Projections of CHP capacity and use to 2030

Report for DECC

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Executive summary

The EU Cogeneration Directive seeks to promote the use of high efficiency CHP where there is an economically justifiable demand for heat, thereby saving energy and reducing CO_2 emissions. It does this by creating a framework that supports and facilitates the installation and proper operation of CHP for all existing foreseeable demand for heat. Article 6 of the Directive places an obligation on Member States to assess national potentials for high efficiency CHP and barriers to their realisation allowing progress towards realising their potentials to be monitored.

This study provides an overview of the development of both conventional (natural gas) and renewable fuel fired CHP markets in the UK to date, covering an evaluation of the technical, economic potentials between now and 2030 and how much of this is likely to be realised with current and planned policies.

Good Quality CHP is an energy efficient technology which uses less fuel in total than the alternative methods of separately generating heat by conventional boilers and electricity in conventional thermal power stations. The capacity of Good Quality CHP has risen from around 4.4GW_e in 2001 to around 6.1GW_e in 2011 (of which 5% is renewable), representing about 7% of the current 89 GW_e total electricity generating capacity in the UK. In 2011 Good Quality CHP generated 27TWh of electricity, equivalent to around 7% of the total 368TWh generated in the UK[1].
Based on Government energy price projections, Ricardo-AEA's bottom up economic model has been used to assess the technical and economic potential of CHP across a range of sectors and sizes, representing all potential sites in the UK.

The technical potential of CHP was calculated at 29.4GW_e in 2012 rising to 31.8GWe in 2020 and 33.8GW_e in 2030, mainly as a result of anticipated growth in the service sector. The current capacity of approximately 6.1GW_e represents 21% of current technical potential. The cost effective potential, based on a discount rate of 15% pre-tax over 10 years, was calculated at 18.1GW_e (57% of technical potential) in 2020 rising to 20.1GW_e (60% of technical potential) in 2030.

A separate investment model (the 'Monte Carlo' simulation model) was then used to analyse the opportunities identified by the economic model, to assess the likelihood of investment and account for competition between conventional and renewable CHP (which are likely to have different investment criteria).

The projected capacity was calculated at 12.1GW_e in 2030 (equivalent to about 60% of the cost effective potential in 2030), of which about 17% is expected to be renewable.

Thus, CHP is expected to continue growing despite rising carbon prices which will work increasingly against conventional CHP schemes beyond 2030, which are expected to still dominate CHP capacity. Renewable CHP capacity is growing at a significant rate aided by the current Renewables Obligation (RO) policy which

[1] Digest of UK Statistics (DUKES), Department of Energy and Climate Change (DECC), 2012.

rewards Good Quality CHP over and above power-only generation for most technologies.

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1 Introduction

The EU Cogeneration Directive seeks to promote the use of high efficiency CHP where there is an economically justifiable demand for heat, thereby saving energy and reducing CO_2 emissions. It does this by creating a framework that supports and facilitates the installation and proper operation of CHP for all existing and foreseeable demand for heat. Article 6 of the Directive places an obligation on Member States to assess national potentials for high efficiency CHP and barriers to their realisation. A regular review allows the European Commission to monitor Member States' progress towards realising the potential identified.

This study provides an overview of the development of both conventional (primarily natural gas) and renewable fuel fired CHP markets in the UK to date, covering an evaluation of the technical, economic potentials between now and 2030 and how much of this is likely to be realised with current and planned fiscal policies.

2 CHP Modelling Procedure

Ricardo-AEA's bottom up economic model was used to assess the cost-effectiveness of CHP for various industrial and building sectors and scales of energy demand, representing potential sites in the UK. For each sector/size category, the bottom-up model compares the whole-life costs of electrically-led and heat-led CHP with conventional boilers and grid electricity import to meet heat and electricity demands, identifying potential CHP capacity where this provides a saving. The results from each sector/size category are then aggregated for the UK.

Current thermal demands for industrial sites and service sector buildings were derived from the UK CHP development map data[2]. The electrical demands were derived by combining data from the Digest of UK Energy Statistics[3] and reported electricity import data within the Chemical, Food and Drink, Paper and Engineering sectors where available. Projected future energy demands were based on assumptions of expansion or contraction in industrial and service sectors.

For each of 38 sectors, sites were divided into groups within and outside the EU-ETS and subdivided into 6 size range tranches per sector, each with approximately the same total thermal demand[4], tranche 1 containing a large number of small sites and tranche 6 a few large sites (often just one). For non EU-ETS sites, a minimum size restriction of 50kW peak thermal demand was applied to prevent the smallest tranches in each sector from being dominated by very small sites.

Thus out of about 2 million UK businesses, approximately 140,000 where found to have peak heat demand in excess of 50kW. These were modelled and were divided into 456 representative segments (38 sectors x EUETS/Non EUETS x 6 size

[2] The UK CHP development map can currently be found on the DECC website at http://chp.decc.gov.uk/developmentmap/
[3] The Digest of UK Energy Statistics (DUKES) can currently be found on the DECC website at https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/digest-of-uk-energy-statistics-dukes

tranches. Tabled examples of the tranche heat and electricity demands used by the model are shown in Annex 2.

A separate investment model (the ‘Monte Carlo’ simulation model), operated by DECC, taken into the commercial investment criteria (established in discussion with a number of companies operating and developing CHP in the UK), was then used to assess the likelihood of investment in the identified sector/size categories. Whilst the bottom-up model assessed the cost-effectiveness of conventional and renewable CHP separately, both types of CHP will often compete for the same applications. In some cases conventional CHP is more cost-effective and vice versa. The decision between conventional and renewable CHP is made in the Monte Carlo model. The methodology is described below in section 2.2.

We have used the same end-use size tranche splits and sub-sector splits for both technology applications (conventional and renewables), although certain site sizes/areas were removed from the analysis when considering renewable CHP, because of technical/commercial restrictions.

The current policies influencing investment decisions differ between conventional and renewable CHP because of the differing effects on fuel prices, investment and operating costs, etc.

2.1 Specific Monte-Carlo Modelling Tasks

The following defines in detail the tasks undertaken in this set of analyses:

Task 1. Identify and obtain the technology cost and operating information required for renewable CHP technologies at the tranche sizes and sector breakdown within the existing site and sub-sector end-use mappings. Conventional gas CHP is split according to technology sizes and types: <= 3.7MW_e gas engines, 3.7MW_e - 40MW_e open-cycle gas turbines (OCGTs) and >40MW_e CCGTs.

Task 2. Run the investment model for the required policy/ input scenarios and build up a composite summary spread-sheet to include the probabilities of investments for both renewable CHP and conventional CHP. This task provided forecasts of renewable and conventional CHP up to 2030.

From this we were able to develop an analysis of the competition of conventional CHP versus renewable CHP, with a view on the likely development/projection due to the particular level of incentive provided to each. They compete for the same end-use areas that have already been defined in the bottom-up modelling so far.

2.2 How the Practicality of Renewable CHP is Modelled

The CHP Model calculates a probability of investment for both conventional (gas) and renewable (biomass/biodiesel) projects. However a further adjustment needs to be applied to the renewables probability to take account of the fact that not all sites are suited to renewables. Therefore the probability is multiplied by a Renewables Suitability Criterion which represents the proportion of sites in each size and tranche suited to renewable technologies. These were supplied by Ricardo-AEA to DECC's modelling team.

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 renewables and only 50% for conventional clearly a larger proportion of renewables will be built.
The formula used to calculate the renewable probability (which always has a lower technical potential) is therefore:

Expected Renewable Capacity

= BottomUpPotentialRens * ProbRens * ProbRens / (ProbRens + ProbConv)

The first two terms therefore represent the expected capacity if there was no trade off while the last three represent the proportion that is actually built given the trade-off. Once we know the expected capacity for renewable the conventional capacity is simply calculated as:

Expected Conventional Capacity

= BottomUpPotentialConv * ProbConv - Expected capacityRens

3 Key Technical and Cost Assumptions

3.1 CHP Technologies

The vast majority of conventional CHP schemes are likely to be fuelled by natural gas. There are 3 main types of gas-fired power generators suitable for CHP

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

Two main types of biomass power generators suitable for CHP were considered in the study; these are:-

1. Boilers with Steam Turbines
2. Bio-liquid Engines

Other technologies were considered but rejected on the grounds of inefficiency or lack of track record.

See Annex 3 for further detail.

3.2 Design and Operating Heat to Power Ratio

For reciprocating engines, open cycle gas turbines and back-pressure steam turbines, the level of available useful heat, electricity and fuel input all increase or decrease in tandem. The ratio of useful heat available to the amount of power that is generated (heat to power ratio) is determined by the CHP design and is relatively constant regardless of the level of output. When the ratio of site heat demand to power demand is lower, the generator must either be modulated to suit the heat load resulting in a shortfall in power output or run at a higher output to meet power demand and excess heat is wasted. If the CHP follows the electrical load and wastes heat, it may not fully qualify as Good Quality CHP so modulating to follow heat demand is best practice.

With pass-out condensing steam turbines on the other hand (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 therefore be controlled according to heat demand from a level where heat extraction is maximised (delivering heat to power ratio as high as 4:1 for steam turbine based schemes down to 0.5:1 for CCGT) and power generation minimised, to zero heat extraction (i.e. fully-condensing) where power generation is maximised.

The ratio of heat extracted from a pass-out steam turbine 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 decreased drop in power production.

Which means the higher the heat to power ratio, the higher the CHP's overall efficiency. Maximising useful heat to power ratio will mean sizing and modulating the CHP to suit the site heat load. See Annexes 4 and 5 for further detail.

3.3 Assumed Prime Mover Technology and Defined Energy Price User Category versus CHP Capacity

To account for the range of efficiencies and cost characteristics of different sizes and technologies of CHP, different Capacity/Prime Mover categories were modelled as shown below (four for conventional CHP and five for renewable CHP). Each category has its own assumed efficiencies, and capital and operating cost functions of size as shown in Annex 6 (the smallest and largest conventional categories are subdivided further for capex and opex pricing purposes). These were assigned to segments according to average heat load.

Energy prices are generally lower for larger energy consumers. To account for this, 3 different energy price user categories were assumed and assigned to the CHP size/technology categories as shown below.

