RICARDO-AEA

Review of the Reference Values for High-Efficiency Cogeneration

Final Report

Report for EC DG Energy

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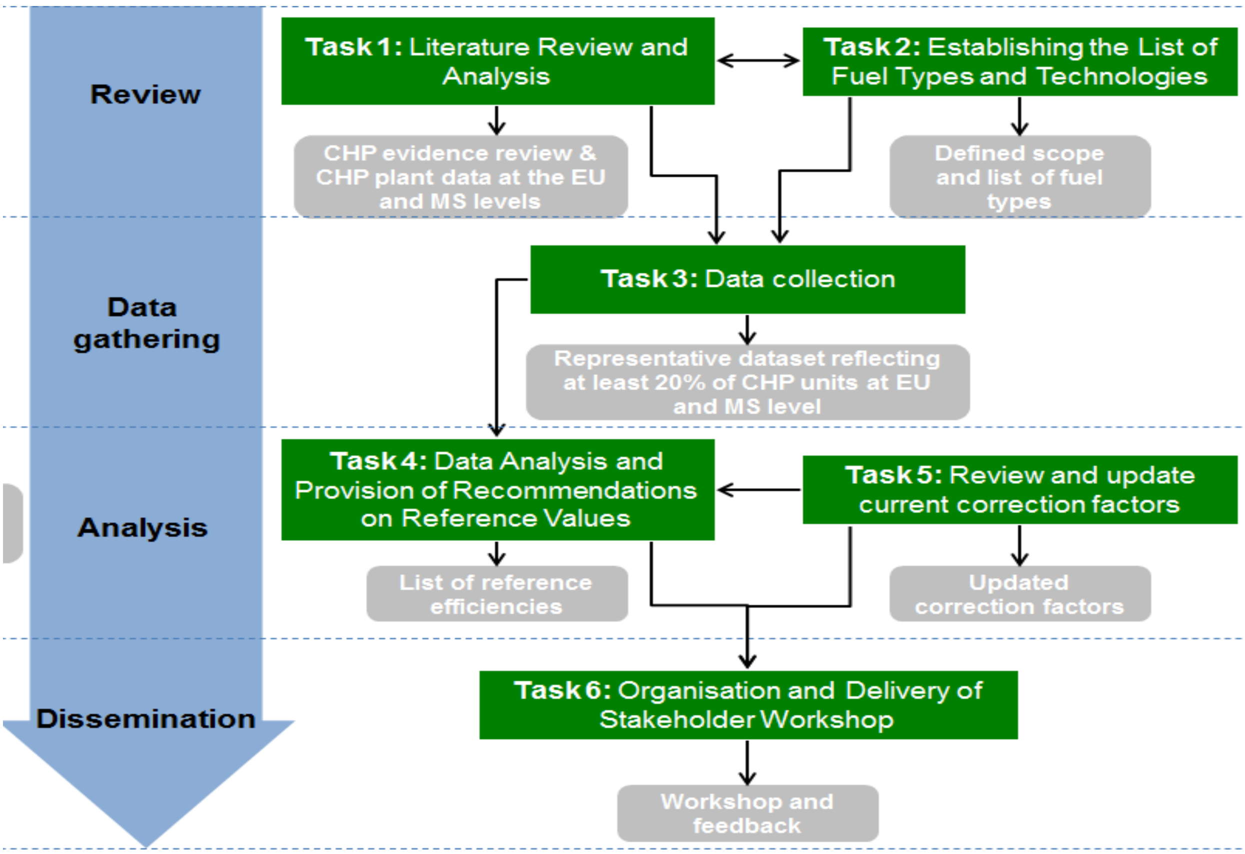
Executive summary

This report is prepared as part of a project led by Ricardo-AEA on reviewing the cogeneration reference efficiencies as required by Article 14(10) of the Energy Efficiency Directive (EED). The overall purpose of the study at the core of this report is to develop a list of harmonised reference values for the separate production of electricity and heat for the period 2016 – 2019. The approach chosen to achieve this objective has aimed to be comprehensive and versatile, encompassing consultation with the relevant stakeholders and industry in the power generation, heat generation and cogeneration industries.

