 19 row 4. This means that almost half of the capacity incentivised by the 50th percentile support levels modelled is cost-effective and likely to be built in the baseline—i.e. it is deadweight.

  For these reasons, the additionality of the 50th percentile support level is limited to around 25% of the >20% exporting supply curve (approximately 540 MW) as shown in table 19 below.

Table 19 Breakdown of how potential additional capacity is excluded

	Potential capacity excluded at each stage	Remaining potential
Full Supply Curve		7.3 GWe
Excluding cost-effective potential	3.3 GWe	4.0 GWe
Excluding <20% exporting CHP (non-cost effective part of)	1.6 GWe	2.4 GWe
Cost-effective (deadweight) capacity remaining	0.4 GWe	2.0 GWe
Capacity above 50th percentile	1.5 GWe	0.5 GWe

120. Another significant contributory factor to the low modelled incremental capacity is the impact of investment probability modelling in the Monte Carlo model. A maximum probability of investment of around 80% (depending on sector) is applied and the investment probability at the nominal hurdle rate is around 40% (depending on sector). The investment probability curve (defining investment probability as a function of project IRR) is asymmetric and is slightly skewed towards the lower probabilities. The investment probability curve approach represents non-financial constraints (e.g. planning, grid connections, investment cycles, knowledge and expertise).

121. Although the probability values used are open to debate, it is clear from the Qualitative Research[39] that non-financial constraints do exist and hence applying an investment probability curve with a maximum probability below 100% is appropriate. As a result of the probability curve shape and maximum investment probability, the model will never build the full economic potential capacity. Investigation of the model output suggests that it generally only builds up to two thirds of the nominally cost-effective capacity in any segment. This would reduce the 540 MW from the supply curve to a maximum of 360 MW build, but in practice the investment probability drops off, as IRRs decrease, to around 40% at the nominal hurdle rate and lower if the IRR is below the hurdle rate. This is potentially an argument for modelling incentive levels which exceed the 50th percentile levels from the supply curve. However, although higher support levels, based on the 75th percentile of the supply curve, go some way to overcoming these effects, they still only deliver a few hundred megawatts of CHP.

122. Implausibly high projections of biomass CHP build in the baseline are also suppressing modelled gas CHP build slightly, but restricting these only increases the above figures by around a hundred MW (see section 4.5.2 for sensitivity results).

4.3.1 Capacity Market Influence

123. Modelling produced by LCP[40] suggests that many types of gas CHP would be successful in Capacity Market auctions (although not Oil & Gas and DH sector CHP). Capacity Market revenue has therefore been accounted for in the BU and MC model baselines for those segments which LCP's modelling suggests would be successful in the auction. As per Renewables Obligation and Contracts for Difference policy, plant receiving bespoke gas CHP policy support in the policy scenario modelling has been assumed to be ineligible to receive Capacity Market support. Capacity auction clearing prices used have come from Dynamic Dispatch Model runs from summer 2013.

124. The impact of Capacity Market revenue on CHP capacity has been examined by running the baseline with and without Capacity Market revenue. Figure 20 shows a breakdown of the additional capacity modelled as brought forward by the Capacity Market for 2020 and 2025 modelled years. Unlike the additional capacity brought forward by the bespoke CHP policy options, this is dominated by industrial CHP rather than the Transport, Commercial and Admin CHP sectors.

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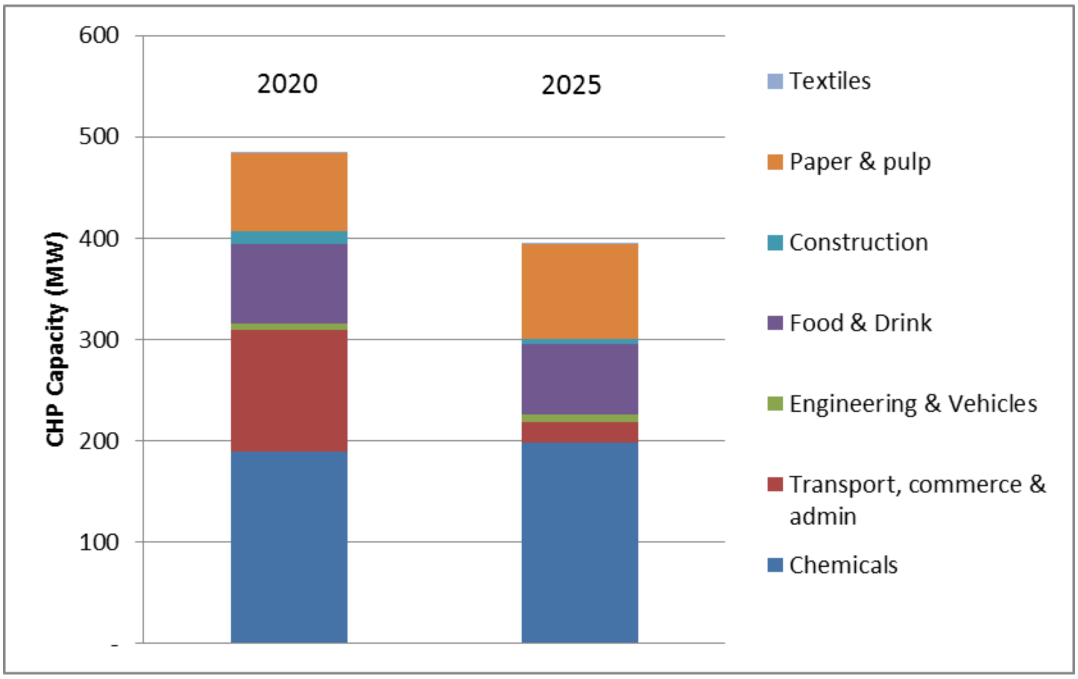
[39] Factors Affecting the Uptake of Gas CHP, September 2014
[40] Modelling the impacts of additional Gas CHP capacity in the GB electricity market, October 2014

Figure 20. Breakdown of additional CHP brought forward by Capacity Market in 2025



4.4 Off-Model DH and Oil & Gas Projections

125. Tables 20 and 21 below show the IRR in 2020 and 2025 for individual oil and gas sector schemes which are not named for reasons of confidentiality. For clarity, this omits existing schemes designed primarily as large power stations which already provide all of the heat requirement for their adjacent refineries and LNG stations.

Table 20 IRR For Individual Oil and Gas Sites 2020.

Scheme	Baseline IRR 2020	IRR 2020 with Capital Grant	IRR 2020 with PES Incentive	IRR 2020 with PFiT Incentive	IRR 2020 with QI Weighted Heat Incentive	IRR 2020 with QI Weighted Capacity Incentive	IRR with 75th Percentile Capital Grant Sensitivity
Refinery 1	19.1%	24.7%	24.2%	29.6%	24.8%	27.7%	35.5%
Refinery 2	-8.2%	-6.0%	-3.3%	2.7%	-2.9%	0.2%	-2.1%
Refinery 2	-4.4%	-1.8%	0.5%	6.2%	0.9%	3.9%	2.8%
Refinery 4	4.2%	7.8%	9.2%	14.5%	9.4%	12.1%	14.4%
Refinery 5	1.5%	4.7%	6.4%	11.0%	6.3%	8.9%	10.7%
LNG Terminal 1	2.4%	7.0%	9.1%	14.8%	5.6%	12.3%	17.7%
LNG Terminal 2	2.4%	7.0%	9.1%	14.8%	5.6%	12.3%	17.7%

Table 21 IRR For Individual Oil and Gas Sites 2025.

Scheme	Baseline IRR 2020	IRR 2020 with Capital Grant	IRR 2020 with PES Incentive	IRR 2020 with PFiT Incentive	IRR 2020 with QI Weighted Heat Incentive	IRR 2020 with QI Weighted Capacity Incentive	IRR with 75th Percentile Capital Grant Sensitivity
Refinery 1	17.1%	22.3%	22.2%	27.5%	22.7%	25.7%	32.5%
Refinery 2	-15.3%	-13.8%	-10.6%	-4.0%	-10.2%	-6.8%	-11.3%
Refinery 2	-9.7%	-7.7%	-4.9%	1.3%	-4.4%	-1.2%	-4.0%
Refinery 4	1.0%	4.2%	6.0%	11.4%	6.1%	8.9%	10.1%
Refinery 5	-0.2%	4.0%	6.4%	12.3%	2.9%	9.7%	13.5%
LNG Terminal 1	-1.9%	1.0%	3.1%	7.8%	3.0%	5.6%	6.3%
LNG Terminal 2	-0.2%	4.0%	6.4%	12.3%	2.9%	9.8%	13.5%

126. Tables 22 and 23 below show the IRR for each DH tranche in 2020 and 2025.

Table 22 IRR For Individual DH Tranches 2020.

Tranche	Baseline IRR 2020	IRR with Capital Grant 2020	IRR with PES Incentive 2020	IRR with PFiT Incentive 2020	IRR with QI Weighted Heat Incentive 2020	IRR with QI Weighted Capacity Incentive 2020	IRR with 75th Percentile Capital Grant Sensitivity 2020
	%	%	%	%	%	%	%
DH_1	19.7%	31.3%	28.8%	26.0%	27.6%	30.6%	80.8%
DH_2	25.0%	41.0%	35.5%	33.3%	33.9%	37.3%	143.4%
DH_3	22.7%	38.9%	33.7%	31.5%	32.1%	35.7%	168.7%
DH_4	15.8%	29.4%	26.9%	24.7%	25.3%	29.1%	168.5%
DH_5	None	0.0%	2.5%	3.0%	2.8%	5.2%	5.9%
DH_6	None	-5.6%	-1.4%	-0.4%	-0.9%	2.8%	2.4%

Table 23 IRR For Individual DH Tranches 2025.

Tranche	Baseline IRR 2025	IRR with Capital Grant 2025	IRR with PES Incentive 2025	IRR with PFiT Incentive 2025	IRR with QI Weighted Heat Incentive 2025	IRR with QI Weighted Capacity Incentive 2025	IRR with 75th Percentile Capital Grant Sensitivity 2025
	%	%	%	%	%	%	%
DH_1	20.1%	31.9%	29.3%	26.5%	28.1%	31.1%	82.4%
DH_2	25.5%	41.8%	36.1%	33.9%	34.5%	37.9%	146.0%
DH_3	23.1%	39.5%	34.1%	31.9%	32.5%	36.1%	171.3%
DH_4	15.9%	29.5%	27.0%	24.8%	25.4%	29.2%	169.2%
DH_5	None	-2.2%	0.5%	1.1%	0.8%	3.3%	3.2%
DH_6	None	-7.4%	-3.0%	-1.9%	-2.4%	1.3%	-0.1%

127. The corresponding total economic potentials for the Oil and Gas sector (based on the 18% hurdle rate) and the District Heating sector (based on the 12% hurdle rate) are as shown in tables 24 and 25 below. 18% was assumed for the oil and gas sector (same as chemicals sector) and 12% was assumed for District heating, (same rate assumed for developing the Renewable Heat Incentive) based on discussion with CHP and DH developers.

Table 24 Results for Non-Modelled Sectors in MWe

	Existing Capacity	Technical Potential	Baseline Economic Potential	With Capital Grant	With PES Incentive	With Premium FiT	With QI Weighted Heat Incentive	With QI Weighted Capacity Incentive	75th percentile Capital Grant (Sensitivity)
2020 Oil & Gas	805	2,576	177	177	177	177	177	177	177
2025 Oil & Gas			0	177	177	177	177	177	177
2020 DH	132	3,191	1,975	1,975	1,975	1,975	1,975	1,975	1,975
2025 DH		4,392	2,718	2,718	2,718	2,718	2,718	2,718	2,718

Table 25 Additional Economic Potential Capacity Resulting from Bespoke policies in MWe for Non-Modelled Sectors

	With Capital Grant	With PES Incentive	With Premium FiT	With QI Weighted Heat Incentive	With QI Weighted Capacity Incentive	75th percentile Capital Grant (Sensitivity)
2020 Oil & Gas	0	0	0	0	0	0
2025 Oil & Gas	177	177	177	177	177	177
2020 DH	0	0	0	0	0	0
2025 DH	0	0	0	0	0	0

128. CHP potential sized to meet site heat demand would export a high percentage of electricity for all Oil & Gas sector CHP. Exported power has a lower value than power consumed on-site (which displaces electricity imported from the grid at retail price). The consequence of the high percentage export figures is that most schemes would not achieve the assumed hurdle rate of 18% (post tax real) even under the 75th percentile Capital Grant sensitivity.

129. In 2020, only one Oil & Gas scheme would be cost-effective to install at projected energy prices without bespoke support. This scheme would source most of its fuel from refinery off-gases. If not built in 2020, the modelling predicts this scheme would only be cost-effective in 2025 with bespoke policy support. Other schemes would be uneconomic even with bespoke policy support, mainly due to a much higher reliance on natural gas, coupled with a higher proportion of power being exported.

130. In both 2020 and 2025, smaller DH schemes served by gas engines are cost-effective (IRR> the assumed 12% hurdle rate) with or without bespoke policy support and larger DH schemes served by gas turbines are not cost-effective even with bespoke support, so bespoke policy support is not modelled as having any impact, purely on the basis of a pass or fail hurdle rate. It should be noted that the modelling only considers whether the CHP is economic, so network costs have not been included. The baseline projections are therefore an assessment of the capacity which would be cost-effective provided that the networks are also economic. Consequently the figures are likely to be high relative to likely deployment. The key point is that there is no difference between the baseline and with-policy results.

131. In summary, the off-model assessment suggests that a substantial proportion of CHP capacity in District Heating would be cost-effective in the baseline and the policy options do not make any additional capacity cost-effective. The assessment for the Oil & Gas sector suggests that only a single plant is cost-effective in the baseline and no others become cost-effective with the application of policy support. The 4.8 GWe non-modelled sector additional potential capacity is therefore insensitive to the policy options, because 2.7 GWe is cost-effective in the baseline and the incentives do not provide a return which meets the hurdle rates for the remaining 2.1 GWe.

4.4.1 Oil & Gas Sensitivity (reduced Hurdle Rate)

132. A sensitivity was run with a reduced hurdle rate for the oil & gas sector with results shown in tables 26 and 27 below.

Table 26 Potential Results for Oil & Gas Sectors at a Reduced Hurdle Rate of 12%

	Baseline Economic Potential	With Capital Grant	With PES Incentive	With Premium FiT	With QI Weighted Heat Incentive	With QI Weighted Capacity Incentive	With 75th percentile Capital Grant (Sensitivity)
2020 Oil & Gas	177	177	177	1,501	177	1,501	1,501
2025 Oil & Gas	177	177	177	1,033	177	177	1,033

Table 27 Increased Economic Potential Capacity Resulting from Bespoke policies in MWe for Non-Modelled Sectors at a Reduced Hurdle Rate of 12%

	With Capital Grant	With PES Incentive	With Premium FiT	With QI Weighted Heat Incentive	With QI Weighted Capacity Incentive	With 75th percentile Capital Grant (Sensitivity)
2020 Oil & Gas	0	0	1,324	0	1,324	1,324
2025 Oil & Gas	0	0	856	0	0	856

133. Thus under this scenario the premium FiT has an impact making a few schemes cost-effective in both 2020 and 2025. The QI weighted capacity incentive has an impact in 2020 but none in 2025. As explained in section 4.1, schemes benefit more from some policies than others due to differing ratios between PES, QPO, QHO and TPC. Schemes in the oil and gas sector are suited to CCGT which has a lower heat to power ratio than the average modelled segment for which policy levels are set. Therefore the ratio of power output and capacity to heat or PES is higher than average so these schemes tend to benefit more from the power output and capacity based incentives than from the PES and heat based incentives.

4.4.2 Discussion of Model Baseline Results

134. The BU, MC and off-model assessments do not model legacy capacity, but rather model the capacity that would be cost-effective to build in the modelled year if there was no existing capacity. Baseline results therefore have to be viewed with caution, but are reported here to help understand some of the incremental build results. Table 28 shows the modelled baseline gas CHP capacity in comparison to current (2012) good quality gas CHP capacity. Baseline capacity in the modelled sectors is shown under two different assumptions regarding Capacity Market participation as discussed above. The low estimates assume CHP does not participate in the Capacity Market. The high estimate assumes CHP in the modelled sectors does participate.

Table 28 Projected baseline CHP capacity v current capacity

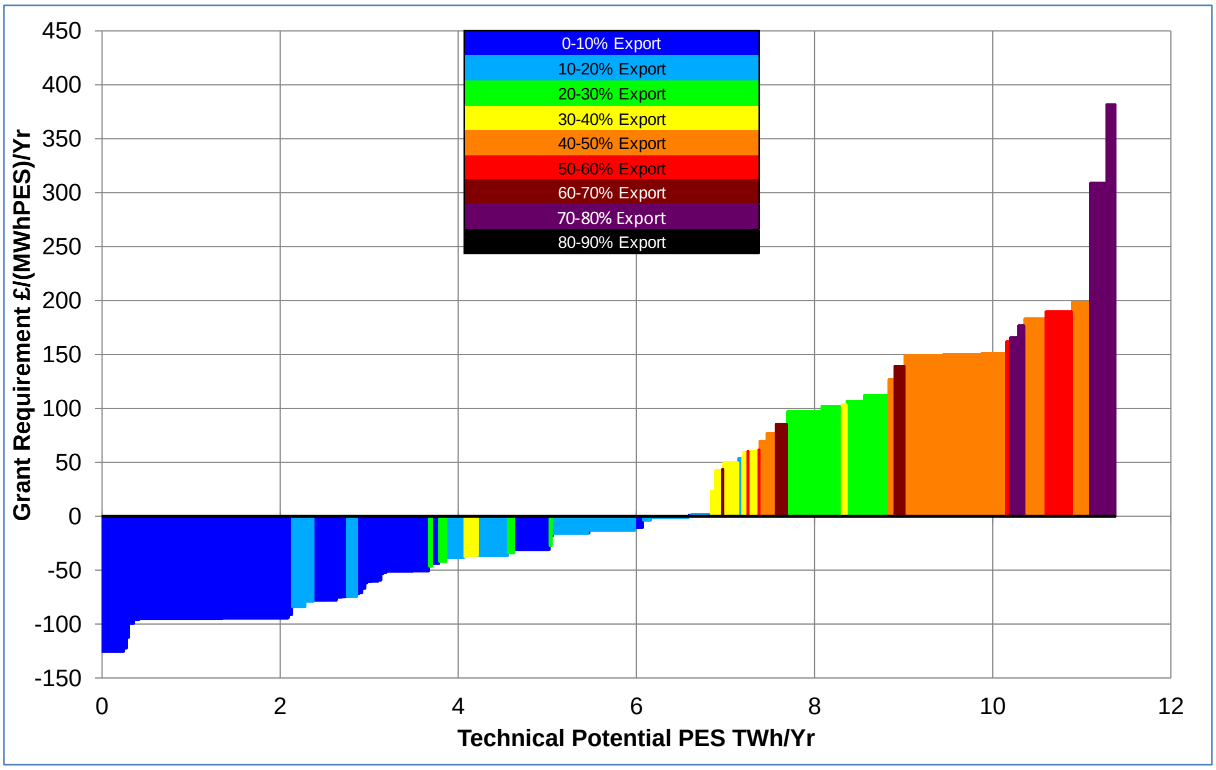
	Capacity Market assumption	**2012**	**2020**	**2025**
Modelled sectors	No participation	2586 MW	2285 MW	1732 MW
	Full participation		2613 MW	2126 MW

4.5 Sensitivities & Investigations

4.5.1 Supply Curve data investigation

135. The DECC CHP capacity modelling showed that CHP deployed in response to the above incentives and eligibility criteria is primarily in the non-ETS sector. This CHP has the potentially undesirable effect of displacing power generation emissions from the ETS sector into the non-ETS sector where emissions are more challenging to abate. This is reflected in the social NPV analysis conducted by LCP as a cost. We have therefore explored how much of the supply curve CHP potential there is in the ETS sector, to which support might be targeted in order to avoid this impact and what this might imply for support levels. Figure 21 below shows the full Capital Grant supply curve for ETS only.