Table 1:- Technology and fuel price categories versus CHP capacity for <u>conventional</u> CHP used in the model

Power Capacity corresponding to Average Heat Demand MW_e	Prime Mover	Energy Price User Category
<=3.7 MW_e	Gas Engine	Small
3.7-7 MW_e	Small GT	Medium
7-40 MW_e	Large GT	Large
>40 MW_e	CCGT	Large

Table 2:- Technology and fuel price categories versus CHP capacity for <u>renewable</u> CHP

Power Capacity corresponding to Average Heat Demand MWe	Prime Mover	Energy Price User Category
≤1MW_e	Bio-liquid Engine	Small
1-3 MW_e	Bio-liquid Engine	Medium
3-5 MW_e	Biomass Steam Turbine	Medium
5-25 MW_e	Biomass Steam Turbine	Medium
>25 MW_e	Biomass Steam Turbine	Large

3.4 Energy Price Projections, £/MWh (2012 Real)

Table 3 Basic energy prices

<u>Conventional CHP and displaced boiler Fuel (Natural Gas)</u>	2010	2013	2020	2025	2030
Small and Medium Energy Users (Central Projection)	£22.42	£36.31	£38.37	£39.01	£39.65
Large Energy Users (Central Projection)	£16.42	£27.45	£29.01	£29.49	£29.97
<u>Bio-liquid CHP Fuel (Bio-diesel)</u>					

Conventional CHP and displaced boiler Fuel (Natural Gas)	2010	2013	2020	2025	2030
All scales of Energy User (Central Projection)	£77.95	£77.78	£72.98	£72.16	£71.99
Biomass CHP Fuel (Wood Chips)					
All scales of Energy User (Central Projection)	£23.67	£23.67	£23.67	£23.67	£23.67
Electricity Import					
Small Energy Users (Central Projection)	£74.84	£97.05	£124.73	£141.78	£139.54
Medium and Large Energy Users (Central Projection)	£59.64	£76.94	£98.89	£112.41	£110.63
Electricity Export					
Small and Medium Energy Users (Central Projection)	£34.24	£46.19	£52.55	£62.77	£68.36
Large Energy Users (Central Projection)	£42.80	£57.73	£65.69	£78.47	£85.45

The fuel price categories for conventional and renewable CHP and the basic retail/export values are given in table 3 above. These exclude policy additions payable by or to the CHP Operator for Carbon and CCL and policy support from ROCs and RHI etc. which are shown in tables 4-7.

3.5 Energy Policy Additions/Support

Table 4 Energy policy costs, relief and carbon intensities relevant to CHP (2012 Real)

Year	2013	2020	2025	2030
Central Carbon Market Price Projection £/tCO_2	£5.98	£8.55	£10.26	£12.30
Carbon Price Floor (CPF) Projection £/tCO_2	£9.59	£32.42	£54.04	£75.65
Carbon Price Support (CPS) Projection (CPF – Market Price)	£3.61	£23.87	£43.78	£63.35
CRC Carbon Price £/tCO_2	£12.00	£16.00	£16.00	£16.00
Natural Gas Carbon Intensity Projection tCO2/MWh	0.184	0.184	0.184	0.184
Bio-liquid and Biomass Carbon Intensity Projection tCO2/MWh	0.000	0.000	0.000	0.000
Grid Electricity Carbon Intensity Projection tCO2/MWh	0.512	0.414	0.329	0.233
Full CCL Rate (in 2012) on Natural Gas £/MWh	£1.77	£1.77	£1.77	£1.77
Full CCL Rate (in 2012) on Electricity £/MWh	£5.09	£5.09	£5.09	£5.09
ROC Value (in 2012) £/MWh	£45.00	£45.00	£45.00	£45.00
Renewable ROCs/MWhe for GQCHP	2	1.5	1.5	1.5
RHI Value (in 2012) £/MWh	£0	£41.00	£41.00	£41.00
Assumed Efficiency of displaced boiler (%GCV)	75%	75%	75%	75%
Assumed average Displaced boiler fuel / total CHP fuel ratio for small energy users (Based on Gas Engines)*	55%	55%	55%	55%
Assumed average Displaced boiler fuel / total CHP fuel ratio for medium energy users (Based on Small Open Cycle Gas Turbines)*	62%	62%	62%	62%

Year	2013	2020	2025	2030
Assumed average Displaced boiler fuel / total CHP fuel ratio for large energy users (Based on CCGT)*	41%	41%	41%	41%
EU-ETS Phase 3 Heat Allowance for boiler fuel (% of displaced fuel)	80%	30%	8.6%	0%
Assumed % of small schemes which are <2MWe and therefore exempt from CPS**	50%	50%	50%	50%
Assumed CCL % Payable on Gas for CCA Sites	35%	35%	35%	35%
Assumed CCL % Payable on Electricity for CCA Sites	35%	35%	10%	10%
Assumed CHP LEC value % of Full CCL value for conventional CHP	0%	0%	0%	0%
Assumed Renewable LEC value % of Full CCL Value	80%	80%	80%	80%

* As explained in section 3.3 above, the model was developed with three different energy price sets depending on the size of CHP. The effect of policies is to effectively increase or decrease the energy prices. With the exception of CCL, the average effects across all segments were calculated for each of the three energy user size categories in energy terms (£/MWh) as shown in table 5 below. CCL is sector dependent and therefore the differences are applied within the model.

All schemes outside the EU-ETS were assumed to be covered by CRC and modelled in a parallel version of the model as their carbon costs are so different.

Both the EU-ETS Phase 3 and the CPS policies allow a rebate for the fuel displaced by the CHP heat output. In order to estimate the average rebate for each of the energy user size categories, the average electrical efficiency and heat to power ratio for each have been estimated based on the related CHP technology/size categories. The differences are reflected in the different EUETS and CPS costs (£/MWh) in tables 5 and 6 below for the different energy user size categories.

** As explained in section 3.3 above, the small/med/large energy user energy and policy prices were assigned according to the technology/size categories. The smallest CHP technology/size category is <=3.7MWe but CPS will only apply to schemes with installed electricity generating capacity >2MWe. To account for this it was assumed that the average CPS cost applying to <3.7MWe schemes is reduced by 50%.

Table 5 Resulting carbon prices in energy terms, £/MWh (2012 Real)

Year	2013	2020	2025	2030
EU-ETS on CHP Gas for Small Energy Uses where applicable	£0.62	£1.31	£1.80	£2.26
EU-ETS on CHP Gas for Medium Energy Uses	£0.56	£1.28	£1.78	£2.26
EU-ETS on CHP Gas for Large Energy Uses	£0.74	£1.38	£1.82	£2.26
CRC on CHP Gas for sites outside EU-ETS	£0.00	£0.00	£0.00	£0.00
Carbon on Electricity Import for EU-ETS Sites (CRC)	£0.00	£0.00	£0.00	£0.00
Carbon on Electricity Import for sites outside EU-ETS (CRC)	£6.14	£6.63	£5.27	£3.73
EU-ETS (Where applicable) on gas for boilers £/MWh	£0.22	£1.10	£1.72	£2.26
CRC (Where Applicable) on gas for boilers £/MWh	£2.20	£2.94	£2.94	£2.94

Table 6 Resulting Climate Change Levy/LECs value, £/MWh (2012 Real)

Year	2013	2020	2025	2030
CCL on GQ CHP Gas	£0.00	£0.00	£0.00	£0.00
Carbon Price Support payable on CHP Gas for Average Small Scale Energy User	£0.15	£1.00	£1.83	£2.64
Carbon Price Support payable on CHP Gas for Medium Energy Users (Small OCGT)	£0.26	£1.69	£3.09	£4.47
Carbon Price Support payable on CHP Gas for Large Energy Users (CCGT / Large OCGT)	£0.39	£2.58	£4.73	£6.84
LEC Value for Conventional GQ CHP Electricity Export	£0.00	£0.00	£0.00	£0.00
LEC Value for Renewable GQ CHP Electricity Export	£4.07	£4.07	£4.07	£4.07
CCL on Conventional Industrial Boiler Gas for Sites with a CCA	£0.62	£0.62	£0.62	£0.62
CCL on Conventional Boiler Gas for Sites outside CCA	£1.78	£1.78	£1.78	£1.78
CCL on Conventional Electricity Import for sites with a CCA	£1.78	£1.78	£0.51	£0.51
CCL on Conventional Electricity Import for sites outside CCA	£5.09	£5.09	£5.09	£5.09

Table 7 Resulting ROCs and RHI values for Renewable CHP, £/MWh (2012 Real)

Year	2013	2020	2025	2030
RHI Value £/MWht	£0.00	£41.00	£41.00	£41.00
ROC Value £/MWhe GQCHP	£90.00	£67.50	£67.50	£67.50

4 Modelling Results

4.1 Restricted Technical CHP Potential

As CHP is capital intensive, produces both electricity and heat and usually operates alongside supporting boiler plant, selecting the CHP capacity for a site is more complex than for boilers which must simply meet the peak heat load. CHP sizing typically involves optimising the financial benefits which depend on a site’s electrical and thermal demands, on site and export energy prices and the performance of CHP technology employed. Environmental and practical considerations also play a part in the decision.

It is therefore not possible to give a definitive overall technical potential for CHP, for each site simply based on their energy demands but this needs to be modelled in the same way as for economic potential but with the requirement to be more cost effective than conventional boilers and grid import removed.

The technical potential for CHP across the UK given below, assumes that a conventional CHP would be installed at every industrial site or service sector building with a peak heat demand above a minimum threshold of 50kW, regardless of economic viability or practicality but sized to give the most economic CHP possible based on a low discount rate.

The decision on whether to size CHP according to the heat or electricity demand and fine tuning of sizing will depend on the relative heat and electricity demands and prices at each site and also costs or benefits due to energy policies.

The optimum renewable or conventional electrical CHP capacity will be similar where sized on electrical demand, but renewable CHP will typically have a higher heat to power ratio and therefore lower power capacity where sized on heat demand. Employing conventional CHP across all sectors will therefore tend to give a higher power capacity overall, so in assessing technical potential we have assumed that all new CHP would be gas-fired, similar to the majority of existing capacity. This is likely to remain the case for some time.

A number of sectors have not been modelled including Refineries, LNG and Oil Terminals, District Heating and domestic micro-CHP potential within the model, as their potential is very uncertain. Instead we have projected their uptake based on a combination of CHPQA applications for new schemes, market knowledge and historic trends. The potential for CHP in District Heating is extremely uncertain as it depends on the penetration of District Heating and the size of each network and widespread penetration would reduce the potential in other sectors. In addition the criteria for sizing CHP in various industrial sectors such as refineries is very different to that of the more typical sectors modelled.

The off-model projections for these sectors are included in the technical potential below and in the projections later in the report.

On this basis, the restricted technical potential for GQCHP in the UK was estimated to be in the order of 29.3 GW_e in 2013, as shown in Table 8.

Table 8 Restricted Technical CHP potential

	2013	2020	2025	2030
Technical CHP Potential MW_e	29,324	31,877	32,795	33,783
Total Power Capacity Central Govt Projection[5]	98,361	107,351	105,875	111,215
Technical CHP potential of total projected electrical capacity	29%	27%	30%	29%

The technical potential is expected to grow primarily as a result of growth in UK energy demands.

4.2 Economic CHP Potential

Ricardo-AEA (previously as AEA) have developed an economic bottom-up model which is used to assess the economic potential of installing CHP for a number of sectors and size categories representing every energy demand in the UK. For each

[5] DECC Updated Energy & Emissions Projections - October 2011 Annex J
http://webarchive.nationalarchives.gov.uk/20130106105028/http://www.decc.gov.uk/media/viewfile.ashx?filetype=4&filepath=11/about-us/economics-social-research/3125-annex-j-total-capacity.xls

category, the model calculates the discounted whole life cost of providing heat and power from three options:-

1. Conventional base case - heat from gas boilers and electricity imported from the grid

2. CHP sized to follow electrical demand

3. CHP sized to follow thermal demand

The model only counts CHP where it is cheaper than the conventional methods (electricity from a power station and heat from on-site boilers) and sizes according to electrical or thermal demand, whichever gives the greater capacity. The same model is also used to assess technical potential but in this case, the saving compared to the conventional base case is not considered so CHP is always counted with the model deciding between electrically-led and heat-led sizing.