Section 1 of the report provides an introduction to the project, explaining its rationale within the context of the EED requirements and describing the methodology followed.

The project responds to the need to be able to compare the impacts of Member States' cogeneration policies on a like-for-like basis, while taking into account the latest technological developments and changes in the distribution of energy sources.

According to the Energy Efficiency Directive (EED), in order to be judged as High Efficiency CHP, cogeneration plants must, when compared with the separate generation of electricity and heat, provide primary energy savings (PES) ≥ 10% for plants with a capacity of 1 MWe or greater (≥ 0% for schemes with capacity less than 1 MWe). This is why it is important to define reference efficiencies for the separate generation of heat and electricity in order to calculate the PES. In this regard, the methodology adopted was based on a full overview of the existing relevant scientific literature and other evidence, including best available technologies. Below a graphic describing the overall approach:



Section 2 provides a summary of historic development of the cogeneration market in Europe and describes the current status of the market.

This section of the report provides the necessary understanding of the current status of cogeneration technologies and fuels instrumental in the process of developing the list of reference values.

The current situation of the CHP market in Europe has been reviewed through data collection and detailed analysis of CHP data extracted from Eurostat and IEA databases and provided by contacts in different countries. Moreover, the CODE project, led by COGEN Europe, (developed for policy purposes and requiring each each Member State to include in their national reports an update of their national CHP legislation and identify the barriers for the development of CHP) has been analysed. Additional data sources, such as the Joint Research Centre (JRC) implementation report, National Energy Institutes and National Statistical Centres, have also been consulted.

In the current situation, the total installed capacity of conventional power plants in Europe is around 500 GW, of which around 20% is CHP capacity. According to Eurostat, the total installed CHP capacity across the EU increased from 102 GW in 2005 to 109 GW in 2012. The production of electricity from CHP in Europe has been steadily increasing in recent years. Analysis of IEA historic data for the EU-28 shows an increase of 60% in electricity produced from CHP plants since 1990 and 1.2% since 2005. Heat produced from CHP in the EU-28 has also increased by 1.1% since 1990 but decreased by 7.2% since 2005.

Renewable fuels, mainly biomass (used in steam turbine-based CHP), but also biogas (from AD plants and mainly used in engine-based CHP) and combustible waste (used in steam turbine-based CHP), are becoming increasingly important. These fuels, while small in absolute terms, have shown significant growth in recent years and are expected to continue to grow as fuels in CHP plants.

Section 3 gives a review of the fuels used in CHP plants in Europe. One of the objectives of the current project is to review the list of fuels currently used in CHP plants in order to establish whether additional categories need to be added to the currently list consisting of 17 fuel categories:

Fuel Category		Description
Solids (S)	1	Hard coal including anthracite, bituminous coal, sub-bituminous coal, coke, semi-coke, pet coke
	2	Lignite, lignite briquettes, shale oil
	3	Peat, peat briquettes
	4	Wood fuels including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse
	5	Agricultural biomass including logs, round wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains, contaminated waste wood
	6	Municipal and industrial waste (non-renewable) and renewable/ bio-degradable waste
Liquids (L)	7	Heavy fuel oil, gas/diesel oil, other oil products
	8	Bio-liquids including bio-methanol, bioethanol, bio-butanol, biodiesel, other liquid biofuels
	9	Waste liquids including biodegradable and non-renewable waste (including pyrolysis oils, black and brown liquor, tallow)
Gases (G)	10	Natural gas, LPG and LNG
	11	Refinery gases hydrogen and synthesis gas
	12	Biogas produced from anaerobic digestion, landfill, and sewage treatment
	13	Coke oven gas, blast furnace gas and other recovered gases (excluding refinery gas)
Others (O)	14	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)
	15	Nuclear
	16	Solar thermal
	17	Geothermal

It is worth noting that many CHP plants utilise both conventional fossil fuels and renewable fuels, either via co-firing or via flexibility to switch between fuels depending on availability. In this regard, a comprehensive analysis of the types of fuels and technologies used by cogeneration plants has been conducted in order to investigate the need for updating the aforementioned 17 fuel categories.