Figure 21 Grant supply Curve for ETS CHP only.

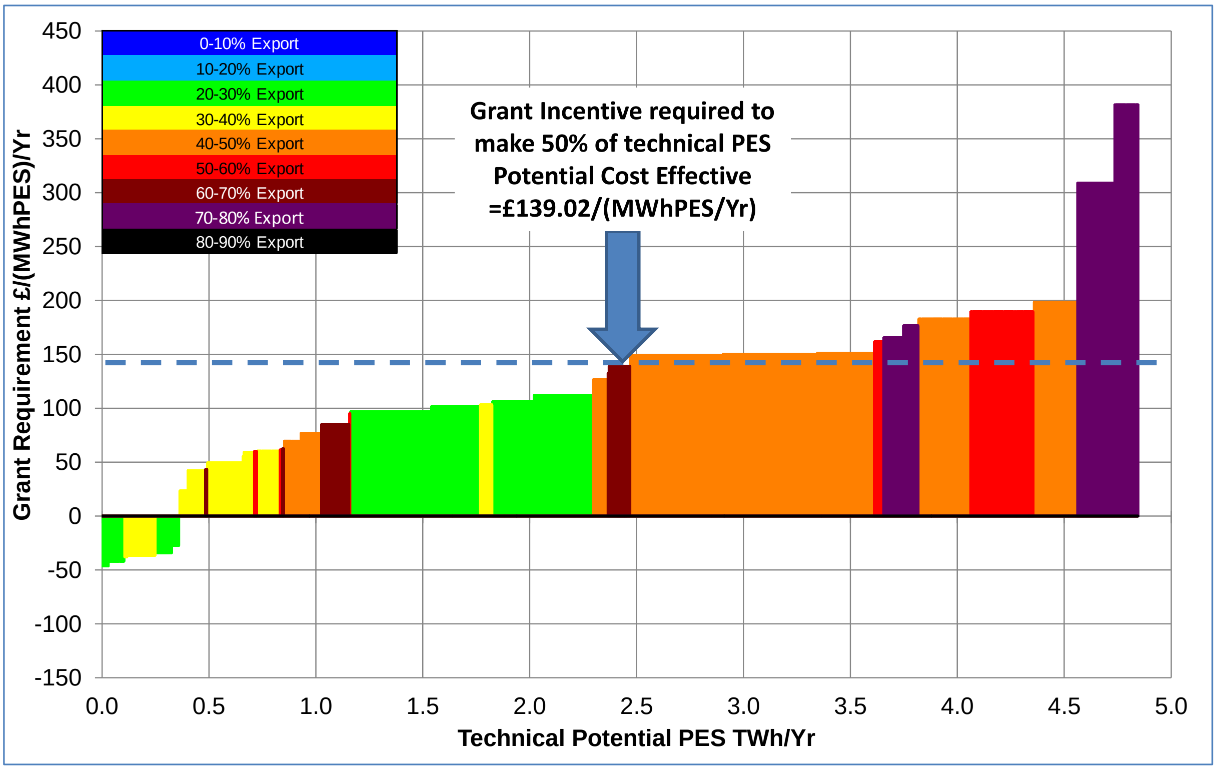


136. In total there is 2.8 GWe of capacity and 11.4 TWh of PES potential for additional ETS sector CHP. Of this, 1.5 GWe is projected to be cost-effective under current policy and projected 2020 energy prices. The remaining potential that might be brought forward by support is 1.3 GWe. The 20% export criterion correlates better with cost-effective capacity in the ETS sector than it did with cost-effective capacity in general. It would successfully exclude 96% of the cost-effective capacity and only fail to capture 6% of the capacity which would need additional support to be cost-effective.

137. If the 20% export criterion were applied to the ETS potential CHP the remaining supply curve (Figure 22) would contain 1.3 GWe in total and a 50th percentile support level would apply to 580 MWe, only 60 MWe of which would be deadweight that was already cost-effective without additional support. In principle then, an incentive for ETS-only CHP capacity might bring forward similar amounts of capacity to the general incentive for both ETS and non-ETS CHP which we have modelled. However, a 50th

percentile Capital Grant for ETS only CHP would be £139.02/MWh PES, i.e. more than double the level for ETS and non-ETS CHP (£56.79/MWh PES). This is because most of the technical potential for ETS schemes is CCGT and open cycle gas turbines, whereas most of the potential for non-ETS schemes is gas engines. The former have lower Primary Energy Savings relative to electrical capacity and CCGT schemes tend to export higher percentages of electricity. These factors generally lead to higher operating costs relative to PES. Therefore, although an ETS-only focussed incentive might bring forward similar capacity to the general incentive we have modelled, it would do so at much higher cost.

Figure 22 Grant supply Curve for ETS CHP only excluding schemes exporting <20%



4.5.2 Further Sensitivity Analysis

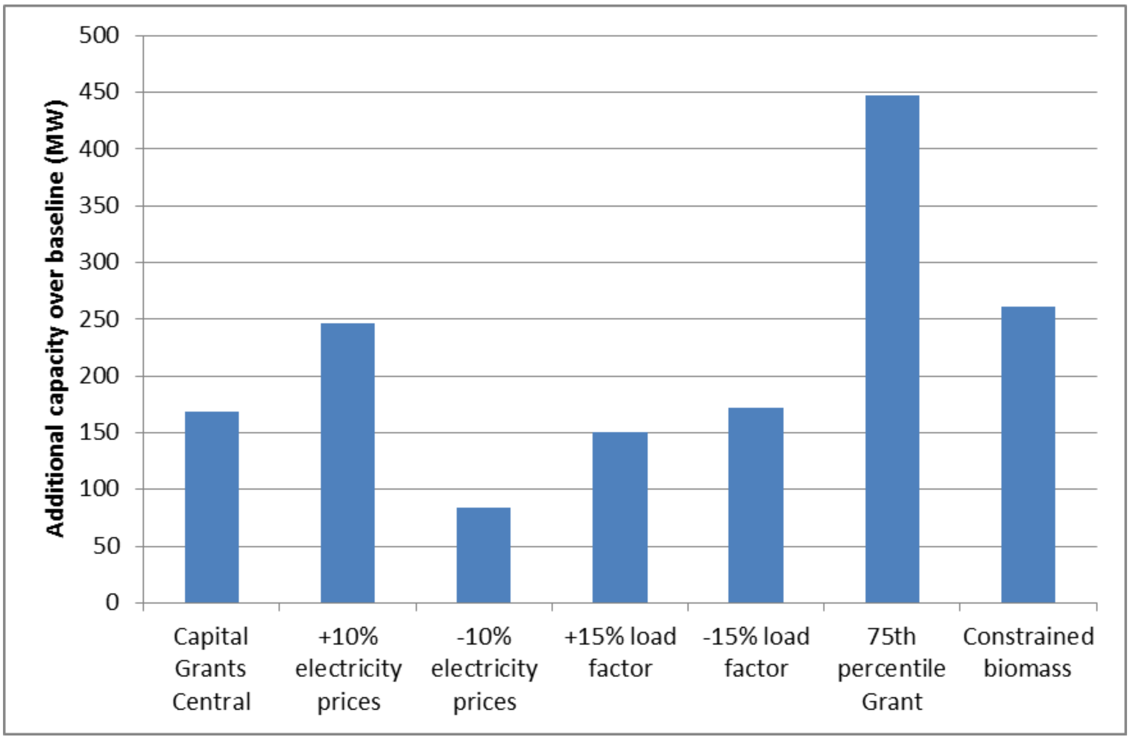
138. The sensitivity of the incremental build in the DECC model under the Capital Grants option to a number of key factors was modelled. In view of the limited additional CHP brought forward over the baseline this includes a sensitivity case on the Capital Grants option with the grant level set at the 75th percentile of the supply curve (Figure 23), increasing the grant level from £56.79/MWh to £124.79/MWh of Primary Energy Saving (results also reported above).

139. DECC have conducted further sensitivity analysis which included examining the sensitivity to electricity prices, CHP load factors, and constraining biomass CHP deployment (which, in the central case, significantly exceeded levels projected in DECC's EMR Final Delivery Plan) to the upper end of the Final Delivery Plan range[41]. The results are shown in Figure 23 below alongside the 50th percentile Capital Grants results. Incremental capacity brought forward by Capital Grants is sensitive to electricity prices,

[41] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/268221/181213_2013_EMR_Delivery_Plan_FINAL.pdf

incentive levels, and reduced biomass CHP deployment, but relatively insensitive to load factors. However, additional capacity brought forward due to policy remains small in absolute terms. With the exception of the 75th percentile Capital Grant scenario, changes in modelling assumptions impact on both baseline and policy scenarios, which contributes to the relatively small changes in additional build i.e. the assumptions have a similar impact on the baseline as on the policy scenario.

Figure 23. Modelled incremental CHP capacity in 2025 – sensitivities (DECC model)



Annex A – Segment Energy Demands and assumptions on Capacity Market

Table A1 Modelling segmentations for EU-ETS Sites

EUETS Status	Sector	Sub-Sector	Sector Size Range	No of sites in segment	Average site power demand (TJpa)	Average site heat demand (TJpa)	Expected to be successful in Capacity Market auctions
EUETS	Chemicals	Dyes and pigments	1	0	-	-	No
EUETS	Chemicals	Dyes and pigments	2	1	2	6	Yes
EUETS	Chemicals	Dyes and pigments	3	1	94	372	Yes
EUETS	Chemicals	Dyes and pigments	4	1	181	717	Yes
EUETS	Chemicals	Dyes and pigments	5	1	228	903	Yes
EUETS	Chemicals	Dyes and pigments	6	1	317	1,257	Yes
EUETS	Chemicals	Inorganic Chemicals	1	7	202	307	Yes
EUETS	Chemicals	Inorganic Chemicals	2	2	1,018	1,543	Yes
EUETS	Chemicals	Inorganic Chemicals	3	1	1,200	1,820	Yes
EUETS	Chemicals	Inorganic Chemicals	4	1	1,593	2,417	Yes
EUETS	Chemicals	Inorganic Chemicals	5	1	2,119	3,214	Yes
EUETS	Chemicals	Inorganic Chemicals	6	1	5,678	8,612	Yes
EUETS	Chemicals	Other Chemicals	1	11	273	259	Yes
EUETS	Chemicals	Other Chemicals	2	1	579	550	Yes
EUETS	Chemicals	Other Chemicals	3	1	1,151	1,094	Yes
EUETS	Chemicals	Other Chemicals	4	1	1,612	1,533	Yes
EUETS	Chemicals	Other Chemicals	5	1	3,790	3,603	Yes
EUETS	Chemicals	Other Chemicals	6	1	8,947	8,505	No
EUETS	Chemicals	Organic chemicals	1	8	168	155	Yes
EUETS	Chemicals	Organic chemicals	2	1	903	832	Yes
EUETS	Chemicals	Organic chemicals	3	1	950	875	Yes
EUETS	Chemicals	Organic chemicals	4	1	1,679	1,547	Yes
EUETS	Chemicals	Organic chemicals	5	1	3,143	2,896	Yes
EUETS	Chemicals	Organic chemicals	6	1	4,025	3,708	Yes
EUETS	Chemicals	Paints	1	0	-	-	No
EUETS	Chemicals	Paints	2	0	-	-	No
EUETS	Chemicals	Paints	3	0	-	-	No
EUETS	Chemicals	Paints	4	0	-	-	No
EUETS	Chemicals	Paints	5	0	-	-	No
EUETS	Chemicals	Paints	6	0	-	-	No
EUETS	Chemicals	Pharmaceuticals	1	8	54	105	Yes
EUETS	Chemicals	Pharmaceuticals	2	6	107	209	Yes
EUETS	Chemicals	Pharmaceuticals	3	3	222	435	Yes
EUETS	Chemicals	Pharmaceuticals	4	2	290	567	Yes
EUETS	Chemicals	Pharmaceuticals	5	2	331	647	Yes
EUETS	Chemicals	Pharmaceuticals	6	1	1,071	2,094	Yes
EUETS	Chemicals	Resins	1	0	-	-	No
EUETS	Chemicals	Resins	2	1	41	96	Yes
EUETS	Chemicals	Resins	3	1	128	300	Yes
EUETS	Chemicals	Resins	4	1	161	379	Yes
EUETS	Chemicals	Resins	5	1	178	418	Yes
EUETS	Chemicals	Resins	6	1	265	624	Yes
EUETS	Chemicals	Rubber Polymer	1	0	-	-	No
EUETS	Chemicals	Rubber Polymer	2	1	173	170	Yes
EUETS	Chemicals	Rubber Polymer	3	1	260	255	Yes
EUETS	Chemicals	Rubber Polymer	4	1	266	261	Yes
EUETS	Chemicals	Rubber Polymer	5	1	303	297	Yes

EUETS	Chemicals	Rubber Polymer	6	1	1,078	1,058	Yes
EUETS	Chemicals	Soap	1	0	-	-	No
EUETS	Chemicals	Soap	2	0	-	-	No
EUETS	Chemicals	Soap	3	0	-	-	No
EUETS	Chemicals	Soap	4	0	-	-	No
EUETS	Chemicals	Soap	5	1	122	145	Yes
EUETS	Chemicals	Soap	6	1	452	540	Yes
EUETS	Chemicals	Synthetic Fibres	1	0	-	-	No
EUETS	Chemicals	Synthetic Fibres	2	0	-	-	No
EUETS	Chemicals	Synthetic Fibres	3	1	273	126	Yes
EUETS	Chemicals	Synthetic Fibres	4	1	1,922	885	Yes
EUETS	Chemicals	Synthetic Fibres	5	1	3,608	1,661	Yes
EUETS	Chemicals	Synthetic Fibres	6	1	11,178	5,146	No
EUETS	Engineering	Electrical Engineering	1	0	-	-	No
EUETS	Engineering	Electrical Engineering	2	0	-	-	No
EUETS	Engineering	Electrical Engineering	3	0	-	-	No
EUETS	Engineering	Electrical Engineering	4	0	-	-	No
EUETS	Engineering	Electrical Engineering	5	0	-	-	No
EUETS	Engineering	Electrical Engineering	6	1	89	42	No
EUETS	Engineering	Mechanical Engineering	1	1	137	116	Yes
EUETS	Engineering	Mechanical Engineering	2	1	138	117	Yes
EUETS	Engineering	Mechanical Engineering	3	1	140	118	Yes
EUETS	Engineering	Mechanical Engineering	4	1	157	133	Yes
EUETS	Engineering	Mechanical Engineering	5	1	166	140	No
EUETS	Engineering	Mechanical Engineering	6	1	715	604	No
EUETS	Engineering	Vehicle Engineering	1	6	45	69	Yes
EUETS	Engineering	Vehicle Engineering	2	4	99	150	No
EUETS	Engineering	Vehicle Engineering	3	4	121	184	Yes
EUETS	Engineering	Vehicle Engineering	4	3	119	181	Yes
EUETS	Engineering	Vehicle Engineering	5	2	237	360	No
EUETS	Engineering	Vehicle Engineering	6	2	349	529	No
EUETS	Food & drink	Baking	1	0	-	-	No
EUETS	Food & drink	Baking	2	0	-	-	No
EUETS	Food & drink	Baking	3	0	-	-	No
EUETS	Food & drink	Baking	4	0	-	-	No
EUETS	Food & drink	Baking	5	0	-	-	No
EUETS	Food & drink	Baking	6	0	-	-	No
EUETS	Food & drink	Brewing	1	1	6	15	Yes
EUETS	Food & drink	Brewing	2	1	16	38	Yes
EUETS	Food & drink	Brewing	3	1	23	57	Yes
EUETS	Food & drink	Brewing	4	1	25	61	Yes
EUETS	Food & drink	Brewing	5	1	136	332	Yes
EUETS	Food & drink	Brewing	6	1	324	791	Yes
EUETS	Food & drink	Creameries	1	1	27	34	Yes
EUETS	Food & drink	Creameries	2	1	64	82	Yes
EUETS	Food & drink	Creameries	3	1	131	167	Yes
EUETS	Food & drink	Creameries	4	1	74	95	Yes
EUETS	Food & drink	Creameries	5	1	161	205	Yes
EUETS	Food & drink	Creameries	6	1	101	129	Yes
EUETS	Food & drink	Distilling	1	0	-	-	No
EUETS	Food & drink	Distilling	2	0	-	-	No
EUETS	Food & drink	Distilling	3	0	-	-	No
EUETS	Food & drink	Distilling	4	1	66	337	Yes
EUETS	Food & drink	Distilling	5	1	90	461	Yes
EUETS	Food & drink	Distilling	6	1	120	612	Yes
EUETS	Food & drink	Red Meat	1	0	-	-	No