The model assumes a discount, or hurdle rate of 15% pre-tax over a 10-year investment period and includes an error margin in favour of CHP which considers it as being viable if the discounted whole life cost is up to 10% higher than the counterfactual gas boilers and grid import. This is relatively lax and many investors would apply more strict criteria so this represents the maximum likely economic potential scenario which excludes highly uneconomic schemes. The results of this BU modelling are then used in the Monte Carlo model which applies much stricter criteria.

As with technical potential, the maximum economic potential was assumed to be the result of modelling all sites as if they will be served by conventional CHP only.

Table 9 Economic CHP potential

	2020	2025	2030
Economic CHP Potential MWe	18,125	20,096	20,138
% of Technical Potential	57%	61%	60%

The total economic potential for conventional and renewable CHP, shown in Table 9, is expected to continue to grow with increasing energy demands up to 2030. However, the intensity of grid electricity is decreasing over time. For this reason, in the long term conventional CHP schemes will cease to deliver any carbon savings over their lifetimes. Therefore EU-ETS / CRC will penalise rather than incentivise such schemes so the economic potential for conventional CHP is likely to decline in the long term. Similarly the carbon savings from renewable CHP schemes will also decrease as the grid decarbonises but they will continue to deliver carbon savings much further into the future.

4.3 Modelling Results – CHP Projections

In practice the theoretical economic potential is unlikely to be implemented for a variety of reasons including risk aversion, stricter criteria of certain sectors, risks related to heat customers, lack of access to finance and lack of awareness in some sectors.

The results of the economic modelling are fed into the Monte-Carlo probability model which assesses these factors in more details to predict the likely uptake of CHP as shown in Table 10. Figure 1 shows the projected Good Quality CHP Capacity for each year.

Table 10 Projection results summary – GQCHP electrical capacity

Elec Capacity in CHP Mode (MW_e)	2013	2020	2025	2030
Renewable GQCHP	535	1,505	1,809	2,021
Conventional GQCHP	7,382	8,893	9,837	10,107
Total GQCHP	7,916	10,398	11,646	12,128
Projection % of Technical Potential	27%	33%	36%	36%
Projected Renewable share of GQCHP Capacity	7%	14%	16%	17%

Thus the projected total GQCHP capacity (conventional and renewable) in 2030 is estimated to be about 36% of the technical potential and around 60% of economic potential. The share of renewable CHP capacity is expected to rise from around 7% in 2013 to 17% of total projected GQCHP capacity by 2030.

The likely GQCHP annual electricity and heat outputs, based on the projected capacity were also estimated, these are shown in tables 11 and 12 and illustrated graphically for each year in Figures 2 and 3.

Table 11 Projection results summary – Good Quality annual CHP electrical output

Annual Elec Output TWh/Yr	2013	2020	2025	2030
Renewable CHP	3.040	7.692	8.960	9.750
Conventional CHP	35.484	49.900	54.624	55.704
Total CHP	38.525	57.591	63.584	65.454

Table 12 Projection results summary – Good Quality annual CHP heat output

Annual Heat Output TWh/Yr	2013	2020	2025	2030
Renewable CHP	4.484	10.989	13.312	14.607
Conventional CHP	50.411	54.682	61.067	63.235
Total CHP	54.895	65.671	74.379	77.842

Figure 1 Good Quality CHP capacity projection, MW_e

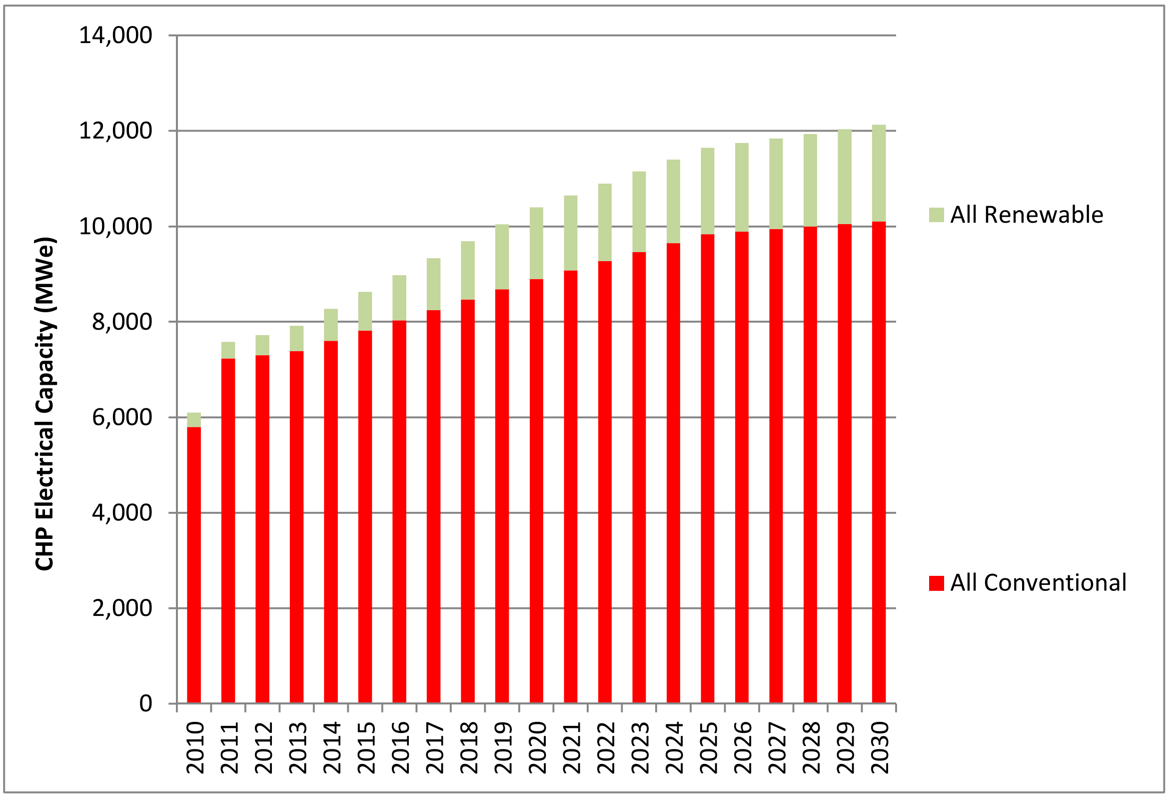


Figure 2 Good Quality CHP electrical output projection, TWh/yr

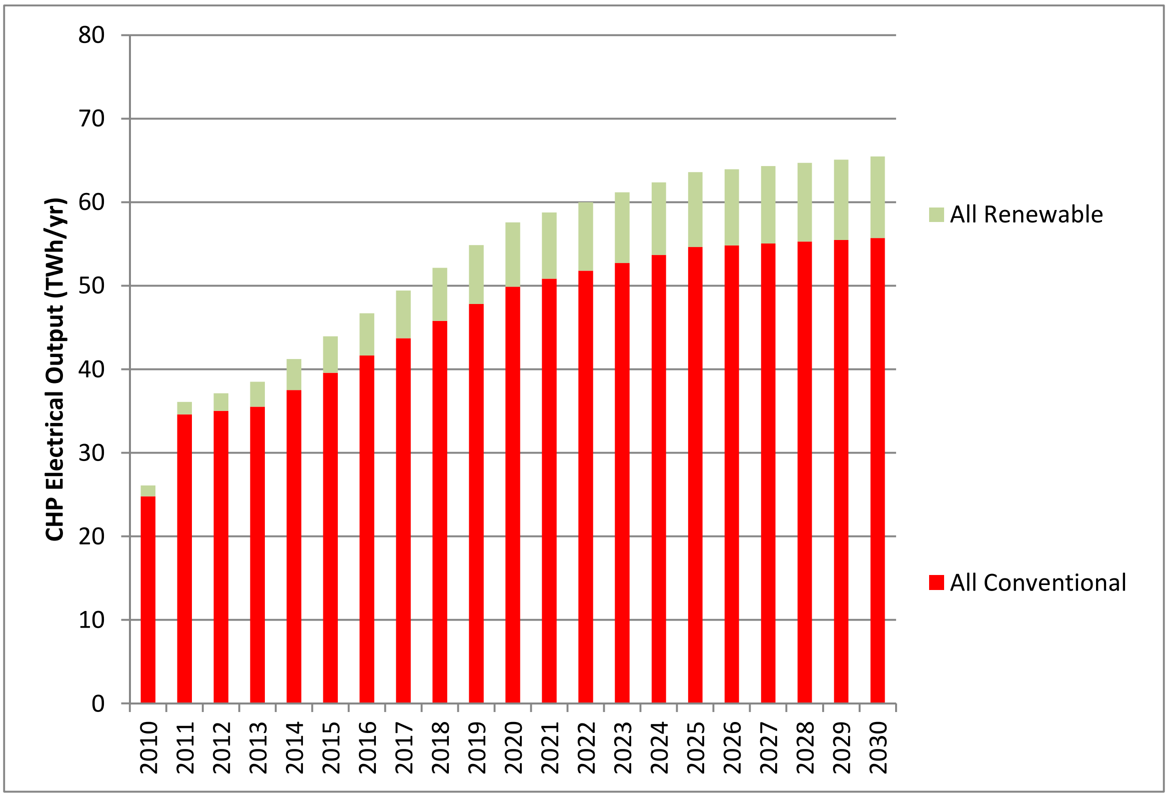
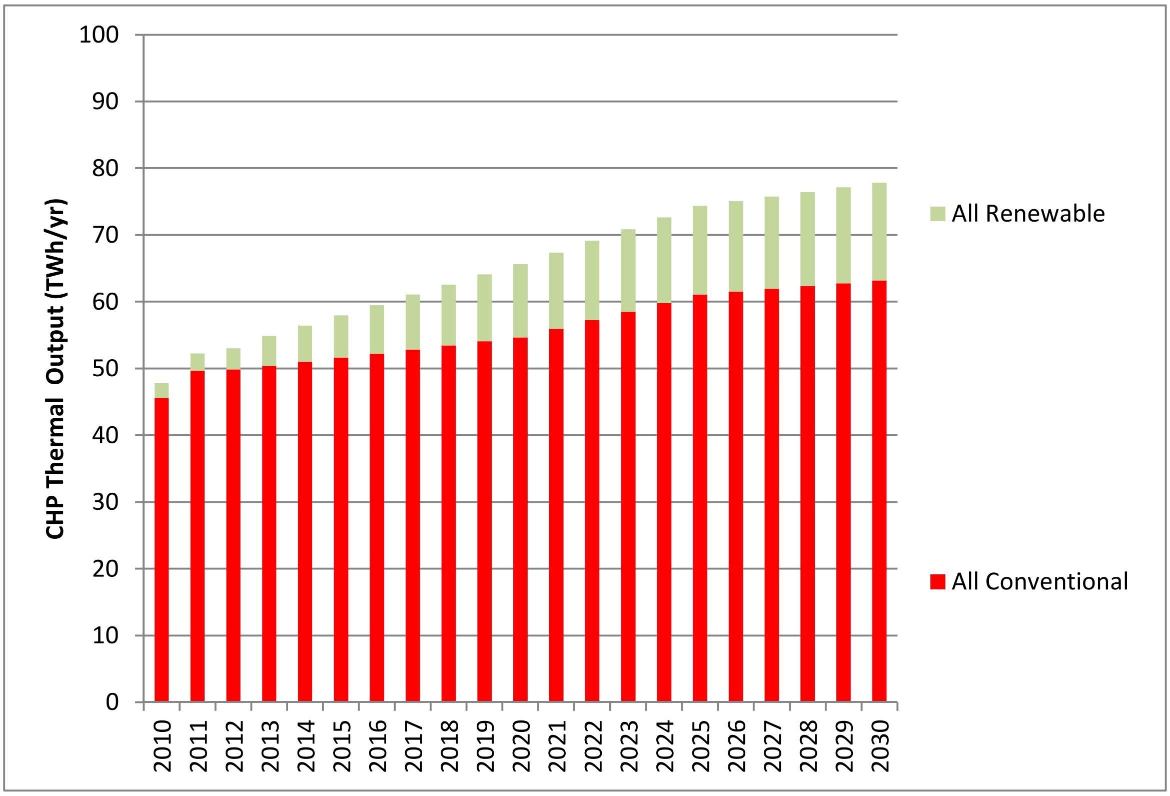