In terms of the main outcomes of the review carried out in this section, in general, it is recommended to keep the fuel categories as they are. The recommended changes for the current list of fuels are summarised in Table 7 below. Further justification to grouping the fuels as given below is given in Section 5.

In order to establish the electrical and heat efficiency reference values, power-only (i.e. from power stations) and heat-only (i.e. boiler) operational data for each of the fuels considered were required. Data from power plant and boilers installed after 2006 were required. It should be noted that in some cases this was not possible. For example, peat and ethane were identified as CHP fuels but, according to the Platts database, there are currently no power plant operating on these fuels.

Section 4 offers a summary of the data collection process, including its rationale and the difficulties encountered.

A major requirement for this project is the collection of operational data. In order to collect operational data from power stations and boilers operating with the fuels identified in Section 3. As a response to this need, questionnaires were developed. Separate questionnaires for power generation and heat generation data collection were developed and distributed via a link on the project website and as direct links to e-mails sent to targeted trade associations and plant operators. In the case of power generating plants, where Ricardo-AEA had already prepared a draft questionnaire spreadsheet (see below), the data required cover the following:

- Fuel consumption (for main fuel used on site)
- Percentage of the main fuel used on site
- Total electricity generated and delivered to the grid
- The electricity supplied to customers (if available)

For plants which operate in CHP mode, the heat output was also required. A boiler data collection questionnaire was sent to MS representatives (via the Commission) to collect data on a country-by-country basis.

In the attempt of gathering as much operational data as possible from power-only and heat-only plants, the developed questionnaires were sent to MS representatives and to Trade Associations. Despite this, insufficient data were collected both in terms of range and quantity.

Ideally, in order to formulate accurate reference values, operational data from several units/plants are required and this applies to each fuel type and/or heating application. The collected data however do not cover all of the fuels considered.

In overall, there is currently a lack of operational data for the majority of fuel types. Due to this lack of operational data, alternative approaches must be undertaken in order to establish future reference values.

Section 5 presents the methodology used in establishing the final recommended list of reference efficiencies, including pertinent explanatory notes and a detailed analysis of the data leading to the recommended values.

For gaseous fuels the operational efficiency needs to be normalised for ambient temperature, i.e. 0.1 percentage point increase or decrease if the ambient temperature is lower or higher than standard ISO conditions (15°C).

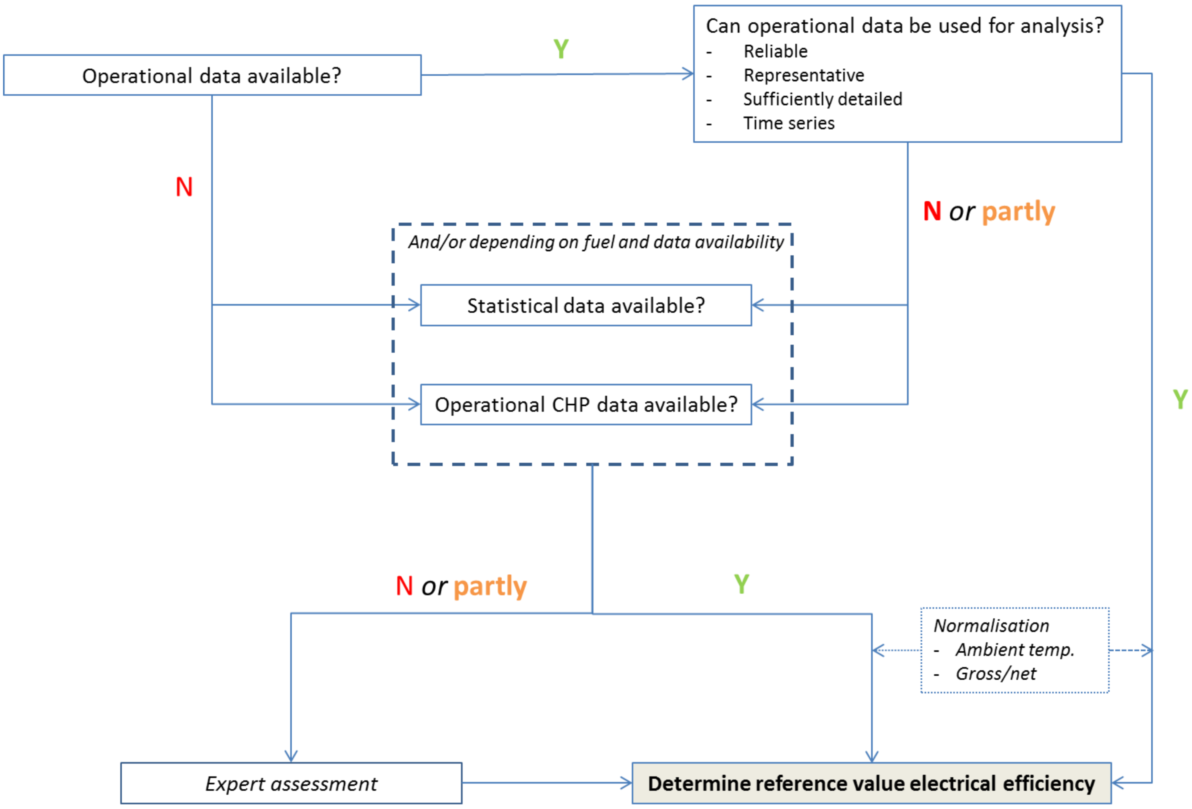
As stipulated by the Directive, the primary approach for each fuel is to collect operational data of power-only production.