EUETS	Food & drink	Red Meat	2	0	-	-	No
EUETS	Food & drink	Red Meat	3	0	-	-	No
EUETS	Food & drink	Red Meat	4	1	60	52	Yes
EUETS	Food & drink	Red Meat	5	1	122	107	Yes
EUETS	Food & drink	Red Meat	6	1	145	127	Yes
EUETS	Food & drink	Rest of Food	1	18	70	119	Yes
EUETS	Food & drink	Rest of Food	2	12	147	250	Yes
EUETS	Food & drink	Rest of Food	3	6	373	633	Yes
EUETS	Food & drink	Rest of Food	4	3	583	991	Yes
EUETS	Food & drink	Rest of Food	5	3	744	1,264	Yes
EUETS	Food & drink	Rest of Food	6	2	1,219	2,071	Yes
EUETS	Other Industry	Plastics	1	0	-	-	No
EUETS	Other Industry	Plastics	2	0	-	-	No
EUETS	Other Industry	Plastics	3	0	-	-	No
EUETS	Other Industry	Plastics	4	0	-	-	No
EUETS	Other Industry	Plastics	5	0	-	-	No
EUETS	Other Industry	Plastics	6	0	-	-	No
EUETS	Other Industry	Rubber	1	0	-	-	No
EUETS	Other Industry	Rubber	2	0	-	-	No
EUETS	Other Industry	Rubber	3	0	-	-	No
EUETS	Other Industry	Rubber	4	0	-	-	No
EUETS	Other Industry	Rubber	5	0	-	-	No
EUETS	Other Industry	Rubber	6	1	48	147	Yes
EUETS	Other Industry	Wood	1	0	-	-	No
EUETS	Other Industry	Wood	2	0	-	-	No
EUETS	Other Industry	Wood	3	0	-	-	No
EUETS	Other Industry	Wood	4	1	109	261	No
EUETS	Other Industry	Wood	5	1	330	792	Yes
EUETS	Other Industry	Wood	6	1	468	1,122	Yes
EUETS	Paper	Papermaking	1	9	299	329	Yes
EUETS	Paper	Papermaking	2	4	896	989	Yes
EUETS	Paper	Papermaking	3	2	1,453	1,602	Yes
EUETS	Paper	Papermaking	4	2	1,685	1,859	Yes
EUETS	Paper	Papermaking	5	1	2,572	2,837	Yes
EUETS	Paper	Papermaking	6	1	4,096	4,517	Yes
EUETS	Paper	Printing and Publishing	1	0	-	-	No
EUETS	Paper	Printing and Publishing	2	0	-	-	No
EUETS	Paper	Printing and Publishing	3	0	-	-	No
EUETS	Paper	Printing and Publishing	4	0	-	-	No
EUETS	Paper	Printing and Publishing	5	1	577	293	No
EUETS	Paper	Printing and Publishing	6	1	620	315	No
EUETS	Services	Education	1	5	20	39	Yes
EUETS	Services	Education	2	4	45	89	Yes
EUETS	Services	Education	3	4	53	104	Yes
EUETS	Services	Education	4	2	69	134	Yes
EUETS	Services	Education	5	3	87	170	Yes
EUETS	Services	Education	6	2	135	265	Yes
EUETS	Services	Health	1	24	27	65	Yes
EUETS	Services	Health	2	16	39	95	Yes
EUETS	Services	Health	3	13	49	119	Yes
EUETS	Services	Health	4	10	63	152	Yes
EUETS	Services	Health	5	8	85	206	Yes
EUETS	Services	Health	6	5	137	333	Yes
EUETS	Services	Hotels	1	0	-	-	No
EUETS	Services	Hotels	2	0	-	-	No
EUETS	Services	Hotels	3	0	-	-	No

EUETS	Services	Hotels	4	0	-	-	No
EUETS	Services	Hotels	5	0	-	-	No
EUETS	Services	Hotels	6	0	-	-	No
EUETS	Services	Offices	1	0	-	-	No
EUETS	Services	Offices	2	5	7	6	Yes
EUETS	Services	Offices	3	1	21	19	Yes
EUETS	Services	Offices	4	1	37	33	Yes
EUETS	Services	Offices	5	2	76	68	Yes
EUETS	Services	Offices	6	1	112	100	Yes
EUETS	Services	Public Buildings	1	13	11	19	Yes
EUETS	Services	Public Buildings	2	9	36	62	Yes
EUETS	Services	Public Buildings	3	9	58	98	Yes
EUETS	Services	Public Buildings	4	4	81	139	Yes
EUETS	Services	Public Buildings	5	3	100	170	Yes
EUETS	Services	Public Buildings	6	3	148	251	Yes
EUETS	Services	Retail	1	0	-	-	No
EUETS	Services	Retail	2	0	-	-	No
EUETS	Services	Retail	3	0	-	-	No
EUETS	Services	Retail	4	0	-	-	No
EUETS	Services	Retail	5	0	-	-	No
EUETS	Services	Retail	6	0	-	-	No
EUETS	Services	Warehouses	1	0	-	-	No
EUETS	Services	Warehouses	2	0	-	-	No
EUETS	Services	Warehouses	3	0	-	-	No
EUETS	Services	Warehouses	4	0	-	-	No
EUETS	Services	Warehouses	5	0	-	-	No
EUETS	Services	Warehouses	6	0	-	-	No
EUETS	Textiles	Carpets	1	0	-	-	No
EUETS	Textiles	Carpets	2	0	-	-	No
EUETS	Textiles	Carpets	3	0	-	-	No
EUETS	Textiles	Carpets	4	0	-	-	No
EUETS	Textiles	Carpets	5	0	-	-	No
EUETS	Textiles	Carpets	6	0	-	-	No
EUETS	Textiles	Dyes and Finishes	1	0	-	-	No
EUETS	Textiles	Dyes and Finishes	2	0	-	-	No
EUETS	Textiles	Dyes and Finishes	3	0	-	-	No
EUETS	Textiles	Dyes and Finishes	4	0	-	-	No
EUETS	Textiles	Dyes and Finishes	5	1	8	29	Yes
EUETS	Textiles	Dyes and Finishes	6	1	18	65	Yes
EUETS	Textiles	Spinning and Weaving	1	0	-	-	No
EUETS	Textiles	Spinning and Weaving	2	0	-	-	No
EUETS	Textiles	Spinning and Weaving	3	0	-	-	No
EUETS	Textiles	Spinning and Weaving	4	0	-	-	No
EUETS	Textiles	Spinning and Weaving	5	0	-	-	No
EUETS	Textiles	Spinning and Weaving	6	1	36	60	Yes
EUETS	Textiles	Woollens	1	0	-	-	No
EUETS	Textiles	Woollens	2	0	-	-	No
EUETS	Textiles	Woollens	3	0	-	-	No
EUETS	Textiles	Woollens	4	0	-	-	No
EUETS	Textiles	Woollens	5	0	-	-	No
EUETS	Textiles	Woollens	6	0	-	-	No

Table A2 Modelling segmentations for Non-EUETS Sites

EUETS Status	Sector	Sub-Sector	Sector Size Range	No of sites in segment	Average site power demand (TJpa)	Average site heat demand (TJpa)	Expected to Participate in Capacity Mechanism
Non-EUETS	Chemicals	Dyes and pigments	1	49	2	10	Yes
Non-EUETS	Chemicals	Dyes and pigments	2	13	10	38	Yes
Non-EUETS	Chemicals	Dyes and pigments	3	7	16	65	Yes
Non-EUETS	Chemicals	Dyes and pigments	4	6	23	90	Yes
Non-EUETS	Chemicals	Dyes and pigments	5	4	32	128	Yes
Non-EUETS	Chemicals	Dyes and pigments	6	2	63	252	No
Non-EUETS	Chemicals	Inorganic Chemicals	1	93	5	8	Yes
Non-EUETS	Chemicals	Inorganic Chemicals	2	19	24	37	Yes
Non-EUETS	Chemicals	Inorganic Chemicals	3	11	40	60	Yes
Non-EUETS	Chemicals	Inorganic Chemicals	4	6	77	116	Yes
Non-EUETS	Chemicals	Inorganic Chemicals	5	4	125	190	Yes
Non-EUETS	Chemicals	Inorganic Chemicals	6	2	248	376	No
Non-EUETS	Chemicals	Other Chemicals	1	218	2	2	Yes
Non-EUETS	Chemicals	Other Chemicals	2	68	7	6	Yes
Non-EUETS	Chemicals	Other Chemicals	3	31	14	14	Yes
Non-EUETS	Chemicals	Other Chemicals	4	16	27	26	Yes
Non-EUETS	Chemicals	Other Chemicals	5	8	57	54	Yes
Non-EUETS	Chemicals	Other Chemicals	6	4	127	121	Yes
Non-EUETS	Chemicals	Organic chemicals	1	200	9	8	Yes
Non-EUETS	Chemicals	Organic chemicals	2	46	39	36	Yes
Non-EUETS	Chemicals	Organic chemicals	3	25	72	66	Yes
Non-EUETS	Chemicals	Organic chemicals	4	13	139	128	Yes
Non-EUETS	Chemicals	Organic chemicals	5	11	172	159	Yes
Non-EUETS	Chemicals	Organic chemicals	6	6	320	294	No
Non-EUETS	Chemicals	Paints	1	86	2	1	Yes
Non-EUETS	Chemicals	Paints	2	35	5	3	Yes
Non-EUETS	Chemicals	Paints	3	22	8	5	Yes
Non-EUETS	Chemicals	Paints	4	15	12	8	Yes
Non-EUETS	Chemicals	Paints	5	9	19	13	Yes
Non-EUETS	Chemicals	Paints	6	5	42	28	Yes
Non-EUETS	Chemicals	Pharmaceuticals	1	264	2	4	Yes
Non-EUETS	Chemicals	Pharmaceuticals	2	54	11	22	Yes
Non-EUETS	Chemicals	Pharmaceuticals	3	29	21	41	Yes
Non-EUETS	Chemicals	Pharmaceuticals	4	18	33	64	Yes
Non-EUETS	Chemicals	Pharmaceuticals	5	13	47	91	Yes
Non-EUETS	Chemicals	Pharmaceuticals	6	8	80	156	Yes
Non-EUETS	Chemicals	Resins	1	344	2	5	Yes
Non-EUETS	Chemicals	Resins	2	82	8	20	Yes
Non-EUETS	Chemicals	Resins	3	45	15	36	Yes
Non-EUETS	Chemicals	Resins	4	29	22	52	Yes
Non-EUETS	Chemicals	Resins	5	23	32	76	Yes
Non-EUETS	Chemicals	Resins	6	13	55	130	Yes
Non-EUETS	Chemicals	Rubber Polymer	1	5	6	6	Yes
Non-EUETS	Chemicals	Rubber Polymer	2	1	18	18	Yes
Non-EUETS	Chemicals	Rubber Polymer	3	1	38	38	Yes
Non-EUETS	Chemicals	Rubber Polymer	4	1	50	49	Yes
Non-EUETS	Chemicals	Rubber Polymer	5	1	87	86	No
Non-EUETS	Chemicals	Rubber Polymer	6	1	90	88	No
Non-EUETS	Chemicals	Soap	1	194	2	3	Yes
Non-EUETS	Chemicals	Soap	2	52	8	10	Yes
Non-EUETS	Chemicals	Soap	3	25	16	19	Yes

Non-EUETS	Chemicals	Soap	4	15	31	37	Yes
Non-EUETS	Chemicals	Soap	5	5	84	101	Yes
Non-EUETS	Chemicals	Soap	6	5	99	118	Yes
Non-EUETS	Chemicals	Synthetic Fibres	1	12	9	4	Yes
Non-EUETS	Chemicals	Synthetic Fibres	2	3	32	15	Yes
Non-EUETS	Chemicals	Synthetic Fibres	3	1	45	20	Yes
Non-EUETS	Chemicals	Synthetic Fibres	4	1	102	47	Yes
Non-EUETS	Chemicals	Synthetic Fibres	5	1	151	70	No
Non-EUETS	Chemicals	Synthetic Fibres	6	1	229	105	No
Non-EUETS	Engineering	Electrical Engineering	1	478	2	1	Yes
Non-EUETS	Engineering	Electrical Engineering	2	256	4	2	Yes
Non-EUETS	Engineering	Electrical Engineering	3	148	7	3	Yes
Non-EUETS	Engineering	Electrical Engineering	4	83	12	6	Yes
Non-EUETS	Engineering	Electrical Engineering	5	42	27	13	Yes
Non-EUETS	Engineering	Electrical Engineering	6	14	81	38	Yes
Non-EUETS	Engineering	Mechanical Engineering	1	183	1	1	Yes
Non-EUETS	Engineering	Mechanical Engineering	2	77	3	3	Yes
Non-EUETS	Engineering	Mechanical Engineering	3	44	6	5	Yes
Non-EUETS	Engineering	Mechanical Engineering	4	21	11	9	Yes
Non-EUETS	Engineering	Mechanical Engineering	5	6	42	36	Yes
Non-EUETS	Engineering	Mechanical Engineering	6	2	120	101	Yes
Non-EUETS	Engineering	Vehicle Engineering	1	1,081	1	2	Yes
Non-EUETS	Engineering	Vehicle Engineering	2	300	5	7	Yes
Non-EUETS	Engineering	Vehicle Engineering	3	136	10	15	Yes
Non-EUETS	Engineering	Vehicle Engineering	4	74	20	30	Yes
Non-EUETS	Engineering	Vehicle Engineering	5	33	43	65	Yes
Non-EUETS	Engineering	Vehicle Engineering	6	16	103	156	Yes
Non-EUETS	Food & drink	Baking	1	482	1	2	Yes
Non-EUETS	Food & drink	Baking	2	122	4	6	Yes
Non-EUETS	Food & drink	Baking	3	65	9	13	Yes
Non-EUETS	Food & drink	Baking	4	28	18	28	Yes
Non-EUETS	Food & drink	Baking	5	17	31	47	Yes
Non-EUETS	Food & drink	Baking	6	9	66	101	Yes
Non-EUETS	Food & drink	Brewing	1	178	1	3	Yes
Non-EUETS	Food & drink	Brewing	2	18	14	34	Yes
Non-EUETS	Food & drink	Brewing	3	10	22	54	Yes
Non-EUETS	Food & drink	Brewing	4	7	34	82	Yes
Non-EUETS	Food & drink	Brewing	5	7	43	105	Yes
Non-EUETS	Food & drink	Brewing	6	3	102	248	No
Non-EUETS	Food & drink	Creameries	1	104	4	5	Yes
Non-EUETS	Food & drink	Creameries	2	25	15	19	Yes
Non-EUETS	Food & drink	Creameries	3	15	25	32	Yes
Non-EUETS	Food & drink	Creameries	4	10	37	47	Yes
Non-EUETS	Food & drink	Creameries	5	5	72	91	Yes
Non-EUETS	Food & drink	Creameries	6	5	89	113	Yes
Non-EUETS	Food & drink	Distilling	1	0	-	-	No
Non-EUETS	Food & drink	Distilling	2	0	-	-	No
Non-EUETS	Food & drink	Distilling	3	0	-	-	No
Non-EUETS	Food & drink	Distilling	4	0	-	-	No
Non-EUETS	Food & drink	Distilling	5	2	5	27	Yes
Non-EUETS	Food & drink	Distilling	6	2	6	32	Yes
Non-EUETS	Food & drink	Red Meat	1	403	2	2	Yes
Non-EUETS	Food & drink	Red Meat	2	109	9	8	Yes
Non-EUETS	Food & drink	Red Meat	3	55	17	15	Yes
Non-EUETS	Food & drink	Red Meat	4	30	31	27	Yes
Non-EUETS	Food & drink	Red Meat	5	21	48	42	Yes

Non-EUETS	Food & drink	Red Meat	6	11	100	88	Yes
Non-EUETS	Food & drink	Rest of Food	1	1,058	2	3	Yes
Non-EUETS	Food & drink	Rest of Food	2	254	7	12	Yes
Non-EUETS	Food & drink	Rest of Food	3	121	15	26	Yes
Non-EUETS	Food & drink	Rest of Food	4	59	26	45	Yes
Non-EUETS	Food & drink	Rest of Food	5	33	53	91	Yes
Non-EUETS	Food & drink	Rest of Food	6	14	119	203	No
Non-EUETS	Other Industry	Plastics	1	1,161	1	1	Yes
Non-EUETS	Other Industry	Plastics	2	541	3	3	Yes
Non-EUETS	Other Industry	Plastics	3	310	5	5	Yes
Non-EUETS	Other Industry	Plastics	4	167	9	9	Yes
Non-EUETS	Other Industry	Plastics	5	84	17	18	Yes
Non-EUETS	Other Industry	Plastics	6	36	51	52	Yes
Non-EUETS	Other Industry	Rubber	1	0	-	-	No
Non-EUETS	Other Industry	Rubber	2	0	-	-	No
Non-EUETS	Other Industry	Rubber	3	0	-	-	No
Non-EUETS	Other Industry	Rubber	4	0	-	-	No
Non-EUETS	Other Industry	Rubber	5	0	-	-	No
Non-EUETS	Other Industry	Rubber	6	1	0	1	Yes
Non-EUETS	Other Industry	Wood	1	334	1	1	Yes
Non-EUETS	Other Industry	Wood	2	119	2	4	Yes
Non-EUETS	Other Industry	Wood	3	58	3	8	Yes
Non-EUETS	Other Industry	Wood	4	29	7	17	Yes
Non-EUETS	Other Industry	Wood	5	15	13	30	Yes
Non-EUETS	Other Industry	Wood	6	8	27	64	No
Non-EUETS	Paper	Papermaking	1	495	2	2	Yes
Non-EUETS	Paper	Papermaking	2	124	9	10	Yes
Non-EUETS	Paper	Papermaking	3	57	19	21	Yes
Non-EUETS	Paper	Papermaking	4	26	40	44	Yes
Non-EUETS	Paper	Papermaking	5	13	92	102	Yes
Non-EUETS	Paper	Papermaking	6	6	239	264	No
Non-EUETS	Paper	Printing and Publishing	1	544	2	1	Yes
Non-EUETS	Paper	Printing and Publishing	2	396	3	1	Yes
Non-EUETS	Paper	Printing and Publishing	3	255	4	2	Yes
Non-EUETS	Paper	Printing and Publishing	4	147	7	4	Yes
Non-EUETS	Paper	Printing and Publishing	5	71	14	7	Yes
Non-EUETS	Paper	Printing and Publishing	6	32	33	16	Yes
Non-EUETS	Services	Education	1	7,389	0	1	No
Non-EUETS	Services	Education	2	5,292	0	1	No
Non-EUETS	Services	Education	3	3,832	1	1	No
Non-EUETS	Services	Education	4	2,659	1	2	No
Non-EUETS	Services	Education	5	1,706	1	3	No
Non-EUETS	Services	Education	6	692	3	7	No
Non-EUETS	Services	Health	1	667	1	2	No
Non-EUETS	Services	Health	2	487	1	3	No
Non-EUETS	Services	Health	3	385	1	4	No
Non-EUETS	Services	Health	4	294	2	5	No
Non-EUETS	Services	Health	5	185	3	7	No
Non-EUETS	Services	Health	6	103	6	14	No
Non-EUETS	Services	Hotels	1	6,229	1	1	No
Non-EUETS	Services	Hotels	2	5,378	1	1	No
Non-EUETS	Services	Hotels	3	4,292	1	1	No
Non-EUETS	Services	Hotels	4	3,275	1	1	No
Non-EUETS	Services	Hotels	5	2,102	2	2	No
Non-EUETS	Services	Hotels	6	829	4	4	No
Non-EUETS	Services	Offices	1	1,318	0	0	No