Figure 3 CHP heat output projection, TWh/yr



Annexes

Annex 1 – Detailed Results by Sector

Table A1 Good Quality CHP capacity projection, MW_e

Year	2010	2013	2020	2025	2030	2010-30 Absolute Growth	2010-30 Growth Factor
Total Conventional CHP	**5,796**	**7,382**	**8,893**	**9,837**	**10,107**	**6,179**	**2.07**
Total Renewable CHP	**305**	**535**	**1,505**	**1,809**	**2,021**	**1,716**	**6.62**
Total CHP	**6,101**	**7,916**	**10,398**	**11,646**	**12,128**	**6,027**	**1.99**
Conventional CHP							
Energy Industry	2,330	3,730	4,210	4,325	4,440	2,110	1.91
Services	335	376	1,725	2,589	2,888	2,553	8.62
Food & Drink	405	433	492	545	527	122	1.30
Chemicals	1,785	1,799	1,325	1,221	1,115	-670	0.62
Paper & Pulp	432	473	364	278	205	-227	0.47
Engineering	63	64	159	166	174	111	2.76
Other Manuf.	45	46	73	111	97	52	2.17
Other	249	280	360	417	474	225	1.90
Minerals	43	69	69	69	69	26	1.59
Sewage	26	29	32	35	36	10	1.37
Metals	82	82	82	82	82	0	1.00
Renewable CHP							
Chemicals	13	25	303	335	380	367	29.49
Food & Drink	5	13	256	248	260	255	53.60
Other	75	114	239	328	414	339	5.55
Other Manuf.	11	103	138	163	188	177	16.49
Energy Industry	-	-	100	150	150	150	N/A
Paper & Pulp	48	88	35	36	37	-11	0.78
Sewage	148	162	180	193	199	50	1.34
Engineering	3	3	91	155	164	161	60.03
Metals	-	18	18	18	18	18	N/A
Services	3	9	144	183	212	210	84.23
Minerals	-	-	-	-	-	-	N/A

Figure A1 Good Quality CHP capacity projection (conventional and Renewable), MW_e

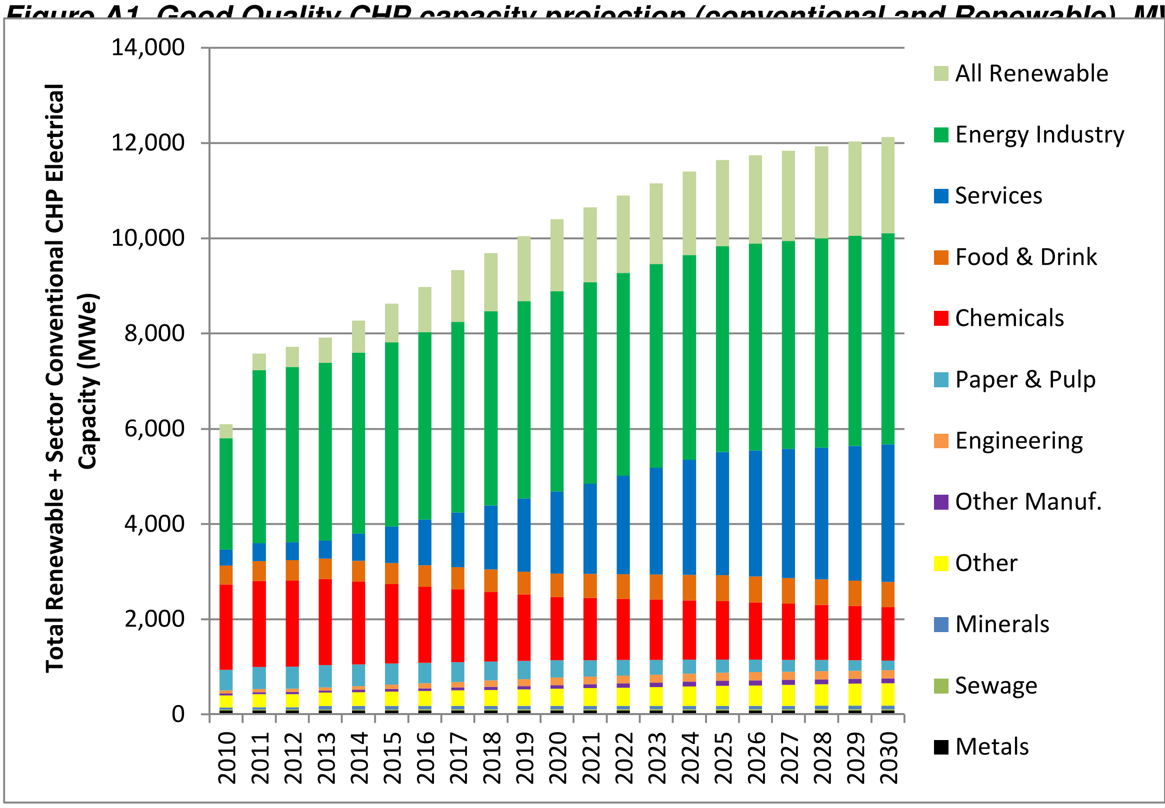
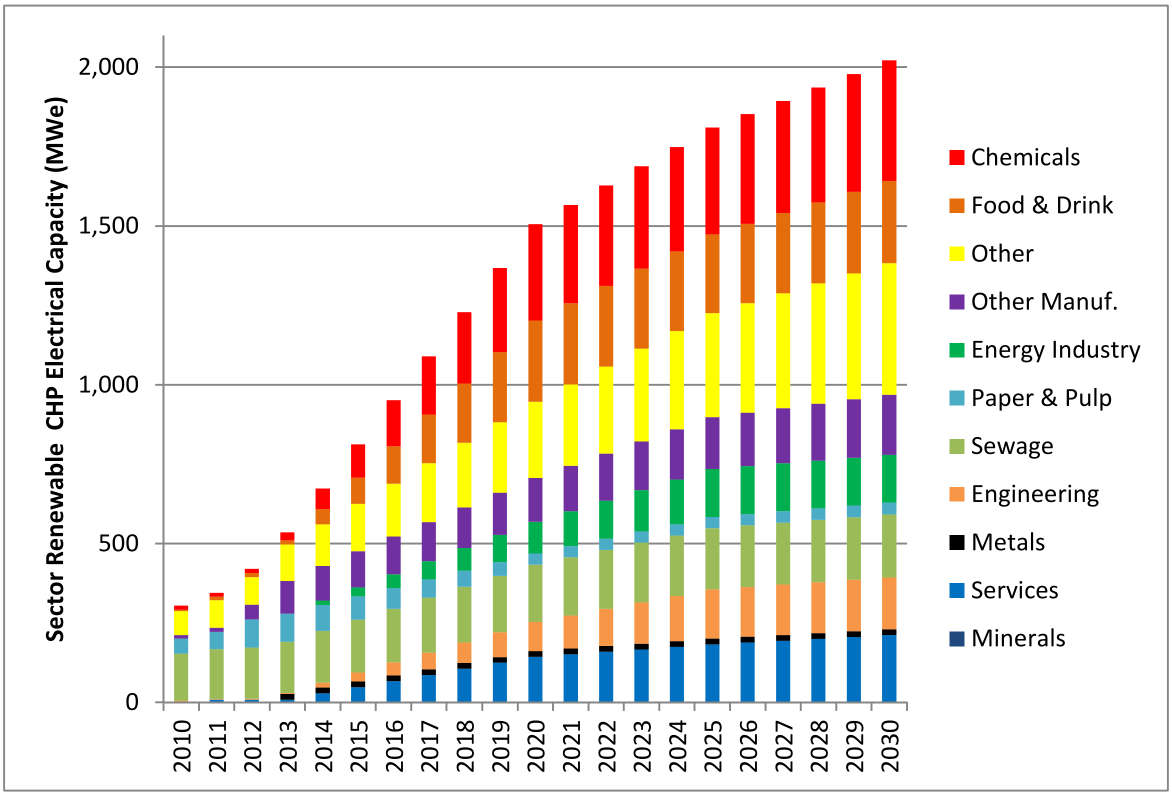


Figure A2 Good Quality renewable CHP capacity projection, MW_e



It can be seen that the sector with the largest anticipated absolute growth in conventional CHP (and also the largest final capacity) is the energy supply sector whereas the chemicals sector is anticipated to have the largest absolute growth (and final capacity) in renewable CHP.

The ‘Energy Industry’ sector comprises oil and gas refineries and terminals including LNG. The ‘Other Manuf’ sector comprises the plastic, rubber, wood and textile industries.

The ‘Other’ sector comprises agricultural activities (Anaerobic digestion and greenhouses), district heating and the residential, sheltered housing sector (mainly communal heating and sports and leisure.