Where operational data was received by the consultancy team, it has been scrutinised in order to assess whether it could be actually used for determining the electrical efficiency reference value.

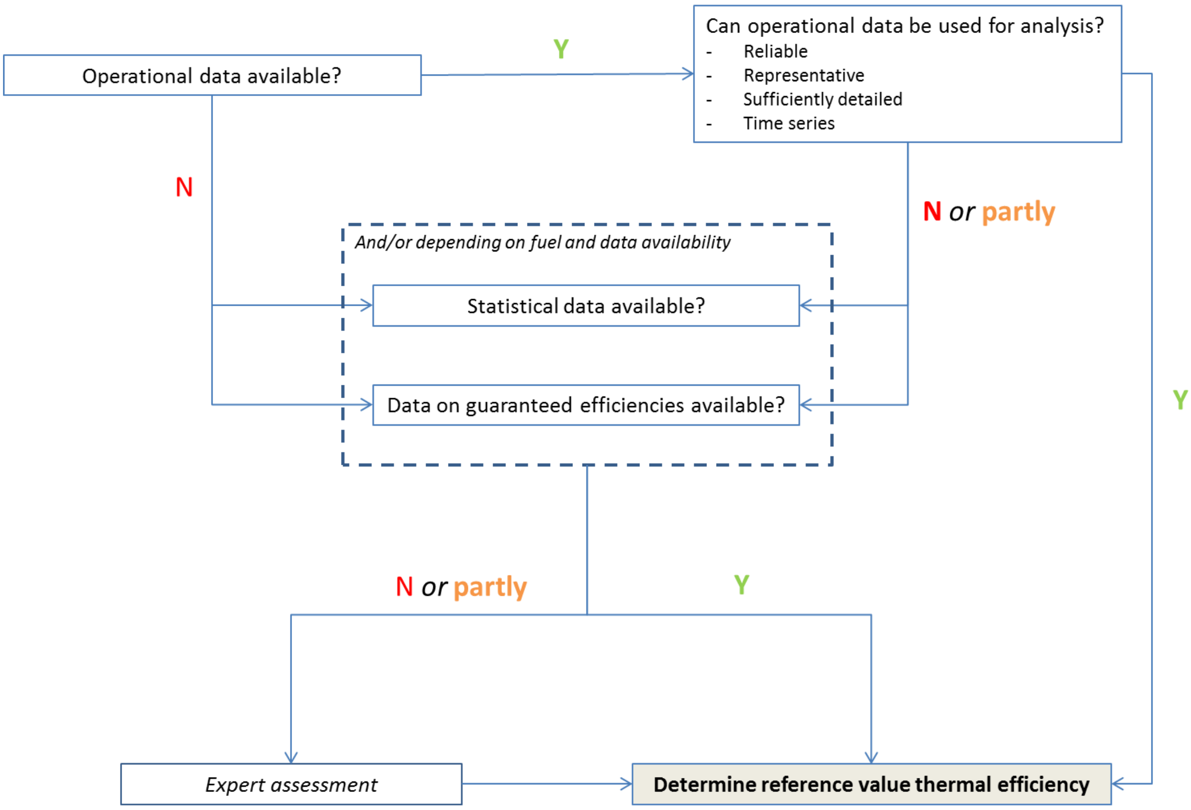
Criteria used for this assessment were

- Data reliability
- Transparency (has sufficient detail been provided regarding location & size of the plant, the (lower or higher) heating value of the fuel, input and output data)
- Representativeness of the data (data from old plants or demonstration plants e.g. do not qualify)
- The availability of time series (to ensure that the operational data does not only reflect and extremely good or bad year)

In case the operational data for an individual fuel passes all checks, they can be used for setting an efficiency reference value after normalisation of the data. In cases where the operational data does not pass or only partially passes the checks, alternative approaches had to be adopted in order to determine the electrical efficiency reference value. Depending on fuel type and data availability, either statistical data and/or data from CHP plants were used to determine the reference values. To follow a description of this logic process:



As for electricity, the approach selected for reviewing and updating the efficiency reference values for heat is to collect operational data of heat-only production. The criteria used for this assessment were the same as those described for the electricity. However, unlike electricity reference values, heat values should not be normalised for ambient conditions.



There is a need to propose that the Commission considers two reference electrical efficiencies for natural gas depending on the size of plant (100 MWe based on evidence). However, it has been considered that splitting the natural gas category into two reference values will add complexity to the existing reference values table. Therefore, it is finally recommended that the Commission does not consider this split for the period 2016-2019 but to revisit this in the next review.