Non-EUETS	Services	Offices	2	1,089	0	0	No
Non-EUETS	Services	Offices	3	800	1	1	No
Non-EUETS	Services	Offices	4	540	1	1	No
Non-EUETS	Services	Offices	5	327	1	1	No
Non-EUETS	Services	Offices	6	139	3	3	No
Non-EUETS	Services	Public Buildings	1	14,285	0	0	No
Non-EUETS	Services	Public Buildings	2	8,604	0	1	No
Non-EUETS	Services	Public Buildings	3	5,948	1	1	No
Non-EUETS	Services	Public Buildings	4	3,900	1	1	No
Non-EUETS	Services	Public Buildings	5	2,442	1	2	No
Non-EUETS	Services	Public Buildings	6	888	4	6	No
Non-EUETS	Services	Retail	1	2,684	1	0	No
Non-EUETS	Services	Retail	2	2,254	2	0	No
Non-EUETS	Services	Retail	3	1,771	2	1	No
Non-EUETS	Services	Retail	4	1,313	3	1	No
Non-EUETS	Services	Retail	5	940	4	1	No
Non-EUETS	Services	Retail	6	349	10	3	No
Non-EUETS	Services	Warehouses	1	14,790	0	0	No
Non-EUETS	Services	Warehouses	2	10,620	0	0	No
Non-EUETS	Services	Warehouses	3	7,365	1	1	No
Non-EUETS	Services	Warehouses	4	4,765	1	1	No
Non-EUETS	Services	Warehouses	5	2,629	2	2	No
Non-EUETS	Services	Warehouses	6	919	5	5	No
Non-EUETS	Textiles	Carpets	1	0	-	-	No
Non-EUETS	Textiles	Carpets	2	0	-	-	No
Non-EUETS	Textiles	Carpets	3	0	-	-	No
Non-EUETS	Textiles	Carpets	4	0	-	-	No
Non-EUETS	Textiles	Carpets	5	0	-	-	No
Non-EUETS	Textiles	Carpets	6	0	-	-	No
Non-EUETS	Textiles	Dyes and Finishes	1	0	-	-	No
Non-EUETS	Textiles	Dyes and Finishes	2	0	-	-	No
Non-EUETS	Textiles	Dyes and Finishes	3	0	-	-	No
Non-EUETS	Textiles	Dyes and Finishes	4	0	-	-	No
Non-EUETS	Textiles	Dyes and Finishes	5	0	-	-	No
Non-EUETS	Textiles	Dyes and Finishes	6	0	-	-	No
Non-EUETS	Textiles	Spinning and Weaving	1	0	-	-	No
Non-EUETS	Textiles	Spinning and Weaving	2	0	-	-	No
Non-EUETS	Textiles	Spinning and Weaving	3	0	-	-	No
Non-EUETS	Textiles	Spinning and Weaving	4	0	-	-	No
Non-EUETS	Textiles	Spinning and Weaving	5	0	-	-	No
Non-EUETS	Textiles	Spinning and Weaving	6	1	11	19	Yes
Non-EUETS	Textiles	Woollens	1	0	-	-	No
Non-EUETS	Textiles	Woollens	2	0	-	-	No
Non-EUETS	Textiles	Woollens	3	0	-	-	No
Non-EUETS	Textiles	Woollens	4	0	-	-	No
Non-EUETS	Textiles	Woollens	5	0	-	-	No
Non-EUETS	Textiles	Woollens	6	0	-	-	No

Table A3 Assumed Site Operating Hours and Load Profiles

Sector	Sub-Sector	Tranche	Assumed Site Operating Hours	Heat load index winter day	Heat load index winter eve	Heat load index winter night	Heat load index summer day	Heat load index summer eve	Heat load index summer night	Elec load index winter day	Elec load index winter eve	Elec load index winter night	Elec load index summer day	Elec load index summer eve	Elec load index summer night
Chemicals	Dyes & pigments	1	8,094	100	90	85	80	75	70	100	95	90	95	90	85
Chemicals	Dyes & pigments	2	8,094	100	90	85	80	75	70	100	95	90	95	90	85
Chemicals	Dyes & pigments	3	8,094	100	90	85	80	75	70	100	95	90	95	90	85
Chemicals	Dyes & pigments	4	8,094	100	90	85	80	75	70	100	95	90	95	90	85
Chemicals	Dyes & pigments	5	8,094	100	90	85	80	75	70	100	95	90	95	90	85
Chemicals	Dyes & pigments	6	8,094	100	90	90	80	80	75	100	100	95	95	95	90
Chemicals	Inorganic Chemicals	1	8,094	100	90	85	80	75	70	100	90	85	90	85	80
Chemicals	Inorganic Chemicals	2	8,094	100	95	90	80	75	70	100	90	85	90	85	80
Chemicals	Inorganic Chemicals	3	8,094	100	95	90	85	80	75	100	90	90	95	85	85
Chemicals	Inorganic Chemicals	4	8,094	100	95	90	85	85	80	100	95	90	95	90	85
Chemicals	Inorganic Chemicals	5	8,094	100	95	90	90	85	80	100	95	90	95	90	85
Chemicals	Inorganic Chemicals	6	8,094	100	95	90	90	90	85	100	95	90	95	90	85
Chemicals	Other Chemicals	1	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	2	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	3	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	4	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	5	8,094	100	100	100	65	65	65	100	100	100	95	95	95
Chemicals	Other Chemicals	6	8,094	100	100	100	65	85	65	100	100	100	95	95	95
Chemicals	Organic chemicals	1	8,094	100	90	85	80	75	70	100	95	85	95	90	80
Chemicals	Organic chemicals	2	8,094	100	90	85	80	75	70	100	95	85	95	90	80
Chemicals	Organic chemicals	3	8,094	100	95	90	85	80	75	100	95	90	95	90	85
Chemicals	Organic chemicals	4	8,094	100	95	90	85	80	75	100	95	90	95	90	85
Chemicals	Organic chemicals	5	8,094	100	95	90	85	80	75	100	95	90	95	95	90
Chemicals	Organic chemicals	6	8,094	100	95	90	90	85	80	100	95	90	95	95	90
Chemicals	Paints	1	8,094	100	90	85	80	75	70	100	90	80	90	85	80
Chemicals	Paints	2	8,094	100	90	85	80	75	70	100	95	85	90	85	80
Chemicals	Paints	3	8,094	100	95	90	80	75	70	100	95	85	95	90	80
Chemicals	Paints	4	8,094	100	95	90	80	75	70	100	95	85	95	90	80
Chemicals	Paints	5	8,094	100	95	90	80	75	70	100	95	85	95	90	80
Chemicals	Paints	6	8,094	100	95	90	80	75	70	100	95	85	95	90	80
Chemicals	Pharmaceuticals	1	8,094	100	80	80	75	65	65	100	95	95	95	90	90
Chemicals	Pharmaceuticals	2	8,094	100	80	80	75	65	65	100	95	95	95	90	90
Chemicals	Pharmaceuticals	3	8,094	100	80	80	75	65	65	100	95	95	95	90	90
Chemicals	Pharmaceuticals	4	8,094	100	80	80	75	65	65	100	95	95	95	90	90
Chemicals	Pharmaceuticals	5	8,094	100	80	80	75	65	65	100	95	95	95	90	90
Chemicals	Pharmaceuticals	6	8,094	100	80	80	75	85	65	100	95	95	95	90	90
Chemicals	Resins	1	8,094	100	100	100	70	70	70	100	82	82	100	65	65
Chemicals	Resins	2	8,094	100	100	100	70	70	70	100	82	82	100	65	65
Chemicals	Resins	3	8,094	100	100	100	70	70	70	100	82	82	100	65	65
Chemicals	Resins	4	8,094	100	100	100	70	70	70	100	82	82	100	65	65
Chemicals	Resins	5	8,094	100	100	100	70	70	70	100	82	82	100	65	65
Chemicals	Resins	6	8,094	100	100	100	70	70	70	100	82	82	100	65	65
Chemicals	Rubber Polymer	1	8,094	100	100	100	70	70	70	100	85	85	100	65	65
Chemicals	Rubber Polymer	2	8,094	100	100	100	70	70	70	100	85	85	100	65	65
Chemicals	Rubber Polymer	3	8,094	100	100	100	70	70	70	100	85	85	100	65	65
Chemicals	Rubber Polymer	4	8,094	100	100	100	70	70	70	100	85	85	100	65	65
Chemicals	Rubber Polymer	5	8,094	100	100	100	70	70	70	100	85	85	100	65	65
Chemicals	Rubber Polymer	6	8,094	100	100	100	70	70	70	100	85	85	100	65	65
Chemicals	Soap	1	8,094	100	70	80	80	65	65	100	80	80	80	70	70
Chemicals	Soap	2	8,094	100	70	80	80	65	65	100	80	80	80	70	70
Chemicals	Soap	3	8,094	100	70	80	80	65	65	100	80	80	80	70	70
Chemicals	Soap	4	8,094	100	70	80	80	65	65	100	80	80	80	70	70
Chemicals	Soap	5	8,094	100	70	80	80	65	65	100	80	80	80	70	70
Chemicals	Soap	6	8,094	100	70	80	80	65	65	100	80	80	80	70	70
Chemicals	Synthetic Fibres	1	8,094	100	90	85	80	75	70	100	95	85	95	90	80
Chemicals	Synthetic Fibres	2	8,094	100	90	85	80	75	70	100	95	85	95	90	80
Chemicals	Synthetic Fibres	3	8,094	100	95	90	85	80	75	100	95	90	95	90	85
Chemicals	Synthetic Fibres	4	8,094	100	95	90	85	80	75	100	95	90	95	90	85
Chemicals	Synthetic Fibres	5	8,094	100	95	90	85	80	75	100	95	90	95	95	90
Chemicals	Synthetic Fibres	6	8,094	100	95	90	90	85	80	100	95	90	95	95	90
Engineering	Electrical Engineering	1	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Electrical Engineering	2	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Electrical Engineering	3	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Electrical Engineering	4	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Electrical Engineering	5	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Electrical Engineering	6	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Mechanical Engineering	1	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Mechanical Engineering	2	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Mechanical Engineering	3	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Mechanical Engineering	4	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Mechanical Engineering	5	8,094	100	50	50	20	15	15	100	50	50	95	45	45

Engineering	Mechanical Engineering	6	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Vehicle Engineering	1	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Vehicle Engineering	2	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Vehicle Engineering	3	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Vehicle Engineering	4	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Vehicle Engineering	5	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Engineering	Vehicle Engineering	6	8,094	100	50	50	20	15	15	100	50	50	95	45	45
Food & drink	Baking	1	8,094	100	100	100	50	50	50	100	100	100	95	95	95
Food & drink	Baking	2	8,094	100	100	100	50	50	50	100	100	100	95	95	95
Food & drink	Baking	3	8,094	100	100	100	50	50	50	100	100	100	95	95	95
Food & drink	Baking	4	8,094	100	100	100	50	50	50	100	100	100	95	95	95
Food & drink	Baking	5	8,094	100	100	100	50	50	50	100	100	100	95	95	95
Food & drink	Baking	6	8,094	100	100	100	50	50	50	100	100	100	95	95	95
Food & drink	Brewing	1	8,094	100	65	65	80	50	50	100	50	50	100	50	50
Food & drink	Brewing	2	8,094	100	65	65	80	50	50	100	50	50	100	50	50
Food & drink	Brewing	3	8,094	100	65	65	80	50	50	100	50	50	100	50	50
Food & drink	Brewing	4	8,094	100	65	65	80	50	50	100	50	50	100	50	50
Food & drink	Brewing	5	8,094	100	65	65	80	50	50	100	50	50	100	50	50
Food & drink	Brewing	6	8,094	100	65	65	80	50	50	100	50	50	100	50	50
Food & drink	Creameries	1	8,094	100	100	100	100	100	100	100	100	85	95	85	85
Food & drink	Creameries	2	8,094	100	100	100	100	100	100	100	100	85	95	85	85
Food & drink	Creameries	3	8,094	100	100	100	100	100	100	100	100	85	95	85	85
Food & drink	Creameries	4	8,094	100	100	100	100	100	100	100	100	85	95	85	85
Food & drink	Creameries	5	8,094	100	100	100	100	100	100	100	100	85	95	85	85
Food & drink	Creameries	6	8,094	100	100	100	100	100	100	100	100	85	95	85	85
Food & drink	Distilling	1	8,094	100	100	100	99	99	99	100	100	100	99	99	99
Food & drink	Distilling	2	8,094	100	100	100	99	99	99	100	100	100	99	99	99
Food & drink	Distilling	3	8,094	100	100	100	99	99	99	100	100	100	99	99	99
Food & drink	Distilling	4	8,094	100	100	100	99	99	99	100	100	100	99	99	99
Food & drink	Distilling	5	8,094	100	100	100	99	99	99	100	100	100	99	99	99
Food & drink	Distilling	6	8,094	100	100	100	99	99	99	100	100	100	99	99	99
Food & drink	Red Meat	1	8,094	100	100	100	87	87	87	95	95	95	100	100	100
Food & drink	Red Meat	2	8,094	100	100	100	87	87	87	95	95	95	100	100	100
Food & drink	Red Meat	3	8,094	100	100	100	87	87	87	95	95	95	100	100	100
Food & drink	Red Meat	4	8,094	100	100	100	87	87	87	95	95	95	100	100	100
Food & drink	Red Meat	5	8,094	100	100	100	87	87	87	95	95	95	100	100	100
Food & drink	Red Meat	6	8,094	100	100	100	87	87	87	95	95	95	100	100	100
Food & drink	Rest of Food	1	8,094	100	100	100	80	80	80	100	100	100	90	90	90
Food & drink	Rest of Food	2	8,094	100	100	100	80	80	80	100	100	100	90	90	90
Food & drink	Rest of Food	3	8,094	100	100	100	80	80	80	100	100	100	90	90	90
Food & drink	Rest of Food	4	8,094	100	100	100	80	80	80	100	100	100	90	90	90
Food & drink	Rest of Food	5	8,094	100	100	100	80	80	80	100	100	100	90	90	90
Food & drink	Rest of Food	6	8,094	100	100	100	80	80	80	100	100	100	90	90	90
Other Industry	Plastics	1	8,094	100	90	90	35	30	30	100	50	70	100	50	70
Other Industry	Plastics	2	8,094	100	90	90	35	30	30	100	50	70	100	50	70
Other Industry	Plastics	3	8,094	100	90	90	35	30	30	100	50	70	100	50	70
Other Industry	Plastics	4	8,094	100	90	90	35	30	30	100	50	70	100	50	70
Other Industry	Plastics	5	8,094	100	90	90	35	30	30	100	50	70	100	50	70
Other Industry	Plastics	6	8,094	100	90	90	35	30	30	100	50	70	100	50	70
Other Industry	Rubber	1	8,094	100	90	90	75	65	65	100	50	70	100	50	70
Other Industry	Rubber	2	8,094	100	90	90	75	65	65	100	50	70	100	50	70
Other Industry	Rubber	3	8,094	100	90	90	75	65	65	100	50	70	100	50	70
Other Industry	Rubber	4	8,094	100	90	90	75	65	65	100	50	70	100	50	70
Other Industry	Rubber	5	8,094	100	90	90	75	65	65	100	50	70	100	50	70
Other Industry	Rubber	6	8,094	100	90	90	75	65	65	100	50	70	100	50	70
Other Industry	Wood	1	8,094	100	20	20	20	5	5	100	15	15	95	15	15
Other Industry	Wood	2	8,094	100	20	20	20	5	5	100	15	15	95	15	15
Other Industry	Wood	3	8,094	100	20	20	20	5	5	100	15	15	95	15	15
Other Industry	Wood	4	8,094	100	20	20	20	5	5	100	15	15	95	15	15
Other Industry	Wood	5	8,094	100	20	20	20	5	5	100	15	15	95	15	15
Other Industry	Wood	6	8,094	100	20	20	20	5	5	100	15	15	95	15	15
Paper	Papermaking	1	8,094	100	90	90	80	80	70	100	100	90	95	85	85
Paper	Papermaking	2	8,094	100	90	90	80	80	70	100	100	90	95	85	85
Paper	Papermaking	3	8,094	100	90	90	80	80	70	100	100	90	95	85	85
Paper	Papermaking	4	8,094	100	90	90	80	80	70	100	100	90	95	85	85
Paper	Papermaking	5	8,094	100	90	90	80	80	70	100	100	90	95	85	85
Paper	Papermaking	6	8,094	100	90	90	80	80	70	100	100	90	95	85	85
Paper	Printing & Publishing	1	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Paper	Printing & Publishing	2	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Paper	Printing & Publishing	3	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Paper	Printing & Publishing	4	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Paper	Printing & Publishing	5	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Paper	Printing & Publishing	6	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Education	1	8,094	100	105	28	54	60	15	100	114	55	91	100	47
Services	Education	2	8,094	100	105	28	54	60	15	100	114	55	91	100	47
Services	Education	3	8,094	100	60	50	54	15	15	100	15	15	91	15	15
Services	Education	4	8,094	100	100	50	54	54	15	100	100	15	91	91	15
Services	Education	5	8,094	100	60	50	54	15	15	100	15	15	91	15	15
Services	Education	6	8,094	100	60	50	54	15	15	100	15	15	91	15	15
Services	Health	1	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	2	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	3	8,094	100	100	100	40	40	40	100	100	55	90	90	45

Services	Health	4	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	5	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Health	6	8,094	100	100	100	40	40	40	100	100	55	90	90	45
Services	Hotels	1	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	2	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	3	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	4	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	5	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Hotels	6	8,094	100	15	15	15	5	5	100	15	15	95	15	15
Services	Offices	1	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	2	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	3	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	4	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	5	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Offices	6	8,094	100	60	20	30	20	10	100	60	20	100	60	20
Services	Public Buildings	1	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Public Buildings	2	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Public Buildings	3	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Public Buildings	4	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Public Buildings	5	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Public Buildings	6	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	1	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	2	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	3	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	4	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	5	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Retail	6	8,094	100	40	20	30	20	10	100	40	20	100	40	20
Services	Warehouses	1	8,094	100	80	80	30	30	30	100	60	20	100	60	20
Services	Warehouses	2	8,094	100	80	80	30	30	30	100	60	20	100	60	20
Services	Warehouses	3	8,094	100	80	80	30	30	30	100	60	20	100	60	20
Services	Warehouses	4	8,094	100	80	80	30	30	30	100	60	20	100	60	20
Services	Warehouses	5	8,094	100	80	80	30	30	30	100	60	20	100	60	20
Services	Warehouses	6	8,094	100	80	80	30	30	30	100	60	20	100	60	20
Textiles	Carpets	1	8,094	100	60	60	60	15	15	100	100	100	95	95	95
Textiles	Carpets	2	8,094	100	60	60	60	15	15	100	100	100	95	95	95
Textiles	Carpets	3	8,094	100	60	60	60	15	15	100	100	100	95	95	95
Textiles	Carpets	4	8,094	100	60	60	60	15	15	100	100	100	95	95	95
Textiles	Carpets	5	8,094	100	60	60	60	15	15	100	100	100	95	95	95
Textiles	Carpets	6	8,094	100	60	60	60	15	15	100	100	100	95	95	95
Textiles	Dyes & Finishes	1	8,094	100	100	110	85	85	90	100	100	103	92	92	97
Textiles	Dyes & Finishes	2	8,094	100	100	110	85	85	90	100	100	103	92	92	97
Textiles	Dyes & Finishes	3	8,094	100	100	110	85	85	90	100	100	103	92	92	97
Textiles	Dyes & Finishes	4	8,094	100	100	110	85	85	90	100	100	103	92	92	97
Textiles	Dyes & Finishes	5	8,094	100	100	110	85	85	90	100	100	103	92	92	97
Textiles	Dyes & Finishes	6	8,094	100	100	110	85	85	90	100	100	103	92	92	97

Annex B – Review of Assumptions

1. This section summarises the revisions to modelling assumptions relative to those used for July 2013 UEP CHP potential modelling[42].