Table A2 Good Quality CHP electrical output projection, TWh/yr

Year	2010	2013	2020	2025	2030	2010-30 Absolute Growth	2010-30 Growth Factor
Total Conventional CHP	**24.762**	**35.484**	**49.900**	**54.624**	**55.704**	**30.941**	**2.25**
Total Renewable CHP	**1.320**	**3.040**	**7.692**	**8.960**	**9.750**	**8.430**	**7.38**
Total CHP	**26.083**	**38.525**	**57.591**	**63.584**	**65.454**	**39.371**	**2.51**
Conventional CHP							
Energy Industry	10.700	20.425	22.937	23.342	23.976	13.276	2.24
Chemicals	7.043	7.170	8.615	7.939	7.245	0.201	1.03
Services	1.257	1.498	9.662	14.497	16.174	14.917	12.86
Food & Drink	2.057	2.238	3.201	3.543	3.428	1.372	1.67
Paper & Pulp	1.943	2.237	2.364	1.804	1.330	-0.614	0.68
Other	0.688	0.768	0.881	0.961	1.045	0.357	1.52
Engineering	0.154	0.156	1.034	1.080	1.132	0.978	7.33
Other Manuf.	0.271	0.272	0.477	0.720	0.632	0.362	2.34
Minerals	0.125	0.189	0.189	0.189	0.189	0.064	1.51
Sewage	0.082	0.089	0.099	0.107	0.111	0.029	1.35
Metals	0.442	0.442	0.442	0.442	0.442	0.000	1.00
Renewable CHP							
Chemicals	0.012	0.123	1.973	2.180	2.467	2.455	204.11
Other	0.296	0.542	0.789	0.965	1.134	0.839	3.84
Food & Drink	0.020	0.053	1.666	1.614	1.687	1.667	84.63
Sewage	0.620	0.675	0.755	0.813	0.840	0.219	1.35
Other Manuf.	0.022	0.787	0.283	0.300	0.307	0.285	13.95
Energy Industry	-	-	0.456	0.685	0.685	0.685	N/A
Paper & Pulp	0.349	0.711	0.230	0.235	0.241	-0.108	0.69
Engineering	0.000	0.000	0.593	1.005	1.064	1.063	9,735.63
Metals	-	0.138	0.138	0.138	0.138	0.138	N/A
Services	0.002	0.010	0.808	1.025	1.188	1.186	716.95
Minerals	-	-	-	-	-	-	N/A

Figure A3 Good Quality CHP electricity projection (Conventional & Renewable) TWh/yr

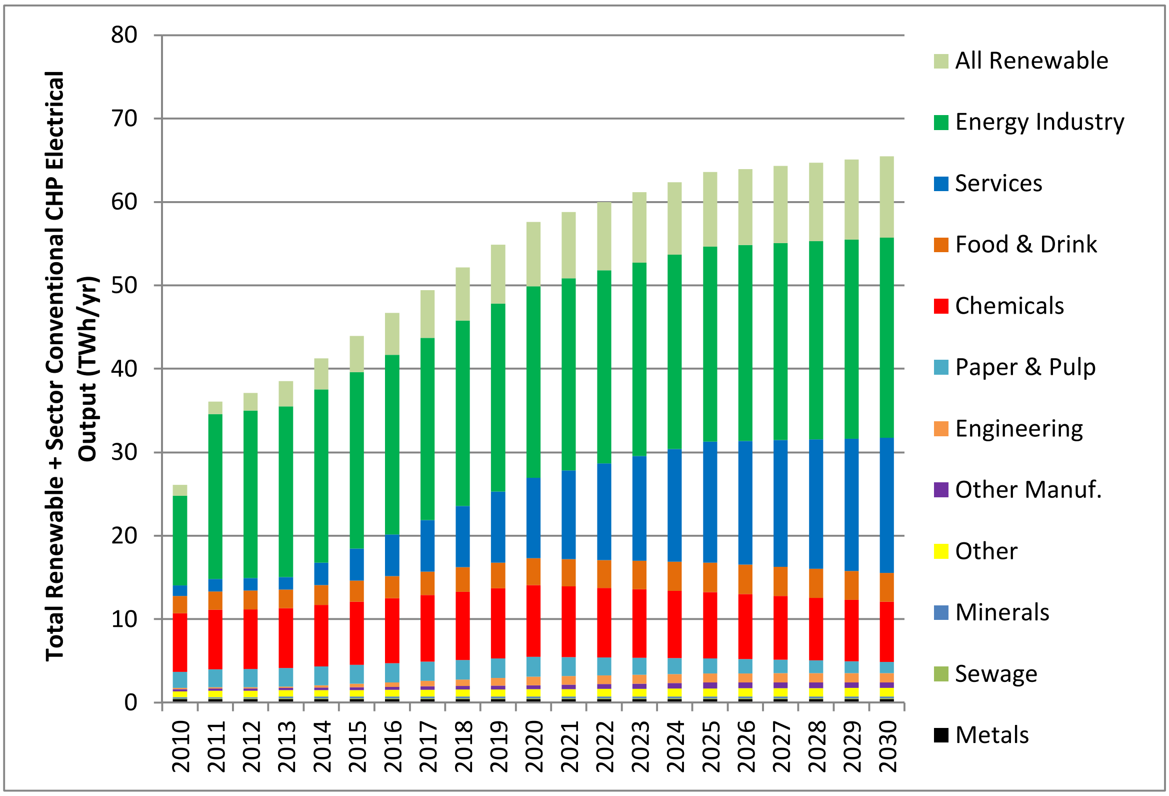


Figure A4 Good Quality renewable CHP electrical output projection, TWh/yr

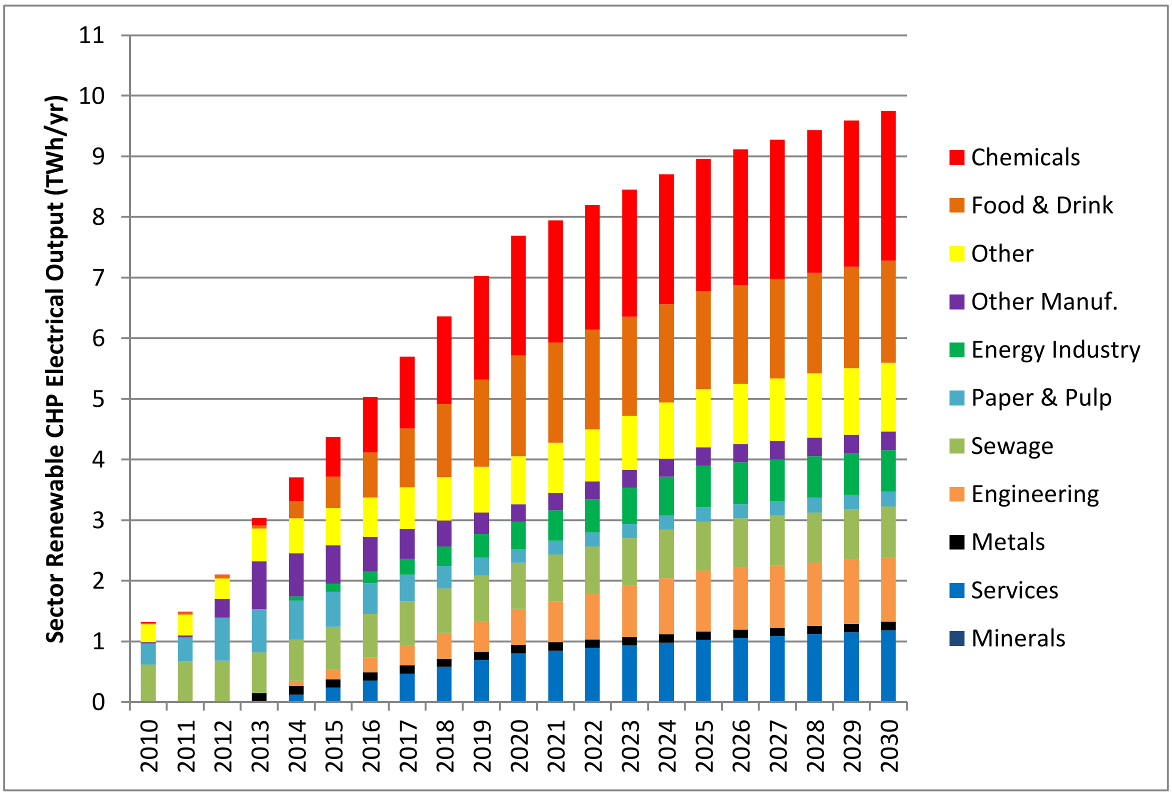


Table A3 CHP heat output projection TWh/yr

Year	2010	2013	2020	2025	2030	2010-30 Absolute Growth	2010-30 Growth Factor
Total Conventional CHP	**45.617**	**50.411**	**54.682**	**61.067**	**63.235**	**17.618**	**1.39**
Total Renewable CHP	**2.198**	**4.484**	**10.989**	**13.312**	**14.607**	**12.409**	**6.65**
Total CHP	**47.815**	**54.895**	**65.671**	**74.379**	**77.842**	**30.027**	**1.63**
Conventional CHP							
Energy Industry	16.752	19.739	20.734	21.002	21.854	5.103	1.30
Chemicals	14.342	14.492	9.348	8.737	8.232	-6.110	0.57
Services	2.214	2.588	11.670	17.516	19.531	17.317	8.82
Food & Drink	4.085	4.383	4.419	4.900	4.744	0.659	1.16
Paper & Pulp	4.227	4.704	2.224	1.911	1.541	-2.686	0.36
Other	1.140	1.281	1.789	2.152	2.515	1.375	2.21
Engineering	0.180	0.183	1.250	1.297	1.364	1.183	7.56
Other Manuf.	0.400	0.405	0.597	0.891	0.787	0.388	1.97
Minerals	0.593	0.945	0.945	0.945	0.945	0.351	1.59
Sewage	0.108	0.116	0.130	0.140	0.145	0.037	1.35
Metals	1.575	1.576	1.576	1.576	1.576	0.000	1.00
Renewable CHP							
Chemicals	0.051	0.567	2.848	3.610	3.972	3.920	77.34
Other	0.413	0.528	1.300	1.852	2.401	1.988	5.82
Food & Drink	0.020	0.246	1.864	1.897	2.001	1.981	100.18
Sewage	0.739	0.822	0.918	0.986	1.018	0.279	1.38
Other Manuf.	0.081	0.646	0.646	0.308	0.316	0.235	3.90
Energy Industry	-	-	1.169	1.754	1.754	1.754	N/A
Paper & Pulp	0.892	1.426	0.476	0.490	0.494	-0.398	0.55
Engineering	0.000	0.000	0.596	1.020	1.072	1.071	5,120.31
Metals	-	0.240	0.240	0.240	0.240	0.240	N/A
Services	0.001	0.009	0.932	1.154	1.340	1.339	1,085.08
Minerals	-	-	-	-	-	-	N/A