Energy Load Profiles and CHP Operation

2. The original BU model assumed energy loads were spread over the whole duration of industrial operation which was assumed to be 8,094 hours/Yr (8,766 hours minus a 2 week shutdown). The same hours were also assumed for service sectors with very low indices for periods such as summer night time. It was also assumed CHP operated for all of these hours.
3. The assumed annual hours of CHP operation were later reduced in line with more typical design load factors for new CHP (6,500 for industry and 5,600 for service sectors), but it was assumed that all of the energy demand would coincide with these reduced hours. This was the assumption in the July 2013 UEP modelling as shown in tables B1 and B2
4. For this study these assumptions were revised and the loads were spread over the original 8,094 hours/Yr whilst assuming the same annual CHP operating hours as in the July 2013 UEP modelling. In addition, the model was refined to allow different operating hour assumptions for each of the 6 time periods so it was assumed that CHP operation would be concentrated in the periods of highest energy demand. The revised assumptions are shown in Tables B3 and B4.

[42] See Updated energy and emissions projections: 2013 at: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2013

Table B1 Hours of Energy Demand assumed in July 2013 UEP modelling

Sector	Energy Demand hours winter day	Energy Demand hours winter evening	Energy Demand hours winter night	Energy Demand hours summer day	Energy Demand hours summer evening	Energy Demand hours summer night	**Total Energy Demand Hours/Yr**
Chemicals	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Engineering	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Food & drink	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Other Industry	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Paper	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Services	933	933	933	933	933	933	**5,600**
Textiles	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**

Table B2Hours of CHP Operation assumed in July 2013 UEP modelling

Sector	CHP Operating hours winter day	CHP Operating hours winter evening	CHP Operating hours winter night	CHP Operating hours summer day	CHP Operating hours summer evening	CHP Operating hours summer night	**Total CHP Operating Hours/Yr**
Chemicals	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Engineering	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Food & drink	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Other Industry	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Paper	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**
Services	933	933	933	933	933	933	**5,600**
Textiles	1,083	1,083	1,083	1,083	1,083	1,083	**6,500**

Table B3 Hours of Energy Demand assumed in This Study

Sector	Energy Demand hours winter day	Energy Demand hours winter evening	Energy Demand hours winter night	Energy Demand hours summer day	Energy Demand hours summer evening	Energy Demand hours summer night	**Total Energy Demand Hours/Yr**
Chemicals	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**
Engineering	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**
Food & drink	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**
Other Industry	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**
Paper	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**
Services	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**
Textiles	1,349	1,349	1,349	1,349	1,349	1,349	**8,094**

Table B4 Hours of CHP Operation assumed in This Study

Sector	CHP Operating hours winter day	CHP Operating hours winter evening	CHP Operating hours winter night	CHP Operating hours summer day	CHP Operating hours summer evening	CHP Operating hours summer night	**Total CHP Operating Hours/Yr**
Chemicals	1,349	1,349	1,349	1,349	1,104	0	**6,500**
Engineering	1,349	1,349	1,349	1,349	1,104	0	**6,500**
Food & drink	1,349	1,349	1,349	1,349	1,104	0	**6,500**
Other Industry	1,349	1,349	1,349	1,349	1,104	0	**6,500**
Paper	1,349	1,349	1,349	1,349	1,104	0	**6,500**
Services	1,349	1,349	1,349	1,349	204	0	**5,600**
Textiles	1,349	1,349	1,349	1,349	1,104	0	**6,500**

CHP Sizing Strategy

Table B5 Sizing Strategy for each segment

	July 2013 UEP	This Study
Choice between Heat/Electricity Match Sizing	Whichever gives larger capacity	Heat Match if economic (IRR>Hurdle Rate) otherwise Elec/Heat Match whichever achieves a higher IRR
Energy Demand Period which CHP is sized to match	Summer Daytime	Summer Daytime

Techno-economic CHP assumptions for Gas-fired CHP

5. The following changes are as described below and can be seen by comparing Tables B6 and B7.
6. Additional reciprocating engine size categories were added to allow for more refined size specific assumptions of CHP efficiency, cost and investment timescale.
7. The electrical efficiency and heat to power ratios were reviewed for gas engines based on the CHPQA unit list for <200KWe engines (which is derived from performance data submitted by engine manufacturers and industry advice for larger engines.
8. Capital costs were reviewed for open cycle gas turbines and a single formula derived to remove discontinuity between the different size ranges.
9. Capital and maintenance costs were reviewed for gas engines using tender information received for a recent project. The former were reasonably in line, but the latter were revised accordingly.
10. An HPR of 0.7 was originally assumed for CCGT based on the minimum required by an average sized CCGT with the assumed condensing efficiency and Z ratio to achieve a QI of 100. This was increased to 0.76 which is required by the largest category of CCGT to ensure all modelled CCGT CHP capacity is good quality.
11. The investment timescale was reviewed and increased from 10 to 15 years for >25MWe schemes based on a survey of 2-25MW operators by R-AEA.
12. In the July 2013 modelling it was assumed that gas engine CHP units would be designed with a supplementary boiler compartment adjacent to the exhaust recovery boiler and that gas turbines would have supplementary firing in the exhaust stream. These are termed ‘after-firing’ in both cases. This is slightly more energy efficient than generating top up heat in external boilers as it utilises some of the residual heat in the exhaust, upgrading it to a useful temperature. As a package, the prime mover and supplementary firing produces higher heat to power output ratios, but lower electrical efficiencies than the prime mover alone. For July 2013 UEP modelling these were assumed to be as shown in Table B8. This was reviewed and following discussion with CHPA members no after-firing was assumed in this study as it is never used in gas engine CHP and rarely in gas turbine CHP.

Table B6 Techno-economic Gas-CHP characteristics assumed in July 2013 UEP modelling (Costs are 2013 real)

CHP Type	Fully Condensing electrical efficiency - GCV (%)	Z Ratio (heat/ power drop	Design H:P ratio	Rated electrical efficiency in CHP Mode (%)	Rated Overall CHP efficiency (%)	Capex - A multiplier (£/kWhe)*	Capex - n exponent*	Maintenance cost factor (£/MWhe)	Technology Investment Period (Years)	Engine/ Turbine Replacement Project Year	Engine/ Turbine Replacement Cost % of CHP Capex
Small Gas Engine <1 MWe	34.0%	-	1.2	34.0%	74.8%	961.29	-0.15	12.82	10	10	0.0%***
Large Gas Engine>=1 to <3.7 MWe	34.0%	-	1.2	34.0%	74.8%	961.29	-0.15	10.68	10	10	0.0%***
Small OCGT>=3.7 to <7 MWe	30.0%	-	1.6	30.0%	78.0%	1634.20	-0.22	9.61	10	10	0.0%***
Large OCGT>=7 to <40 MWe	35.0%	-	1.2	35.0%	77.0%	3204.32	-0.43	8.54	10	10	0.0%***
Small CCGT>=40 to <200 MWe	45.1%	4.5	0.7	39.0%	66.3%	1,345.81**	-0.10	6.41**	10	10	0.0%***
Large CCGT>=200 MWe	45.1%	4.5	0.7	39.0%	66.3%	790.40**	0.00	6.41**	10	10	0.0%***

Table B7 Techno-economic CHP assumptions for Gas-Fired CHP assumed in this Study (Costs are 2013 real)

CHP Type	Fully Condensing electrical efficiency - GCV (%)	Z Ratio (heat/ power drop	Design H:P ratio	Rated electrical efficiency in CHP Mode (%)	Rated overall CHP efficiency (%)	Capex - A multiplier (£/kWhe)*	Capex - n exponent*	Maintenance cost factor (£/MWhe)	Technology Investment Period (Years)	Engine/ Turbine Replacement Project Year	Engine/ Turbine Replacement Cost % of CHP Capex
Small Gas Engine <0.1 MWe	31.7%	-	1.5	31.7%	79.4%	961.29	-0.15	12.86	10	10	0.0%***
Small Gas Engine>=0.1 to <0.2 MWe	33.8%	-	1.3	33.8%	78.0%	961.29	-0.15	12.86	10	10	0.0%***
Small Gas Engine>=0.2 to <1 MWe	38.0%	-	1.2	38.0%	83.6%	961.29	-0.15	12.86	10	10	0.0%***
Large Gas Engine>=1 to <3.7 MWe	38.0%	-	1.2	38.0%	83.6%	961.29	-0.15	10.20	10	10	0.0%***
Small OCGT>=3.7 to <7 MWe	30.0%	-	1.6	30.0%	78.0%	1,720.10	-0.23	9.61	10	10	0.0%***
Large OCGT>=7 to <25 MWe	35.0%	-	1.2	35.0%	77.0%	1,720.10	-0.23	8.54	10	10	0.0%***
Large OCGT>=25 to <40 MWe	35.0%	-	1.2	35.0%	77.0%	1,720.10	-0.23	8.54	15	10	50.0%
Small CCGT>=40 to <200 MWe	45.1%	4.5	0.76	38.6%	67.9%	1,345.81**	-0.10	6.41**	15	10	33.3%
Large CCGT>=200 MWe	45.1%	4.5	0.76	38.6%	67.9%	790.40**	0.00	6.41**	15	10	33.3%

* Capex Formula £/kWe = A x MWe^n

** Capex and Opex formulas for CCGT are in terms of electricity which would be generated in fully condensing mode. The costs in terms of the actual electrical generation in CHP mode are higher by a factor equal to the ratio of electrical efficiency in fully condensing mode / electrical efficiency in CHP mode.

*** The decision whether to replace the engine/GT was assumed to occur at the end of the investment period.

Table B8 After-Firing characteristics assumed in July 2013 UEP modelling

CHP Type	After fired H:P ratio	After fired electrical efficiency (%)	After fired overall efficiency (%)
Small Gas Engine <1 MWe	2.5	22.0%	80.0%
Large Gas Engine>=1 to <3.7 MWe	2.5	22.0%	80.0%
Small OCGT>=3.7 to <7 MWe	2.2	25.0%	80.0%
Large OCGT>=7 to <40 MWe	2.0	25.0%	72.0%

(No after-firing assumed in this study)

DECC Energy Price Projections, £/MWh (2013 Real)

13. DECC's energy price projections are as shown in tables B9 and B10 below. Uniform pricing across different sizes of CHP was used for this study based on a review of non-domestic energy price survey data held by DECC. Pricing in Table B10 is based on energy price projections published in UEP 2013 but amended to exclude policy costs (e.g. CCL and CRC) which are modelled separately.

Table B9 Basic energy prices assumed in July 2013 UEP CHP modelling (Costs are 2013 real)

	Natural Gas	Electricity Imported	Electricity Exported
2020 Small Schemes (<2MWe)	37.51	125.29	55.11**
2020 Med Schemes (2-25MWe)	29.93	101.06	55.11**
2020 Large Schemes (>25MWe)	29.93	101.06	68.89**
2025 Small Schemes (<2MWe)	38.13	138.60	62.78*
2025 Med Schemes (2-25MWe)	30.42	111.79	62.78*
2025 Large Schemes (>25MWe)	30.42	111.79	78.48*

Table B10 Basic energy prices assumed in This Study (Costs are 2013 real)

	Natural Gas	Electricity Imported	Electricity Exported
2020 Small Schemes (<2MWe)	30.77	103.50	50.79**
2020 Med Schemes (2-25MWe)	30.77	103.50	50.79**
2020 Large Schemes (>25MWe)	30.77	103.50	63.49*
2025 Small Schemes (<2MWe)	31.14	112.81	57.37**
2025 Med Schemes (2-25MWe)	31.14	112.81	57.37**
2025 Large Schemes (>25MWe)	31.14	112.81	71.71*

*Wholesale Value

**80% of wholesale value reflecting the reduced value which would typically be achieved through a Power Purchase Agreement (PPA) based on Ricardo-AEA's market knowledge and direct discussion with industry.

Energy Policy Additions/Support

14. Changes in policy cost assumptions for this modelling are shown in Tables B11and B12.

15. Carbon price forecasts were revised by DECC, reflecting the 2014 Budget CPS freeze, new CCL rates applied and Capacity Market payments forecast by DECC and incorporated into the modelling.

Table B11 Energy policy costs, relief and carbon intensities relevant to CHP assumed in July 2013 UEP Modelling (2013 Real)

Year	Market CO2 Price Forecast (£/tCO2)	Carbon Floor Price Forecast (£/tCO2)	CRC CO2 Price Forecast (£/tCO2)	CCL rate gas (£/MWh)	CCL rate electricity (£/MWh)	Natural Gas Carbon factor for EUETS and CRC (tCO2/MWh)	CCA rebate level - gas (%)	CCA rebate level - electricity (%)	Capacity Market Payment (£/kWe)	EUETS Heat Allowance "At Risk" Carbon Leakage Factor	EUETS Heat Allowance "Not At Risk" Carbon Leakage Factor	EUETS Heat Allowance Linear Reduction Factor
2020	4.87	32.67	16.34	1.81	5.20	0.1836	65%	90%	0	100%	30%	88%
2025	5.52	54.45	16.34	1.81	5.20	0.1836	65%	90%	0	100%	9%	79%

Table B12 Energy policy costs, relief and carbon intensities relevant to CHP assumed in This Study (2013 Real)

Year	Market CO2 Price Forecast (£/tCO2)	Carbon Floor Price Forecast (£/tCO2)	CRC CO2 Price Forecast (£/tCO2)	CCL rate gas (£/MWh)	CCL rate electricity (£/MWh)	Natural Gas Carbon factor for EUETS and CRC (tCO2/MWh)	CCA rebate level - gas (%)	CCA rebate level - electricity (%)	Capacity Market Payment (£/kWe)	EUETS Heat Allowance "At Risk" Carbon Leakage Factor*	EUETS Heat Allowance "Not At Risk" Carbon Leakage Factor*	EUETS Heat Allowance Linear Reduction Factor
2020	4.87	20.60	16.34	1.88	5.41	0.1836	65%	90%	21.24	100%	30%	88%
2025	40.55	54.49	16.34	1.88	5.41	0.1836	65%	90%	30.83	100%	9%	79%

Hurdle Rates

16. In the July 2013 modelling, the technical potential which fails to achieve a low hurdle rate of 3.5% is removed in the BU modelling and is not carried forward into the MC modelling.

17. In this study the commercial hurdle rates were used to produce supply curves and to determine whether the CHP is sized based on heat or electrical load, but the full (post-sizing) technical potential is carried forward into the MC modelling with all of the economic screening done in the latter model.

18. This is shown in Table B13 below

Table B13 Hurdle rates assumed in July 2013 UEP Modelling and in this Study

	July 2013 UEP Modelling			This Study		
Sector	Hurdle rate in BU model (%)	Hurdle rate in MC model (%)	Purpose of Hurdle Rate in Bottom Up Model	Hurdle rate in BU model (%)	Hurdle rate in MC model (%)	Purpose of Hurdle Rate in Bottom Up Model
Chemicals	3.5%	18%	To remove very uneconomic schemes prior to MC modelling	18%	18%	To develop supply curves and choose between elec/heat match sizing
Engineering	3.5%	20%	as above	20%	20%	as above
Food & drink	3.5%	25%	as above	25%	25%	as above
Other Industry	3.5%	20%	as above	20%	20%	as above
Paper	3.5%	25%	as above	25%	25%	as above
Textiles	3.5%	25%	as above	25%	25%	as above
Services	3.5%	20%	as above	20%	20%	as above

Other Parameters

19. The following changes are as described below and can be seen by comparing Tables B14 and B15.

20. Based on industry experience, CHP schemes above 10MWe would generally be developed by a third party and would need to sell heat to sites cheaper than they could generate it themselves in order to obtain a heat supply contract. In the July 2013 modelling, the model was restricted to being able to differentiate between CHP in 3 size ranges: - up to 2MWe, between 2 and 25MWe, and greater than 25MWe. So it was conservatively assumed that CHP with a capacity above 2MWe would be developed by a third party who would sell heat to the site at a price 20% less than it would cost customers to generate the heat using conventional on-site gas boilers. Thus the cost-effectiveness of schemes between 2 and 10MWe was underestimated. The model was subsequently redeveloped to allow the minimum size threshold to be amended so this was increased to 10MWe.

21. For EUETS and CPS, a reduction on the proportion of carbon emissions is given based on the ratio of avoided conventional boiler fuel to total CHP fuel input. This ratio, and thus the policy reduction, depends on the electrical efficiency and heat to power ratio which is specific to the CHP technology/size category.

22. In the July 2013 modelling, the proportion of fuel deemed to be ‘fuel for heat’ (i.e. the ratio of conventional boiler fuel displaced to total CHP fuel input) was calculated based on estimated average technology efficiencies across the 3 broad CHP size ranges above, which was necessary due to the way the model was structured. The <2MWe CHP category consists entirely of gas engines whose assumed efficiencies were uniform, but this is no longer the case as efficiencies for smaller engine categories have been revised. The 2-25MWe category was a mix of gas engines and small and large open cycle gas turbines. The efficiencies of gas engines and large OCGTs are similar and small gas turbines are suitable for a relatively small range of energy demands so the average efficiencies were assumed to be the same as for gas engines. The >25MWe category were a mix of Large OCGT and CCGT with the latter assumed to dominate. The actual mix of technologies present in each of the 3 size range aggregate efficiencies depends on the outcome of the modelling so estimating these inputs accurately would be an iterative process.

23. In this study the model was refined to allow the proportion of fuel deemed to be ‘fuel for heat’ to be calculated properly at segment level removing the need to estimate the mix and associated inaccuracy.

24. In the 2014 budget, the rules for CPS changed to exempt fuel used for generation of good quality CHP electricity consumed on-site. As a result, only the fraction of electricity exported is liable for CPS out of ‘fuel for power’.

Table B14 Other parameters assumed in July 2013 UEP Modelling

Size Range	CHP Ownership	Conventional gas boiler efficiency (%)	Discount on Heat sold to site by 3rd party developer compared to cost of generating using conventional on-site boilers	Electrical efficiency assumed to calculate 'Fuel for Heat' Allowance for ETS and CPS (%)	Heat to Power Ratio assumed to calculate 'Fuel for Heat' Allowance for ETS and CPS (%)	CPS Application
0-2MWe	Owner Operator	81.0%	0%	34.0%	1.2	None
2-25MWe	3rd Party	81.0%	20%	34.0%	1.2	Applies to TFI x Fuel for Power
>25MWe	3rd Party	81.0%	20%	39.0%	0.7	Applies to TFI x Fuel for Power

Table B15 other parameters assumed in This Study

Size Range	CHP developed by 3rd party	Conventional gas boiler efficiency (%)	Discount on Heat sold to site by 3rd party developer compared to cost of generating using conventional on-site boilers	Electrical efficiency used to calculate Fuel for Heat Allowance for ETS and CPS (%)	Heat to Power Ratio used to calculate Fuel for Heat Allowance for ETS and CPS (%)	CPS Application
0-10MWe	Owner Operator	81.0%	0%	As per technology selected in each segment	As calculated for each segment	None
10-25MWe	3rd Party	81.0%	20%	As per technology selected in each segment	As calculated for each segment	Applies to TFI x Fuel for Power x Export/TPO
>25MWe	3rd Party	81.0%	20%	As per technology selected in each segment	As calculated for each segment	Applies to TFI x Fuel for Power x Export/TPO

Annex C – Modelling of De-NOx capex and opex costs for reciprocating engines

Modelling of De-NOx capex for reciprocating engines

1. As a sensitivity case in the social NPV modelling conducted by LCP [] the cost of requiring De-NOx equipment on reciprocating engines to prevent adverse local air quality impacts was considered. Relative capital and operating costs of this equipment were estimated as detailed below.

2. As bespoke policy would start in 2018 and run until 2025, it was assumed that CHP suppliers would make CHP units with the necessary De-NOx equipment available by 2018, increasing prices to pay for the cost of additional unit specific parts and also to recover the relatively high research and development costs spread across multiple engines and over a period of 5 years i.e. before the policy ends.

3. The procedure for estimating the capital cost was as follows:-

   i) Ricardo Shoreham Technical Centre provided NOx abatement equipment capex of €600 fixed + €400 variable (as a function of swept volume) costs for an example 3 litre engine. Fixed and per litre of swept volume costs were calculated as follows using an assumed exchange rate of £0.815274/€

Table C1

	per engine	per litre (Swept volume)
Fixed Costs (Urea Injection, 2 x 2 NOx sensors, 2 temp sensors)	£489.16	
Variable Costs* (6l of SCR catalyst + 1.5l Ammonia slip catalyst and canning)		£108.70

*Does not include consumables such as ammonia which would need to be included in opex

   ii) Ricardo Shoreham Technical Centre provided an indicative development cost of €500k per engine model. It was estimated that there are 117 different models of engine currently on the market based on the CHPQA Unit List, CHPQA certifications in 2013 and 2014 and from sales data from the last few years. It was assumed this number will stay constant and thus the total R&D capex for fitting NOx equipment to all engines will be 117 x €500K x £0.815274/€

Table C2

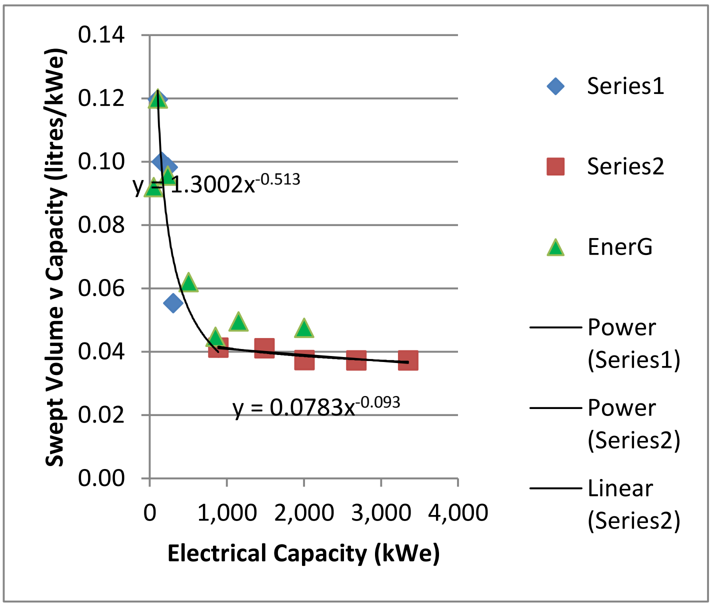
Development Cost per engine size	£407,637
Number of Different Engine Sizes currently operating in UK	117
Total Development Cost	£47,693,529

iii) Formulas for swept volume v kWe capacity were derived by DECC for <1MWe and >1MWe engines and verified by R-AEA using data supplied by a CHP manufacturer.

Table C3

	Capacity (kWe)	Swept Volume (litres)	Swept Volume v Capacity (litres/kWe)
Schmitt FMB-120-GSK:	100	12.0	0.12
Schmitt FMB-190-GSK:	151	15.1	0.10
Schmitt FMB-275-GSK:	230	22.6	0.10
Jenbacher type 2 (208)	300	16.6	0.06
Jenbacher type 4 (412)	889	36.7	0.04
Jenbacher type 4 (420)	1487	61.1	0.04
Jenbacher type 6 (612)	2004	74.9	0.04
Jenbacher type 6 (616)	2679	99.8	0.04
Jenbacher type 6 (620)	3352	124.8	0.04
ENER-G 50	50	4.6	0.09
ENER-G 100	100	12.0	0.12
ENER-G 230	230	22.0	0.10
ENER-G 500	500	31.0	0.06
ENER-G 850	850	38.0	0.04
ENER-G 1150	1150	57.0	0.05
ENER-G 2000C	2000	95.0	0.05

Figure C3



<=1MWe: Litres/kWe = 1.3002 x kWe ^ -0.513

>1MWe: Litres/kWe = 0.0783 x kWe ^ -0.093

iv) The above formulas were used to estimate the swept volumes for each modelling segment for CHP engines installed 2012, for the 2020 baseline projection and for the 2020 and 2025 projections with the PES incentive (the policy giving the lowest projection). Interpolation between 2012 historic and 2020 baseline projections was used to estimate the baseline electrical capacity and swept volume of CHP engines in 2017.

The electrical capacity and swept volume for CHP engines in 2022 was estimated by interpolating between 2020 and 2025 projections under the PES incentive scenario. Electrical capacities can't be readily compared at individual model segment level as the estimated breakdown of 2012 capacity into modelled segments is only approximate, and 2020 and 2025 segments have different probabilities and some different sizing strategies. Therefore the 2017 and 2022 electrical capacity and swept volume interpolations were based on 2012, 2020 and 2025 capacities aggregated at 3 high level segments (<1MWe, >1MWe for modelled sectors and DH). The electrical capacity and swept volume of engine sales between 2017 and 2022 was calculated for these 3 high level segments, based on the increase from 2017 to 2022 and also the assumed replacement of engines existing in 2017 (assuming a 5%/yr. stock replacement rate).

Similarly, the above formulae were used to calculate the swept volumes of engines sold between 2017 and 2022 based on individual engine capacities in each modelling segment for 2012, 2020 and 2025 aggregated to the high levels and interpolated for 2017 and 2022 and the 5% replacement of 2017 stock added as summarised in table C4 below.

Table C4

	no of engines	kWe	swept volume litres
2017-22 Sales Small (<=1MWe) Engine Capacity Projection Modelled Sectors	3,033	349,347	15,761
2017-22 Sales Large (>1MWe) Engine Capacity Projection Modelled Sectors	121	246,114	9,371
2017-22 Sales Domestic DH Engine Capacity	481	1,339,871	47,692
TOTAL	**3,634**	**1,935,332**	**72,825**

v) The total R&D cost was divided by the total number of engines sold between 2017 and 2022 to derive variable development cost per engine and, incorporating the other elements from Table C1, the total NOx capex cost formula, fixed £489.16 /engine + Variable £544.98/litre, was derived and applied to calculate the NOx abatement capex for engines (a fixed element and a variable element proportional to swept volume.

Table C5

	per engine	per litre
Fixed Costs (Urea Injection, 2 x 2 NOx sensors, 2 temp sensors)	£489.16	
Fixed Costs (Development)	£13,122.93	
Variable Costs (SCR catalyst + ammonia slip catalyst and canning)		£108.70
Total Fixed Costs	**£13,612.10**	
Total Variable Costs		**£108.70**

vi) The aggregate capital costs for engines sold between 2017 and 2022 based on current prices and the additional costs for De-NOx equipment were calculated for each of the <1MWe and >1MWe modelled sector and DH categories. Doing so based on the average capacities of engines sold in each of these three categories as shown in Tables C4 and C5 above would have been unnecessarily crude. Therefore, in a process similar to step 4, for each model segment, the notional basic engine and NOx equipment capital cost which would be incurred for replacing existing engine capacity in 2012 or projected capacity in 2020 or 2025 with engines with De-NOx equipment was calculated. This was aggregated to <1MWe and >1MWe modelled sectors and DH categories, interpolated to estimate for 2017 and 2022 and the total sales cost between 2017 and 2022 estimated based on the incremental replacement cost for De-NOx equipment on additional engines and on the 5% per year replacement of 2017 engine stock.

This De-NOx cost was then divided by the basic engine capex cost to establish the % NOx abatement equipment would add for each of the 3 main CHP categories as summarised in Table C6 below.

Table C6

	Purchased Engine Capacity	Purchased Engine Capacity	Purchased Capex Excl NOx Abatement	Purchased NOx Abatement Capex	Purchased NOx Abatement Capex
	MWe	Litres	£K	£K	% addition
2017-22 Sales Small (<=1MWe) Engine Capacity Projection Modelled Sectors	349	15,761	£429,786	£42,993	10.00%
2017-22 Sales Large (>1MWe) Engine Capacity Projection Modelled Sectors	246	9,371	£211,127	£2,666	1.26%
2017-22 Sales Domestic DH Engine Capacity	1,340	47,692	£1,051,101	£11,592	1.10%
TOTAL	**1,935**	**72,825**	**£1,692,014**	**£57,250**	**3.38%**

4. On this basis, NOx abatement equipment would add about 3.4% overall to the capex of engines but a smaller % for large engines and a much higher % for small engines.

Table C7 and figures C8 and C9 below show the range of cost additions which would apply to different engine sizes.

Table C7 NOx Capex % v CHP Size

Engine Capacity	Engine Capacity	Capex Excl NOx Abatement	NOx Abatement Capex	NOx Abatement Capex
MWe	Litres	£/kWe	£/kWe	% addition
0.050	8.7	£1,507	£291	19.33%
0.100	12.2	£1,358	£149	11.01%
0.150	14.9	£1,278	£102	7.95%
0.200	17.2	£1,224	£77	6.32%
0.500	26.8	£1,067	£33	3.10%
1.000	41	£961	£18	1.88%
1.500	59	£905	£13	1.48%
2.000	77	£866	£11	1.27%
2.500	95	£838	£10	1.14%
3.000	112	£815	£9	1.05%
3.500	128	£797	£8	0.99%
3.700	135	£790	£8	0.97%

Figure C8 De-NOx Capex v CHP Size

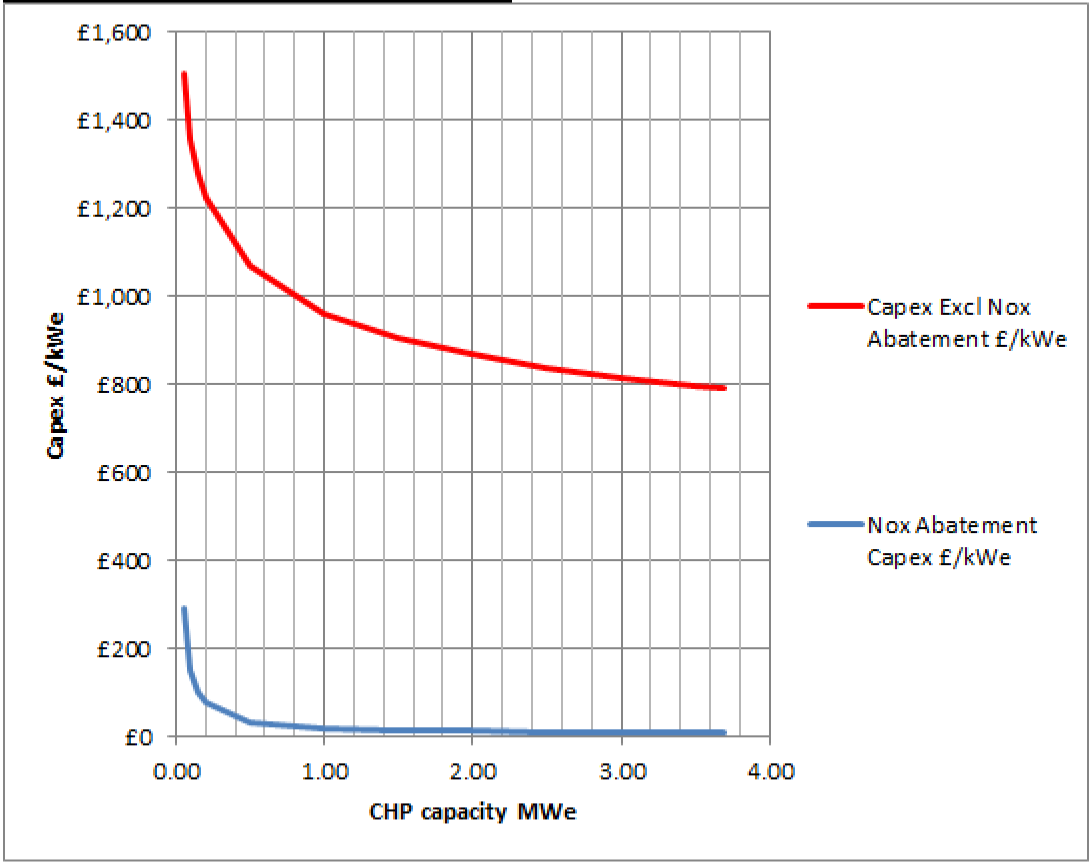
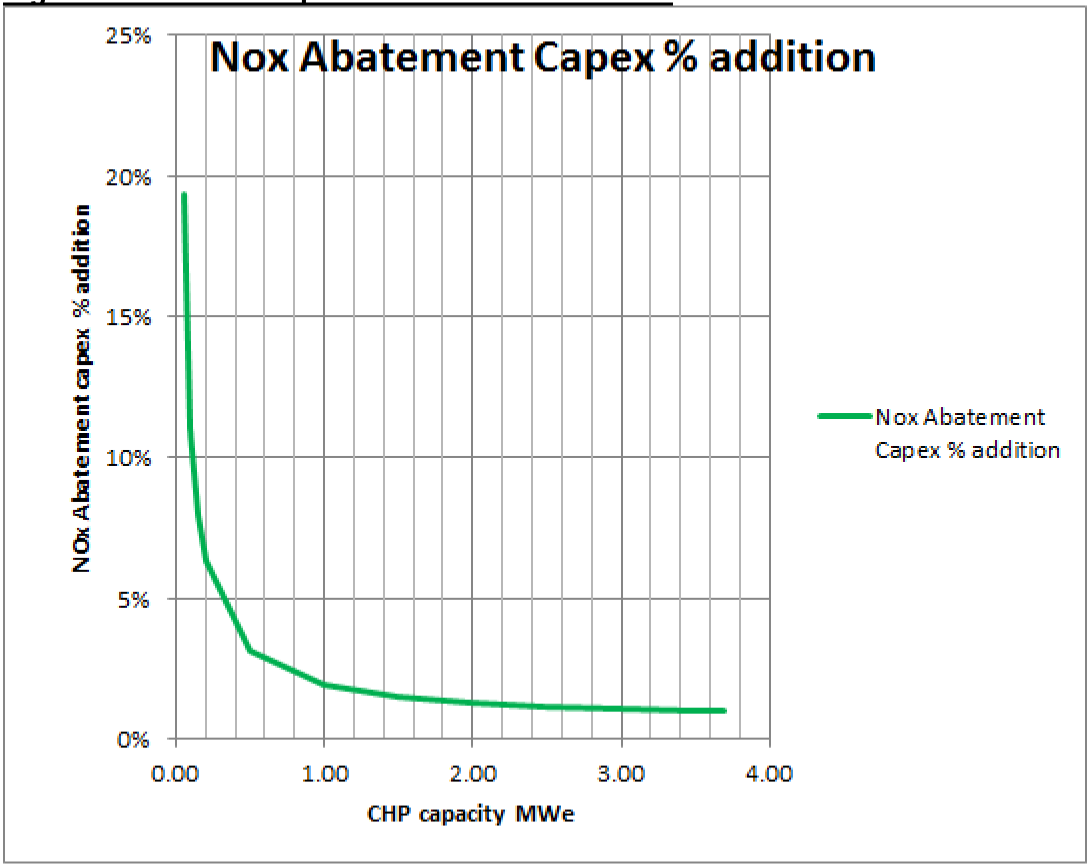


Figure C9 De-NOx Capex % Addition v CHP Size



Modelling of De-NOx opex for reciprocating engines

5. In addition to capex costs, application of Selective Catalytic Reduction De-NOx equipment will increase opex costs due to the use of aqueous urea reagent to reduce NOx. Urea consumption rates are broadly proportional to fuel consumption. For the purposes of this analysis opex costs have been quantified as an equivalent incremental increase in fuel costs.
6. The SCR is assumed to be applied to engines with engine-out NOx levels of 3g/kWh in order to achieve tailpipe NOx levels of 0.15 g/kWh. Base data was provided by Ricardo-AEA's Shoreham Technical Centre from modelling of reagent costs for De-NOx equipment on diesel fuelled engines.