Figure A5 CHP heat output (Conventional and Renewable) projection, TWh/yr

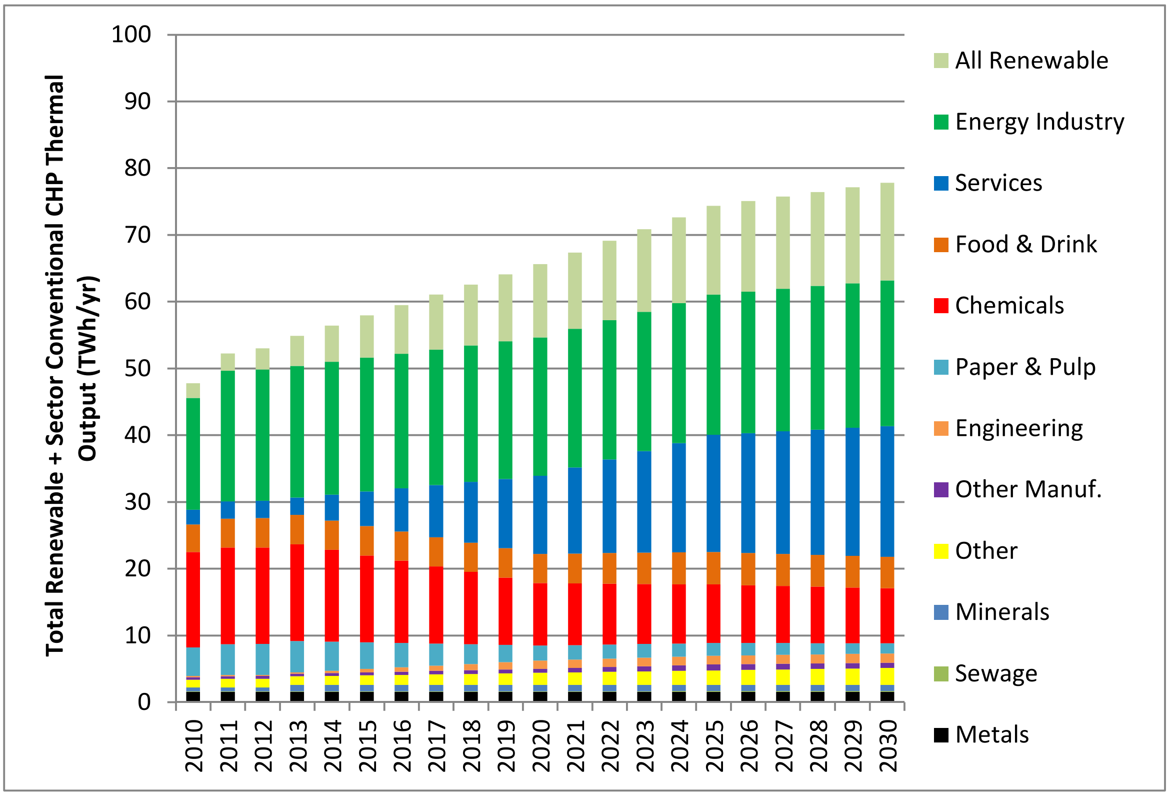
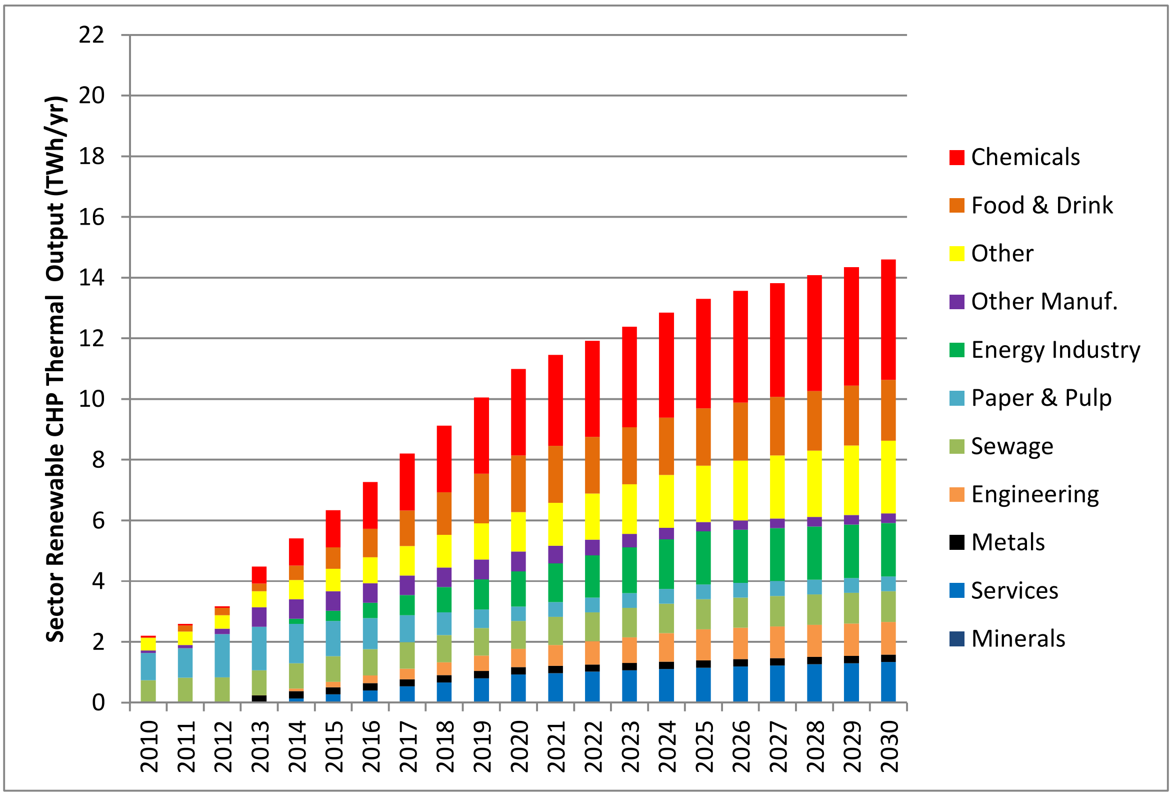


Figure A6 Renewable CHP thermal output projection, TWh/yr



Annex 2 - Examples of modelling segmentations

Table A4 Example of modelling segmentations for EU-ETS Sites

CHEMICLS paints	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	-	-	-	-	-	-
Avg Site electric demand (TJpa)	-	-	-	-	-	-
Avg Site heat demand (TJpa)	-	-	-	-	-	-
Total Tranche Heat Demand (TJpa)	-	-	-	-	-	-
Demand H:P	0.000	0.000	0.000	0.000	0.000	0.000
CHEMICLS rubber poly	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	-	1	1	1	1	1
Avg Site electric demand (TJpa)	-	122	296	164	252	896
Avg Site heat demand (TJpa)	-	170	255	261	297	1,058
Total Tranche Heat Demand (TJpa)	-	170	255	261	297	1,058
Demand H:P	0.000	1.393	0.862	1.597	1.180	1.180
CHEMICLS miscell	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	11	1	1	1	1	1
Avg Site electric demand (TJpa)	49	42	329	311	731	1,726
Avg Site heat demand (TJpa)	259	550	1,094	1,533	3,603	8,505
Total Tranche Heat Demand (TJpa)	2,851	550	1,094	1,533	3,603	8,505
Demand H:P	5.325	13.048	3.327	4.928	4.928	4.928
CHEMICLS resins	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	-	1	1	1	1	1
Avg Site electric demand (TJpa)	-	23	24	83	49	249
Avg Site heat demand (TJpa)	-	96	300	379	418	624
Total Tranche Heat Demand (TJpa)	-	96	300	379	418	624
Demand H:P	0.000	4.247	12.583	4.588	8.447	2.503
CHEMICLS soap	0.000	4.247	12.583	4.588	8.447	2.503
No of sites in size tranche	-	-	-	-	1	1
Avg Site electric demand (TJpa)	-	-	-	-	122	452
Avg Site heat demand (TJpa)	-	-	-	-	145	540
Total Tranche Heat Demand (TJpa)	-	-	-	-	145	540
Demand H:P	0.000	0.000	0.000	0.000	1.197	1.197
CHEMICLS pharms	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	8	6	3	2	2	1
Avg Site electric demand (TJpa)	40	51	110	198	297	731
Avg Site heat demand (TJpa)	105	209	435	567	647	2,094
Total Tranche Heat Demand (TJpa)	841	1,254	1,305	1,133	1,293	2,094
Demand H:P	2.653	4.104	3.942	2.865	2.179	2.865
CHEMICLS organics	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	8	1	1	1	1	1
Avg Site electric demand (TJpa)	147	187	523	207	1,351	1,730
Avg Site heat demand (TJpa)	155	832	875	1,547	2,896	3,708
Total Tranche Heat Demand (TJpa)	1,242	832	875	1,547	2,896	3,708
Demand H:P	1.052	4.444	1.674	7.470	2.144	2.144
CHEMICLS syn fibres	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	-	-	1	1	1	1
Avg Site electric demand (TJpa)	-	-	139	354	149	58
Avg Site heat demand (TJpa)	-	-	126	885	1,661	5,146
Total Tranche Heat Demand (TJpa)	-	-	126	885	1,661	5,146
Demand H:P	0.000	0.000	0.904	2.502	11.181	88.597
CHEMICLS dyes and pigs	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	-	1	1	1	1	1
Avg Site electric demand (TJpa)	-	1	57	128	138	257
Avg Site heat demand (TJpa)	-	6	372	717	903	1,257
Total Tranche Heat Demand (TJpa)	-	6	372	717	903	1,257
Demand H:P	0.000	5.596	6.533	5.596	6.533	4.885
CHEMICLS inorganics	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	7	2	1	1	1	1
Avg Site electric demand (TJpa)	113	1,018	1,200	1,593	7,173	5,678
Avg Site heat demand (TJpa)	307	1,543	1,820	2,417	3,214	8,612
Total Tranche Heat Demand (TJpa)	2,148	3,087	1,820	2,417	3,214	8,612
Demand H:P	2.708	1.517	1.517	1.517	0.448	1.517

Due to the small number of sites in many EU-ETS sectors it is not possible to collate these into six groups of similar heat demand.

Table A5 Example of modelling segmentations for Non EU-ETS Sites

COMMER warehouses	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**14,790**	**10,620**	**7,365**	**4,765**	**2,629**	**919**
Avg Site electric demand (TJpa)	**0.4**	**0.5**	**0.8**	**1.2**	**2.1**	**6.0**
Avg Site heat demand (TJpa)	**0.3**	**0.5**	**0.7**	**1.0**	**1.9**	**5.4**
Total Tranche Heat Demand (TJpa)	**4,910**	**4,915**	**4,921**	**4,911**	**4,917**	**4,918**
Demand H:P	0.885	0.885	0.885	0.885	0.885	0.885
COMMER retail	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**2,680**	**2,252**	**1,770**	**1,312**	**939**	**347**
Avg Site electric demand (TJpa)	**1.6**	**1.9**	**2.4**	**3.1**	**4.9**	**12.4**
Avg Site heat demand (TJpa)	**0.4**	**0.4**	**0.6**	**0.7**	**1.1**	**2.9**
Total Tranche Heat Demand (TJpa)	**990**	**996**	**977**	**948**	**1,058**	**996**
Demand H:P	0.232	0.232	0.232	0.232	0.232	0.232
COMMER public build	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**14,225**	**8,601**	**5,941**	**3,900**	**2,442**	**888**
Avg Site electric demand (TJpa)	**0.3**	**0.4**	**0.7**	**1.0**	**1.6**	**4.4**
Avg Site heat demand (TJpa)	**0.4**	**0.6**	**1.0**	**1.4**	**2.3**	**6.4**
Total Tranche Heat Demand (TJpa)	**5,640**	**5,548**	**5,729**	**5,604**	**5,659**	**5,713**
Demand H:P	1.461	1.461	1.461	1.461	1.461	1.461
COMMER offices	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**1,316**	**1,088**	**799**	**539**	**327**	**139**
Avg Site electric demand (TJpa)	**0.4**	**0.5**	**0.7**	**1.0**	**1.6**	**3.9**
Avg Site heat demand (TJpa)	**0.3**	**0.4**	**0.5**	**0.7**	**1.2**	**3.0**
Total Tranche Heat Demand (TJpa)	**396**	**396**	**397**	**390**	**390**	**411**
Demand H:P	0.750	0.750	0.750	0.750	0.750	0.750
COMMER hotels	0.750	0.750	0.750	0.750	0.750	0.750
No of sites in size tranche	**6,158**	**5,338**	**4,265**	**3,256**	**2,087**	**818**
Avg Site electric demand (TJpa)	**0.7**	**0.8**	**1.0**	**1.3**	**2.1**	**5.3**
Avg Site heat demand (TJpa)	**0.6**	**0.7**	**0.8**	**1.1**	**1.7**	**4.4**
Total Tranche Heat Demand (TJpa)	**3,555**	**3,654**	**3,598**	**3,607**	**3,604**	**3,608**
Demand H:P	0.829	0.829	0.829	0.829	0.829	0.829
COMMER district	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**-**	**-**	**-**	**-**	**-**	**-**
Avg Site electric demand (TJpa)	**-**	**-**	**-**	**-**	**-**	**-**
Avg Site heat demand (TJpa)	**-**	**-**	**-**	**-**	**-**	**-**
Total Tranche Heat Demand (TJpa)	**-**	**-**	**-**	**-**	**-**	**-**
Demand H:P	1.683	1.683	1.683	1.683	1.683	1.683
COMMER health	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**623**	**476**	**375**	**286**	**178**	**98**
Avg Site electric demand (TJpa)	**0.6**	**0.8**	**1.0**	**1.3**	**2.0**	**3.7**
Avg Site heat demand (TJpa)	**1.2**	**1.6**	**2.0**	**2.7**	**4.2**	**8.0**
Total Tranche Heat Demand (TJpa)	**758**	**776**	**765**	**765**	**756**	**785**
Demand H:P	2.139	2.139	2.139	2.139	2.139	2.139
COMMER education	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
No of sites in size tranche	**7,377**	**5,289**	**3,829**	**2,657**	**1,703**	**692**
Avg Site electric demand (TJpa)	**0.4**	**0.5**	**0.8**	**1.1**	**1.7**	**4.2**
Avg Site heat demand (TJpa)	**0.6**	**0.9**	**1.2**	**1.7**	**2.7**	**6.7**
Total Tranche Heat Demand (TJpa)	**4,637**	**4,638**	**4,637**	**4,638**	**4,639**	**4,639**
Demand H:P	1.599	1.599	1.599	1.599	1.599	1.599

Annex 3 - Example of modelling sector/size representations and the ascribed probabilities

Table A5 Example of modelling sector/size representations and the ascribed probabilities

EU-ETS Sites

	Proposed (sites allocated to all 6 tranches of approx equal total TWh Heat)					
Max Probability	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
CHEMICLS paints	0.00	0.00	0.00	0.00	0.00	0.00
no of Sites	0	0	0	0	0	0
CHP Type	0.00	0.00	0.00	0.00	0.00	0.00
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	0.00	0.00	0.00
CHEMICLS rubber poly	0.00	1.00	1.00	1.00	1.00	1.00
no of Sites	0	1	1	1	1	1
CHP Type	0.00	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	0.00	8.88	13.35	13.66	15.55	55.30
CHEMICLS miscell	0.50	1.00	1.00	1.00	1.00	1.00
no of Sites	11	1	1	1	1	1
CHP Type	5-25MWeBiomass	5-25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	11.35	24.09	47.93	67.14	157.82	372.56
CHEMICLS resins	0.00	1.00	1.00	1.00	1.00	1.00
no of Sites	0	1	1	1	1	1
CHP Type	0.00	1-3MWeBioliquid	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.00	2.12	6.63	8.36	9.22	13.77
CHEMICLS soap	0.00	0.00	0.00	0.00	1.00	1.00
no of Sites	0	0	0	0	1	1
CHP Type	0.00	0.00	0.00	0.00	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	0.00	5.42	20.14
CHEMICLS pharms	1.00	0.50	0.75	0.50	0.50	1.00
no of Sites	8	6	3	2	2	1
CHP Type	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	2.32	4.61	9.59	12.49	14.26	46.16
CHEMICLS organics	0.75	1.00	1.00	1.00	1.00	1.00
no of Sites	8	1	1	1	1	1
CHP Type	5-25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	7.53	40.35	41.68	73.70	135.51	173.51
CHEMICLS syn fibres	0.00	0.00	1.00	1.00	1.00	1.00
no of Sites	0	0	1	1	1	1
CHP Type	0.00	0.00	5-25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	0.00	0.00	11.97	84.37	155.54	481.92
CHEMICLS dyes and pigs	0.00	1.00	1.00	1.00	1.00	1.00
no of Sites	0	1	1	1	1	1
CHP Type	0.00	<1MWeBioliquid	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.00	0.13	5.09	9.80	12.35	16.69
CHEMICLS inorganics	1.00	1.00	1.00	1.00	1.00	1.00
no of Sites	7	2	1	1	1	1
CHP Type	5-25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	8.81	44.30	53.63	69.94	93.00	249.19
ENGINEER mechanical	1.00	1.00	1.00	1.00	1.00	0.00
no of Sites	1	1	1	1	1	1
CHP Type	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	8.69	8.75	8.83	9.94	10.49	45.26
ENGINEER electric	0.00	0.00	0.00	0.00	0.00	0.00
no of Sites	0	0	0	0	0	0
CHP Type	0.00	0.00	0.00	0.00	0.00	0.00
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	0.00	0.00	0.00
ENGINEER vehicles	1.00	0.50	0.50	0.50	0.50	0.50
no of Sites	6	4	4	3	2	2
CHP Type	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	2.87	6.26	7.65	7.52	15.01	22.06

Non EU-ETS Sites

	Proposed (sites allocated to all 6 tranches of approx equal total TWh Heat)					
Suitability	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
CHEMICLS paints	1.00	1.00	1.00	1.00	1.00	1.00
no of Sites	1	1	1	2	2	1
CHP Type	<1MWeBioliquid	<1MWeBioliquid	<1MWeBioliquid	<1MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	2.16	2.18	2.31	2.68	3.43	6.72
CHEMICLS rubber poly	1.00	1.00	1.00	1.00	1.00	1.00
no of Sites	1	1	1	1	1	1
CHP Type	<1MWeBioliquid	<1MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	2.22	2.56	5.47	7.16	12.38	12.72
CHEMICLS miscell	1.00	1.00	1.00	0.75	0.50	0.50
no of Sites	16	10	7	6	2	2
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	1.31	1.98	2.60	4.37	8.01	15.26
CHEMICLS resins	0.50	1.00	1.00	1.00	0.75	0.75
no of Sites	73	44	30	22	15	11
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.91	1.54	2.27	3.08	4.36	6.43
CHEMICLS soap	0.50	0.50	1.00	0.75	0.75	0.75
no of Sites	22	16	8	5	3	3
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.71	1.06	1.83	3.61	6.41	5.96
CHEMICLS pharms	1.00	1.00	0.75	0.75	0.75	0.75
no of Sites	49	26	18	13	10	5
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	1.29	2.42	3.49	5.14	6.49	13.14
CHEMICLS organics	1.00	0.75	1.00	1.00	1.00	1.00
no of Sites	71	35	21	10	10	5
CHP Type	<1MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	>25MWeBiomass
Avg Site CHP electric capacity (MW)	2.52	5.07	8.75	16.25	17.26	39.02
CHEMICLS syn fibres	1.00	1.00	1.00	1.00	1.00	1.00
no of Sites	1	1	1	1	1	1
CHP Type	<1MWeBioliquid	<1MWeBioliquid	<1MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	3-5MWeBiomass
Avg Site CHP electric capacity (MW)	0.68	0.92	0.98	2.25	3.28	4.95
CHEMICLS dyes and pigs	1.00	1.00	1.00	1.00	0.75	0.75
no of Sites	21	11	6	5	4	2
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.57	1.21	1.80	2.52	3.41	6.47
CHEMICLS inorganics	1.00	1.00	1.00	1.00	1.00	1.00
no of Sites	31	14	9	4	4	2
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass	5-25MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	1.27	2.76	4.35	8.31	11.81	23.40
ENGINEER mechanical	1.00	1.00	1.00	0.00	1.00	0.00
no of Sites	2	1	3	1	1	1
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	3-5MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	1.83	2.51	3.07	5.21	6.63	11.66
ENGINEER electric	1.00	1.00	1.00	0.50	0.50	0.50
no of Sites	8	7	6	3	3	2
CHP Type	<1MWeBioliquid	<1MWeBioliquid	<1MWeBioliquid	3-5MWeBiomass	3-5MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	2.33	2.75	3.45	4.75	7.28	14.01
ENGINEER vehicles	1.00	1.00	1.00	1.00	0.50	0.25
no of Sites	82	56	36	22	11	11
CHP Type	<1MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	1-3MWeBioliquid	3-5MWeBiomass	5-25MWeBiomass
Avg Site CHP electric capacity (MW)	0.85	1.29	1.86	3.12	4.96	8.68

The above tables show how we have applied the restrictions to renewable CHP. The appropriate CHP technology and restricted technical potential is also shown. Where less than 6 EU-ETS sites exist in a sector, some tranches are blank.

The fraction figures shown in the sub sector named row i.e. the 0.75 for tranche 6 in the chemicals rubber polymer sub-sector (first row) indicates that we have restricted the probability of introducing renewable CHP in such sites to a maximum of 75%. In practice this figure is not likely to be reached, due to competition with conventional CHP which in the majority of cases is more financially attractive and therefore more likely to be the option actually taken up. The 0.75 limiting figure is therefore an absolute upper bound rather than the actual uptake figure.

Annex 4 – CHP Technology Characteristics

Conventional Fuel CHP

Reciprocating Gas Engines

As in petrol car engines, reciprocating spark engines 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 hot water can be recovered from the cooling fluid for site use which would otherwise be wasted. In addition, residual heat remains in the exhaust fumes which can also be recovered as hot water or steam instead of being wasted to the atmosphere.

The electrical efficiency ranges from around 30% for smaller engines around 100kWe up to around 40% for 4MWe gas engines based on Gross Calorific Value 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). However if the value of power is high compared to the cost of fuel it may be more economic to generate maximum power and waste excess heat.

Gas Turbines

In gas turbines air is compressed to a high pressure, and fuel is burned steadily (not explosively) in the compressed air within a combustion chamber and finally expanded in turbines (which drive the compressor and provide shaft power output). The combustion chamber does not increase the pressure of the fuel/air mix as in a reciprocating engine, but rather increases the temperature. The combustion gas temperature drops across the turbines, and therefore the mechanical energy extracted by the turbines, exceeds the energy required to drive in the compressor and so the surplus mechanical energy can be used to drive a generator. Residual heat remains in the exhaust fumes which can be recovered instead of wasted to the atmosphere.

The electrical efficiency is lower than similarly sized 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.

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.

Steam Turbines

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, 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.
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, but are likely to increase. 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.

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

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.
The high pressure steam required by turbines can either be generated in fired boilers or recovered from gas turbines (see CCGT below). 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.

Combined Cycle Gas Turbines (CCGT)
In a CCGT residual heat from a gas turbine is used to generate steam which is then used to drive a steam turbine which can either be back pressure or condensing. 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) (GCV), but this is reduced in CHP operation where the turbine is designed as a pass-out steam turbine allowing steam to be extracted from the turbine to meet the site's steam demand. This results in a drop in power generation. It is also possible to form a CCGT scheme by coupling reciprocating engines and steam turbines but this is uncommon.