Table C8 Base Engine Urea Consumption Data

Parameter	Base Data
Engine out NOx g/kWh	3.0
Tailpipe NOx g/kWh	0.15
Urea volumetric consumption as % of diesel fuel consumption	3.05
Diesel gross cost £/l	1.39
Urea cost £/l	0.70

7. The gas fuel cost equivalent to the energy content of 1 litre of diesel was calculated using the following data (2013 gas prices as used throughout this analysis and DUKES 2013 Annex A fuel density and calorific value data).

Table C9 Base Engine Urea Consumption Data

Parameter	Base Data
Gas price £/MWh	26.33
Diesel GCV GJ/tonne	45.7
Diesel litres/tonne	1195

Energy content of 1 litre of diesel = 45.7 x 1000/1195 MJ
= 38.2 MJ
= 0.0106 MWh
Equivalent natural gas cost = 26.33 x 0.0106
= £0.28

8. Reagent consumption cost as an equivalent incremental increase in fuel costs was then calculated as follows using the urea consumption rate and cost from Table C8 and the above natural gas cost;

Urea consumption cost per litre of diesel = 0.0305 x 0.70
= £0.021
Urea cost as % of gas fuel use cost = 0.021/0.28
= 7.6%

9. In LCP's social NPV sensitivity modelling the cost of urea for reciprocating engine NOx control was therefore modelled as equivalent to a 7.6% increase in fuel costs.

Annex D – Description of CHP Technologies

Reciprocating Gas Engines

1. As in petrol car engines, gas-fired reciprocating engine CHPs compress gas and air in cylinders and ignite the mixture which causes explosive forces which turn the engine. The engine must be cooled to avoid expansion and seizing up of moving parts and heat, as hot water (which would otherwise be wasted) can be recovered from the cooling fluid for site use. In addition, residual heat remains in the exhaust gas which can also be recovered as hot water or steam instead of being wasted to the atmosphere.

2. Spark-ignition gas engines are available at outputs of up to around 4 MW and operate on gaseous fuel only. Compression-ignition ('diesel') engines are available at power outputs of up to 15 MW and can be designed to operate on gas-oil, heavy fuel oil or a mixture of gas (up to 95%) and oil (5%) but are usually only used in CHP applications in areas with no natural gas.

3. Annual average electrical efficiency for spark ignition engines ranges from around 32% for smaller engines around 100kWe up to around 38% for 4MWe gas engines based on Gross Calorific Value of Fuel Input (GCV). The amount of waste heat available for use is approximately proportional to the fuel input and electrical output so to avoid wasting heat, the engine needs to be modulated (fuel input and electrical output reduced) to suit the heat demand (Heat Led Operation).

Open Cycle Gas Turbines

4. In gas turbines, air is compressed to a high pressure, fuel is injected and burned steadily in the compressed air within a combustion chamber, and the exhaust gases are expanded in turbines (which drive the compressor and provide shaft power output). The mechanical energy extracted by the turbines exceeds the energy required to drive the compressor and the surplus mechanical energy is used to drive a generator. Residual heat remains in the exhaust which can be recovered instead of being wasted to the atmosphere.

5. The electrical efficiency is lower than similarly sized reciprocating gas engines (typically between around 25% (GCV) for small turbines below 1MWe up to around 36% for very large turbines over 100MWe. However, gas turbines are usually smaller and have less maintenance and vibration than reciprocating engines and provide a large quantity of relatively high grade heat. All of this heat can be used to provide steam and so gas turbines tend to be favoured for industrial applications of several MW where there is a significant process steam demand.

6. Gas turbines used in isolation are referred to as Open Cycle Gas Turbines as opposed to Combined Cycle Gas Turbines where they are coupled with Steam Turbines as explained below. As with gas engines, waste heat availability from Open Cycle Gas Turbines is approximately proportional to electrical output so energy efficient operation will mean heat led modulation, but economics may make it preferable to generate more power and waste excess heat.

Combined Cycle Gas Turbines (CCGT)

7. In a CCGT, residual heat from a gas turbine is used to generate steam in a Heat Recovery Steam Generator (HRSG) which is then used to drive a steam turbine. CCGT with fully condensing steam turbines can achieve very high electrical efficiencies (typically around 45% for industrial CCGT schemes but over 50% for power stations based on the GCV of fuel input, but this is reduced in CHP operation where the turbine is designed as a pass-out steam turbine allowing steam to be extracted to meet the site's steam demand. This results in a drop in power generation.

8. In steam turbines, high-pressure steam is fed into a turbine which consists of several different sets of turbine blades or stages, each with angles optimised to capture power from steam with a decreasing density. In a condensing steam turbine, typically used in a large power station, power generation is maximised by minimising the output pressure of the steam to sub atmospheric pressures around 0.1Bara (-0.09barg) before condensing and pumping the water back to the boiler.

9. For CHP applications, heat could be extracted from the exhaust steam but this is uncommon as the temperature is very low (approximately 50^{o}C) and applications for such low temperature water are uncommon. One such application is the re-evaporation of Liquefied Natural Gas (LNG) where the temperature of the required heat source is low and waste heat from the condenser is ideal. However such applications are rare and temperature demands are usually higher.

10. A back-pressure steam turbine is designed as a CHP such that the steam leaves the final stage of turbine at a higher pressure corresponding to the temperature demand. As the exhaust steam has a higher amount of potential energy, less power is generated than in a condensing steam turbine, but the overall efficiency is higher if the heat can be used. With this arrangement, as with gas engines and turbines, waste heat availability is approximately proportional to electrical output so energy efficient operation will mean heat led modulation, but unlike engines and turbines, there is greater flexibility in designing the grade of heat output and therefore the heat to power ratio.

11. A pass-out condensing steam turbine is designed with outlets between turbine stages to allow steam to be diverted to serve heat loads. Extracting steam to meet thermal demands in this way reduces the volume of steam going to downstream turbine stages and thus the power generation. The steam can be extracted at the required rate so when the thermal demand is lower, less steam is extracted and therefore more electricity can be generated which makes the pass-out turbine highly flexible. We therefore assume pass-out steam turbines are used in our modelling.

12. The high pressure steam required by turbines can either be generated in fired boilers or recovered from gas turbines (see CCGT above). The former arrangement is commonly employed in nuclear and solid-fuelled power generation, but the latter arrangement, which constitutes a CCGT, is much more efficient and is commonly used in large natural gas fuelled applications. Gas-fired boiler driven steam turbine generation is therefore unlikely to be used for future gas-fired generators.

Annex E – Unrestricted Policy Supply Curves

Figure E1. Gas CHP Potential 2020 Capital Grant Supply Curve Banded by Size Range

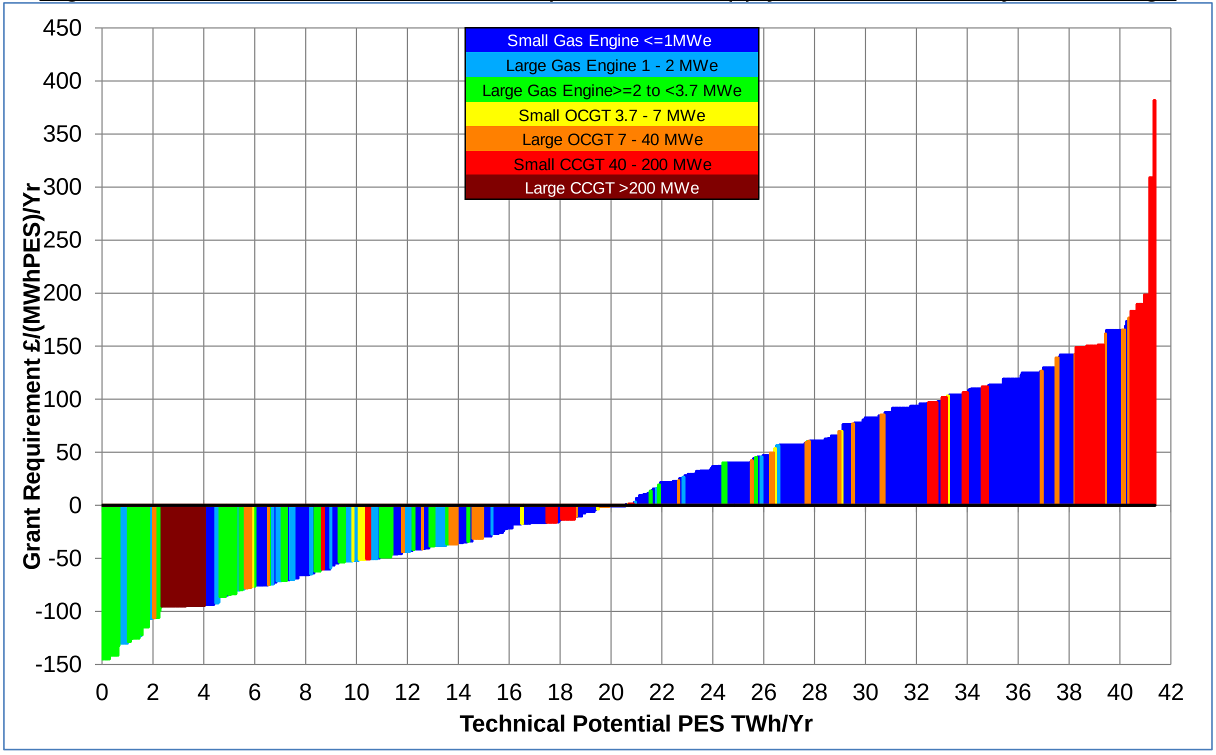


Figure E2. Gas CHP Potential 2020 Capital Grant Supply Curve Banded by Export % Range

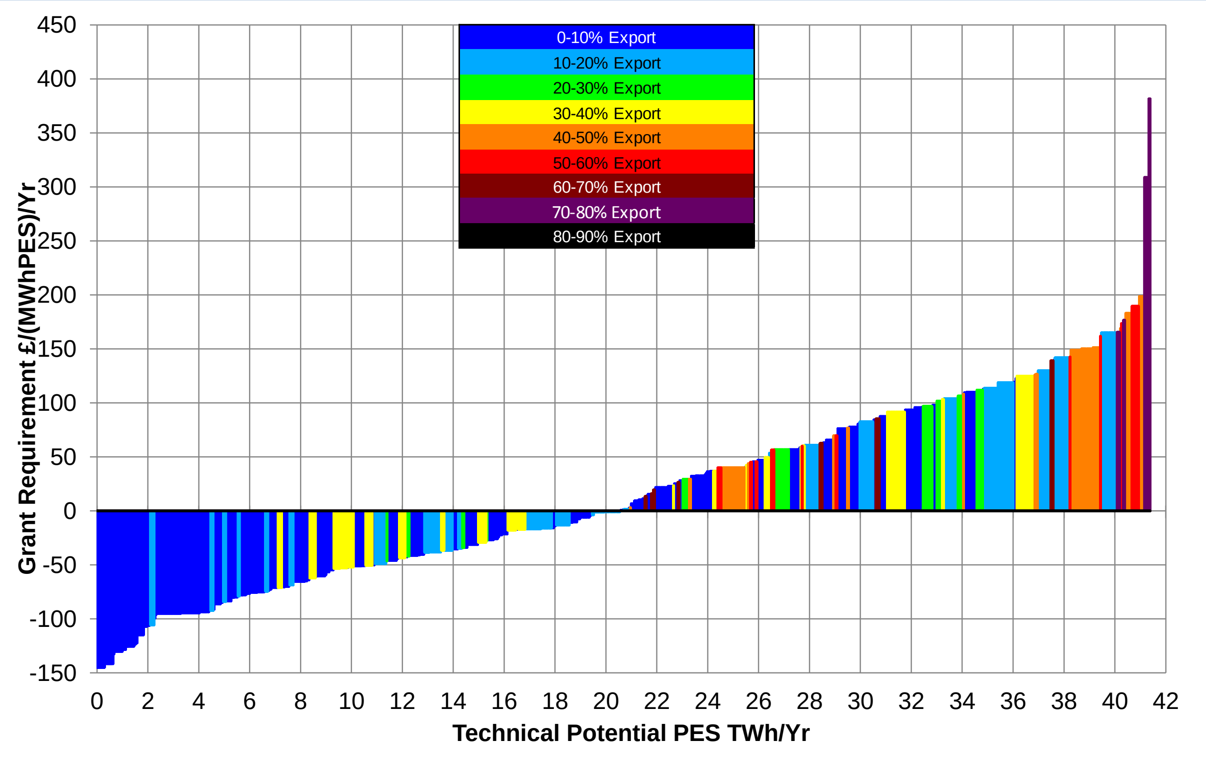


Figure E3. Gas CHP Potential 2020 PES Incentive Supply Curve Banded by Size Range

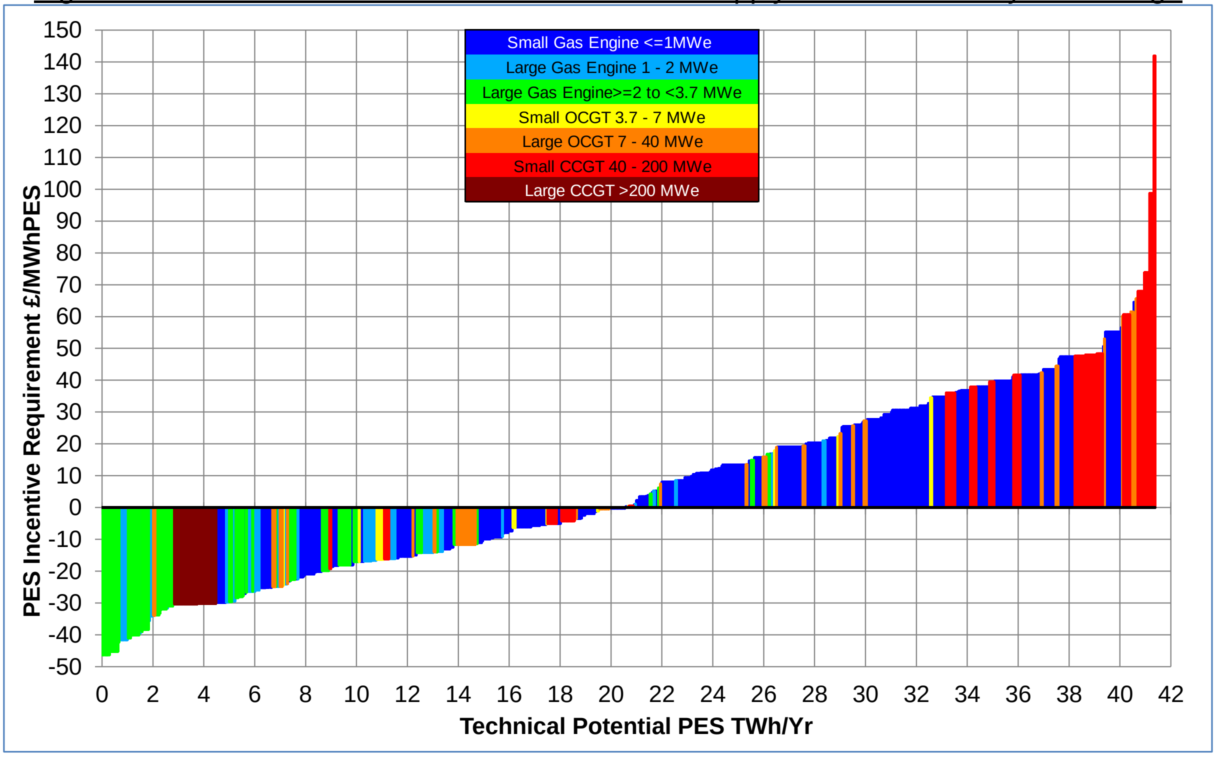


Figure E4. Gas CHP Potential 2020 PES Incentive Supply Curve Banded by Export % Range

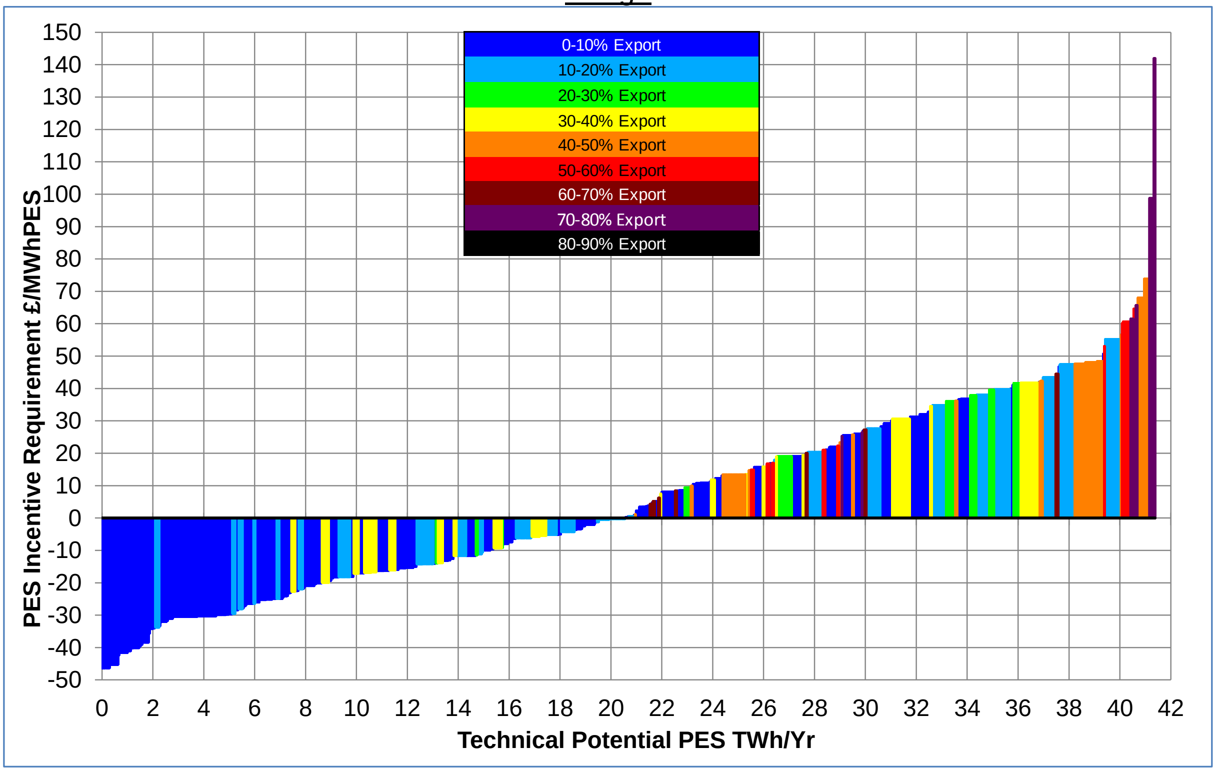


Figure E5. Gas CHP Potential 2020 PFiT Supply Curve Banded by Size Range

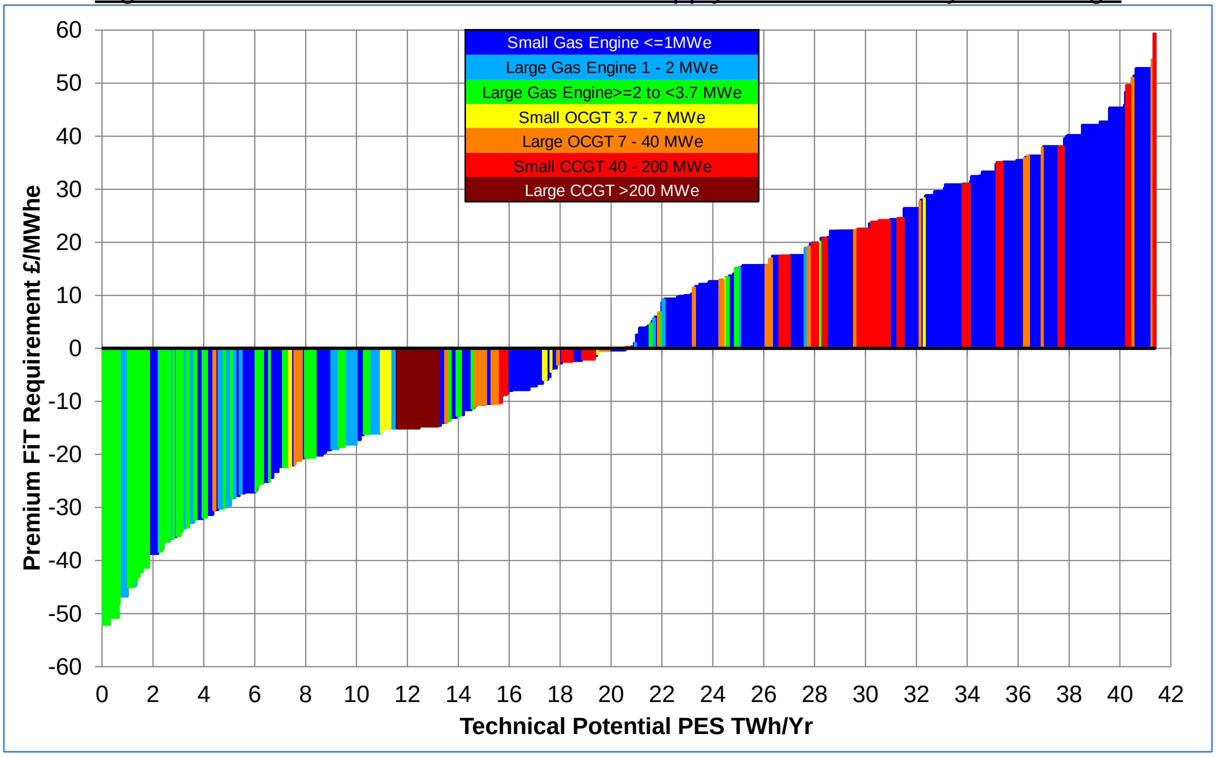
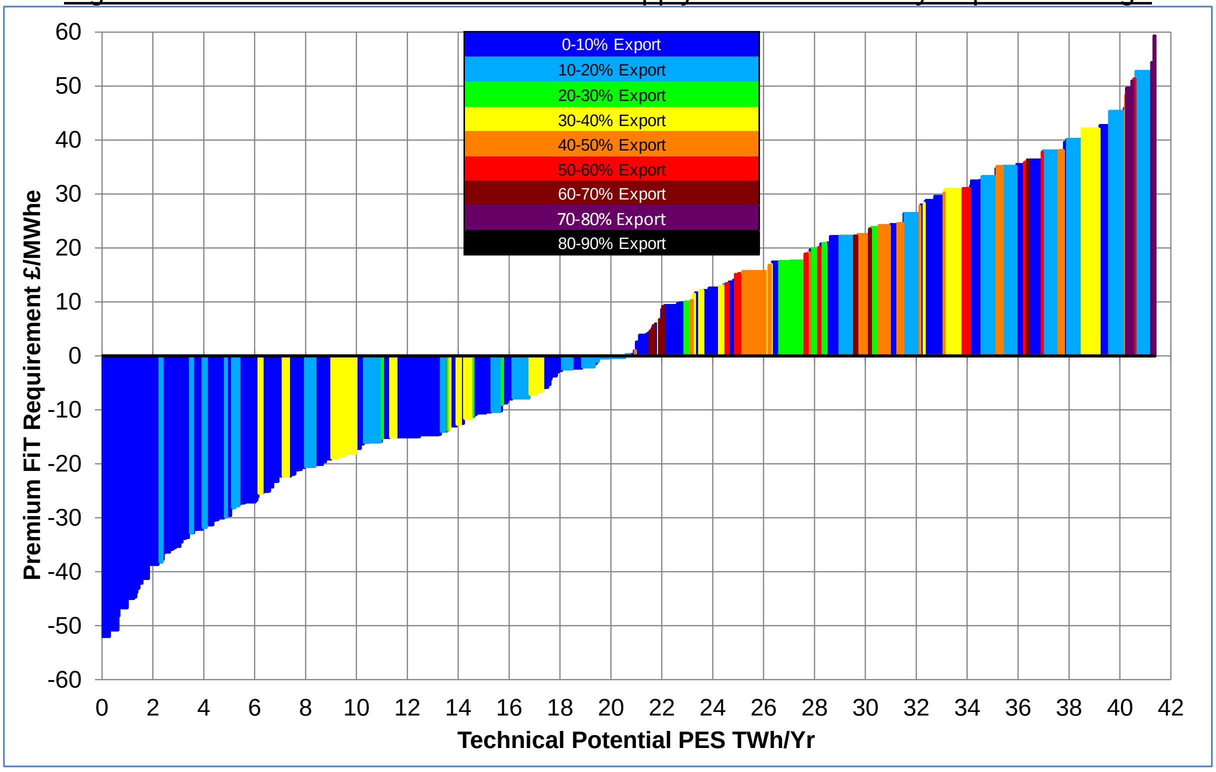
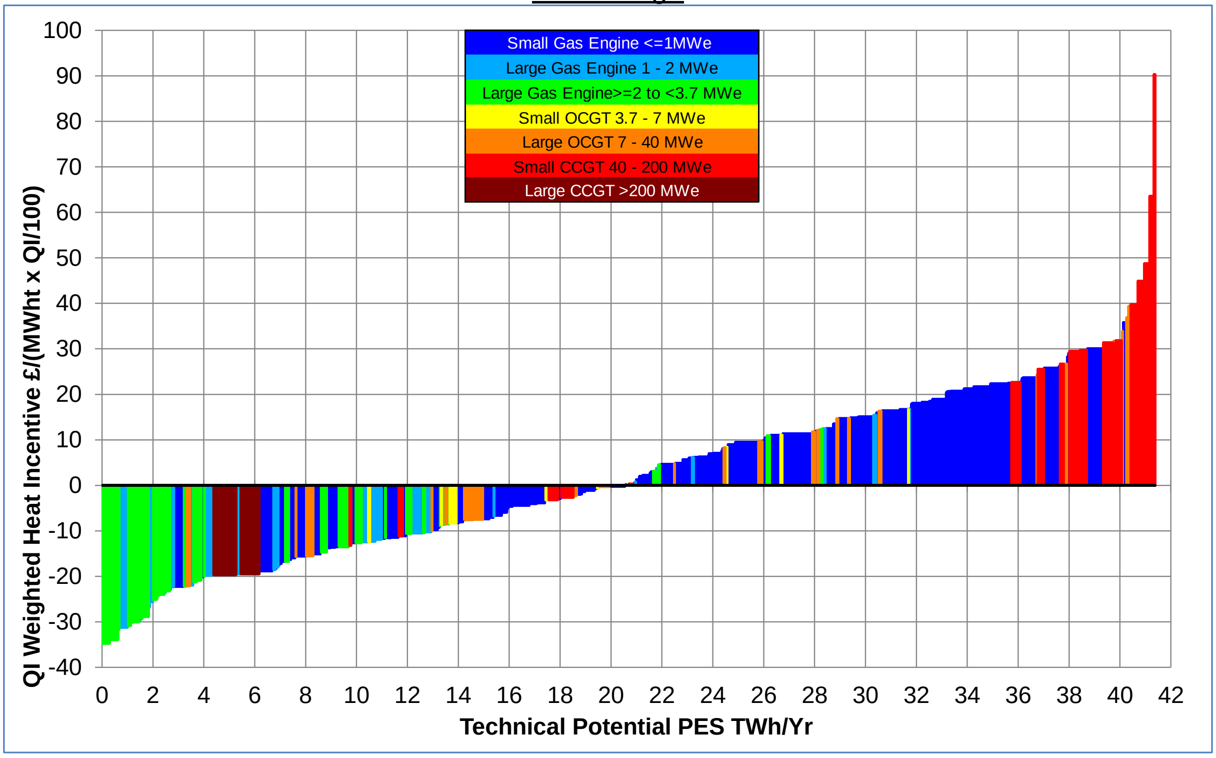


Figure E6. Gas CHP Potential 2020 PFiT Supply Curve Banded by Export % Range



<u>Figure E7. Gas CHP Potential 2020 QI Weighted Heat Incentive Supply Curve Banded by Size Range</u>



<u>Figure E8. Gas CHP Potential 2020 QI Weighted Heat Incentive Supply Curve Banded by Export % Range</u>

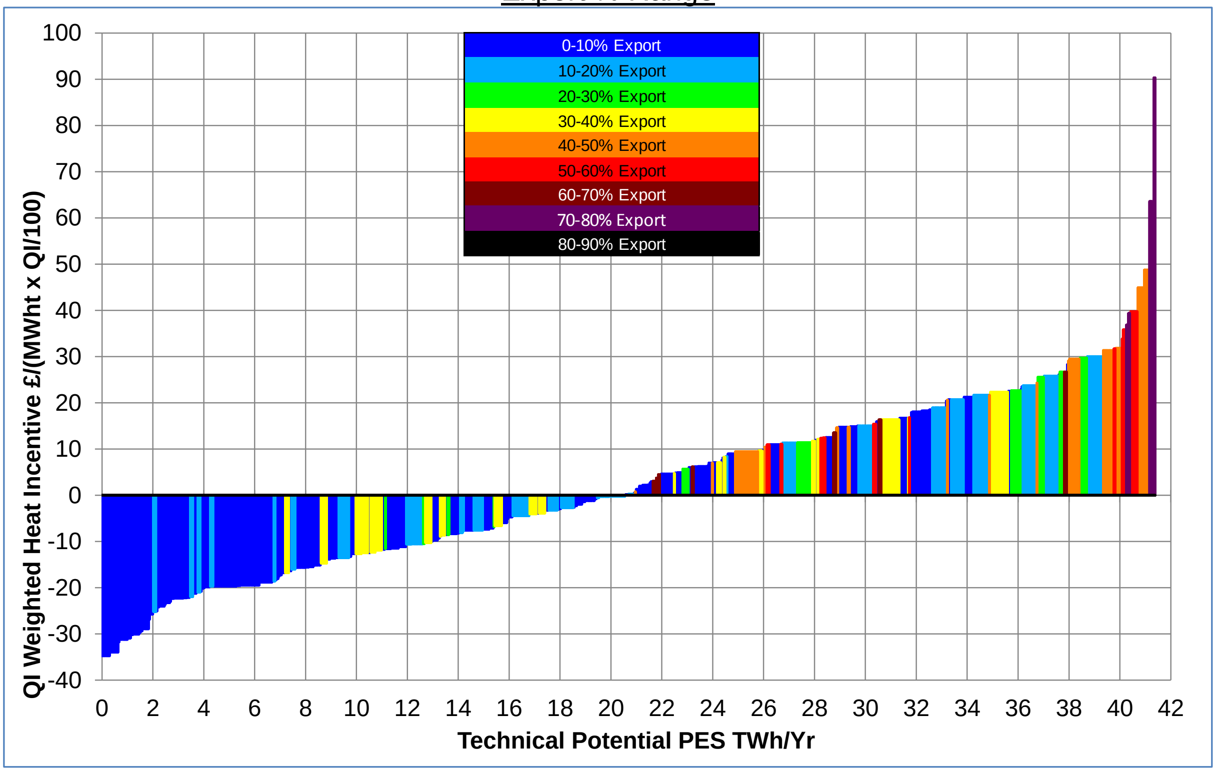


Figure E9. Gas CHP Potential 2020 QI Weighted Capacity Incentive Supply Curve Banded by Size Range

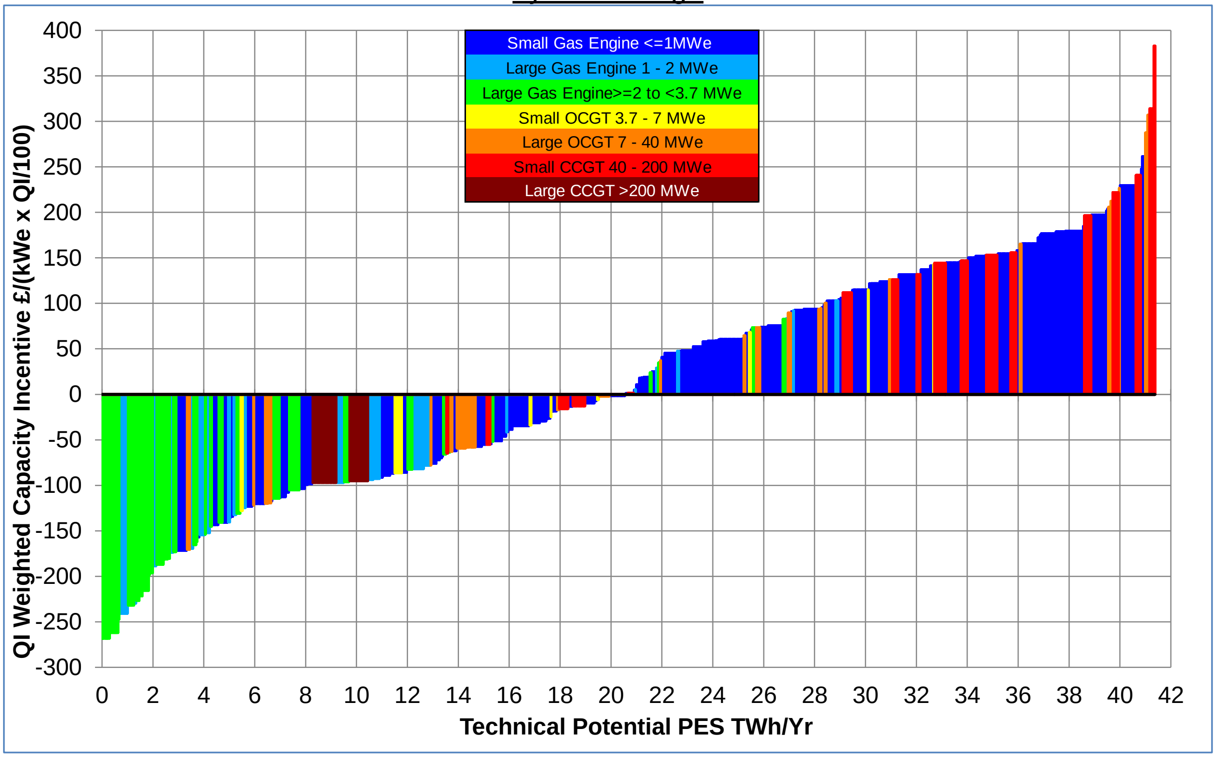
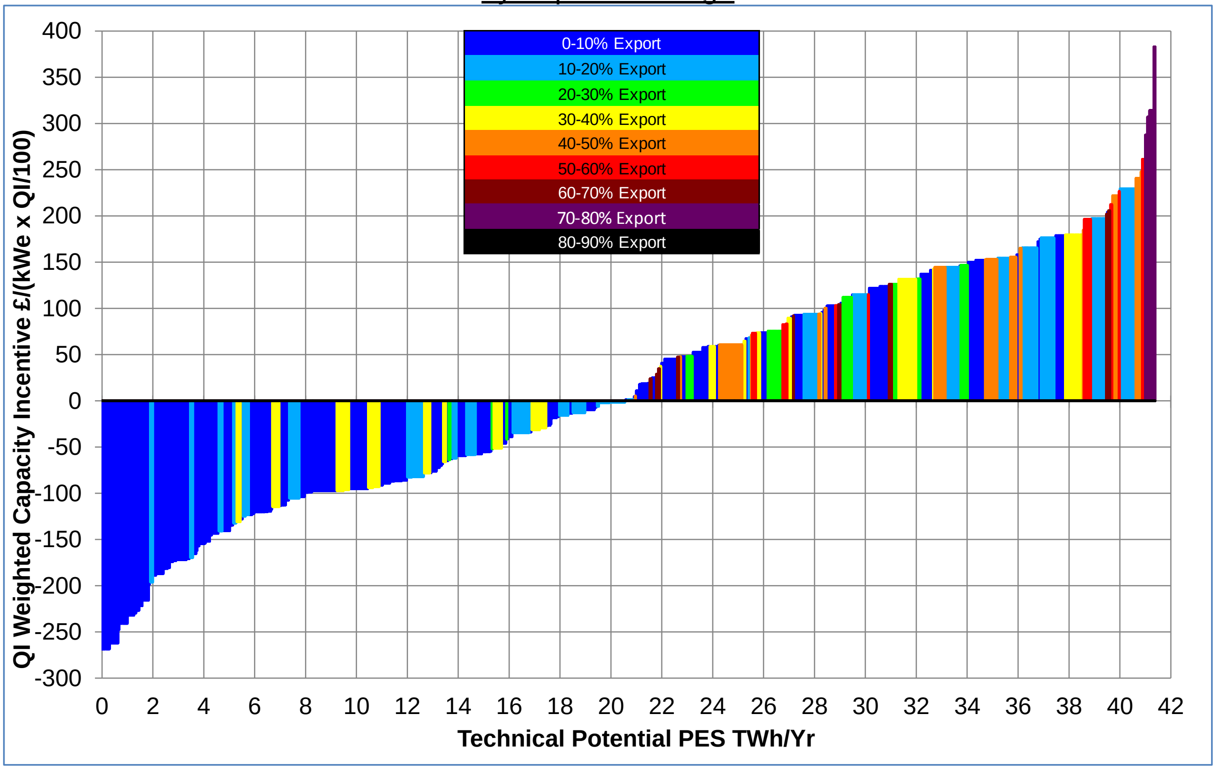


Figure E10. Gas CHP Potential 2020 QI Weighted Capacity Incentive Supply Curve Banded by Export % Range



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