Renewable CHP

Biomass Boiler with Steam Turbines

This is most commonly employed technology for renewable CHP schemes, over 3MWe in size. Smaller steam turbines are very inefficient, particularly in CHP mode, and therefore uncommon. The characteristics of Condensing Pass-out and Back Pressure Steam Turbines are explained above.

Reciprocating Bio-liquid Engines

Bio-liquids such as biodiesel and bioethanol can be burned in reciprocating engines with the same technology as diesel and petrol car engines as explained above for natural gas engines. Most small scale renewable CHP schemes are bio-liquid engines operating on the diesel cycle. The efficiency is slightly higher than for natural gas engines due to the more efficient diesel cycle.
As with natural gas engines, 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). However, if the value of power is high compared to the cost of fuel it may be more economic to generate maximum power and waste excess heat.

Biomass Indirect Air Turbines

This is a relatively new technology for small applications up to around 100kWe where steam turbines would be very inefficient with small but growing market penetration to date.
An indirect air turbine operates on a similar same principle to the conventional gas turbine except that the working fluid which moves the turbine is clean air heated by combustion gases in a heat exchanger as biomass combustion products contain tar and other chemicals which present problems for gas turbine operation. Hot water can be generated from residual heat in the clean air and/or combustion gases.

Reciprocating Steam Engines

Reciprocating Steam engines used in early locomotives are relatively inefficient and have high maintenance compared to the alternatives and therefore not commonly employed.

Organic Rankine Cycles

Organic Rankine cycles operate on the same principle as steam turbines except that the working fluid is not water, but either a fluid with a relatively low boiling point, such as a refrigerant, or with a relatively high boiling point such as oil. Low temperature fluids allow power to be generated at lower temperatures than conventional steam turbines and can achieve higher electrical efficiencies for smaller capacities below 1MWe.

However, the working fluid is at a very low temperature after power generation and therefore of limited value or else the working fluid must be diverted to supply heat prior to entering the turbine, which is outside the definition of CHP. High temperature oils on the other hand offer the opportunity to extract heat from the condenser without incurring a penalty on power output as the condensing temperature of oil is higher than that of water and therefore the grade of heat is still useful. Organic Rankine cycles are a relatively new technology with little operating experience in the CHP market.

Annex 5 – Design and Operation Heat to Power Ratio

As explained above, the ratio of available heat to the amount of power generated (heat to power ratio) for engines, open cycle gas turbines and back pressure steam turbines is determined by the CHP design and is approximately the same regardless of how much fuel is used and power generated. This ratio may vary slightly with modulation, but cannot be controlled by the operator in operation. The higher the power output the higher the heat output and vice versa. When the ratio of heat demand to power demand is lower, the generator must either be modulated to suit the heat load, resulting in a shortfall in power output, or run at full output/modulated to suit power demand and excess heat wasted. If the CHP follows the electrical load and wastes heat, it may not fully qualify as Good Quality CHP so modulating to follow heat demand is best practice. However, for pass-out steam turbines, the less heat that is extracted, the more power is generated. In CHPQA, the ratio of heat extracted to loss of power output is defined as the Z ratio, not to be confused with heat to power ratio. Heat extracted at a lower pressure, i.e. at a later turbine stage, will incur less of a power drop and therefore a higher Z ratio, so heat should only be extracted at the required grade no higher.

In general, the overall CHP efficiency and primary energy savings generally increase as the heat (usefully used) to power ratio is maximised. However, where electricity values are high, it may be more economic to operate at lower heat to power ratios. To encourage energy efficient CHP operation CHPQA uses a Quality Index (QI) to assess the overall efficiency of CHP compared to the alternative forms of separate heat and power generation and if a QI of 100 is achieved, all generated electricity is considered as coming from Good Quality CHP http://chpqa.decc.gov.uk/.

For conventional CHP, Climate Change Levy (CCL) on electricity can be avoided and for renewable CHP, additional ROCs (or a "ROC uplift") are currently awarded on every MWh of electricity which qualifies as GQCHP in addition to the 1.5 ROCs awarded for non-CHP power generation. The ROCs benefit is usually maximised when just enough heat is extracted to achieve a CHPQA QI of 100. The CHP would therefore typically be sized and operated to achieve a QI of 100 either on electrical demand or heat demand whichever gives the most economical design. It is believed that, under the current RO banding, developers are commonly sizing renewable CHP schemes to give the maximum annual electrical output which can achieve a QI of 100 for a given annual site heat demand with any surplus power exported. However, from April 2015, for new schemes, it is proposed that the ROC uplift will be replaced by an RHI tariff. This will incentivise a site to design and operate renewable CHP to meet all of its heat demand, but the ROC benefits on electricity generation will be reduced so it is likely that future CHP schemes will be designed with smaller electrical capacities to match their heat and electrical demands without high levels of electricity export.

The technical and cost characteristics assumed for modelled CHP technologies are summarised below and assume steam turbine and CCGT schemes are designed to give a QI of around 100. As shown in Annex 6, the biomass technologies covered in this study range from <1MWe Bio-liquid engines to >25MWe biomass steam turbines. Air turbine, steam engine and Organic Rankine Cycle CHP schemes are rare and therefore not considered in this analysis.

Annex 6 – Key Techno-Economic CHP Assumptions

Table A6 Techno-economic CHP assumptions for conventional CHP

CHP Electrical Capacity	<=1MWe	1- 3.7MWe	3.7-7 MWe	7-40 MWe	40-200MWe	>200 MWe
Assumed Fuel	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Generating technology	Reciprocating Engine	Reciprocating Engine	Open Cycle Gas Turbine	Open Cycle Gas Turbine	CCGT	CCGT
Example Heat Grade	Hot Water	Hot Water	11.4Bara Steam	11.4Bara Steam	11.4Bara Steam	11.4Bara Steam
Ratio of heat Extracted / reduction in gross power output (Z ratio)	N/A	N/A	N/A	N/A	4.4	4.4
Gross Electrical efficiency in Fully Condensing Mode (GCV fuel basis)	34%	34%	30%	35%	45%	45%
Operating electrical efficiency in CHP Mode (GCV fuel basis)	34%	34%	30%	35%	39%	39%
Operating thermal efficiency (GCV fuel basis)	41%	41%	48%	42%	27%	27%
Operating total power + heat efficiency (GCV fuel basis)	75%	75%	78%	77%	66%	66%
Heat to Power Ratio	1.2	1.2	1.6	1.2	0.7	0.7
Standard CHPQA X value based on GN10	249	195	195	186-195	176-186	172-173
Standard CHPQA Y value based on GN10	115	115	115	115	115	115
QI	132	113	114	113 - 117	100-104	98 - 99
Capex £/MWe (2012 real)	£942/ kWe x Capacity (MWe) ^-0.15	£942/ kWe x Capacity (MWe) ^-0.15	£1,600/ kWe x Capacity (MWe) ^-0.22	£3,138/ kWe x Capacity (MWe) ^-0.43	£1,318/kWe x Capacity (MWe) ^-0.1	£774/ kWe
Opex 2012 Real)	£12.55/MWhe	£10.46/MWhe	£9.42/MWhe	£8.37/MWhe	£6.28/MWhe	£6.28/MWhe
Opex % of Capex	Approx 7% /Yr	Approx 7% /Yr	Approx 5% /Yr	Approx 7% /Yr	Approx 5% /Yr	Approx 5% /Yr
Min power turndown ratio	50%	50%	25%	25%	25%	25%
Example Run Hrs / Yr	5,600 (Service Sector)	5,600 (Service Sector)	6,500 (Industry)	6,500 (Industry)	6,500 (Industry)	6,500 (Industry)

Table A7 Techno-economic CHP assumptions for renewable CHP

CHP Electrical Capacity	<=1MWe	1-3 MWe	3-5 MWe	5-25 MWe	>25 MWe
Example Fuel	Biodiesel	Biodiesel	Agricultural Biomass	Agricultural Biomass	Agricultural Biomass
Generating technology	Reciprocating Engine	Reciprocating Engine	Pass-out Steam Turbine	Pass-out Steam Turbine	Pass-out Steam Turbine
Example Grade of Heat	Hot Water	Hot Water	11.4Bara Steam	11.4Bara Steam	11.4Bara Steam
Ratio of heat Extracted / reduction in gross power output (Z Ratio)	N/A	N/A	5.7	5.3	4.4
Electrical efficiency in Fully Condensing Power Mode (Gross Power GCV fuel basis)	35%	35%	23%	25%	30%
Operating electrical efficiency in CHP Mode (gross power GCV fuel basis)	35%	35%	18.25% Currently but variable to suit site H:P when RHI replaces ROC Uplift	22.18% Currently but variable to suit site H:P when RHI replaces ROC Uplift	18.96% Currently but variable to suit site H:P when RHI replaces ROC Uplift
Operating thermal efficiency in CHP Mode (GCV fuel basis)	35%	35%	27.05% Currently but variable to suit site H:P when RHI replaces ROC Uplift	14.94% Currently but variable to suit site H:P when RHI replaces ROC Uplift	48.57% Currently but variable to suit site H:P when RHI replaces ROC Uplift
Operating total gross power + heat efficiency in CHP Mode (GCV fuel basis)	70%	70%	45.30% Currently but variable to suit site H:P when RHI replaces ROC Uplift	37.12% Currently but variable to suit site H:P when RHI replaces ROC Uplift	67.53% Currently but variable to suit site H:P when RHI replaces ROC Uplift
CHP Operating H:P (based on gross power output)	1.0	1.0	1.5 Currently but variable to suit site H:P when RHI replaces ROC Uplift	0.7 Currently but variable to suit site H:P when RHI replaces ROC Uplift	2.6 Currently but variable to suit site H:P when RHI replaces ROC Uplift
Standard CHPQA X value based on GN10	275	191	370	370	220
Standard CHPQA Y value based on GN10	120	120	120	120	120
QI	138	109	100 Currently but variable to suit site H:P when RHI replaces ROC Uplift	100 Currently but variable to suit site H:P when RHI replaces ROC Uplift	100 Currently but variable to suit site H:P when RHI replaces ROC Uplift
Parasitic Load % of Generated Electricity	0%	0%	10.00%	10.00%	10.00%
Capex £/MWe fully condensing (2011 real)	£1,130/ kWe x Capacity (MWe) ^-0.15	£1,130/ kWe x Capacity (MWe) ^-0.15	£3,661 / kWe	£3,661 / kWe	£3,661 / kWe
Opex £/MWhe fully condensing (2012 Real)	£13.81/MWhe	£11.51/MWhe	£20.92/MWhe	£20.92/MWhe	£20.92/MWhe
Opex % of Capex	Approx 6% /Yr	Approx 7% /Yr	Approx 4% /Yr	Approx 4.5% /Yr	Approx 4% /Yr
Min power turndown ratio	50%	50%	25%	25%	25%
Example Run Hrs / Yr	5,600 (Service Sector)	6,500 (Industry)	6,500 (Industry)	6,500 (Industry)	6,500 (Industry)

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