Regarding the consideration of a capacity threshold for wood fuel, whilst a split in this category may have merits, there is insufficient evidence to suggest that the market would build small power-only plant without subsidy regimes that support such projects. Thus it is recommended keeping it as a single set of reference values with. On another related matter, it is also proposed that the reference values for steam should be lowered by five percentage points from the hot water reference values for each of the fuels. This reflects a mid-point in the range of efficiencies for the factors discussed above.

The key changes in the reference values are

- **For reference electrical efficiencies**
  - Maintaining the reference efficiency for
    - the coal, lignite and peat categories at the previous levels
    - the solid waste category at 25%
    - Biofuel at 44.2%
    - biogas at 42%
    - Oil at 44.2%
    - coke over gas, blast furnace gas, etc. at 35%
  - Increasing the reference efficiency for
    - wood fuels from 33% to 37%
    - agricultural biomass from 25% to 30%
    - the liquid waste category from 25% to 29%
    - natural gas from 52.5% to 53%
  - Decreasing the reference efficiency for
    - Refinery gas from 44.2% to 42%

  - Setting the reference efficiency for
    - Nuclear at 33%
    - Waste heat, solar thermal and geothermal at 30%

- **For reference heat efficiencies**
  - For the Hot water category
    - Maintaining the reference efficiencies for all solid fuels the same as previously
    - Deceasing the reference thermal efficiencies in the liquid fuel category as follows
      - For oil and biofuel (categories L7 AND I8), from 89% to 85%
      - For waste liquids, from 80% to 75%
    - Increasing the reference thermal efficiencies
      - For natural gas, from 90% to 92%
      - For refinery gas from 89% to 90%
      - For Biogas, from 70% to 80%
      - For coke over gas, etc., from 80% to 85%
    - Setting the reference heat efficiency for
      - Nuclear at 92%
      - Waste heat, solar thermal and geothermal at 100%
  - Splitting the hot water / steam categories into two separate categories (as discussed in Section 5.3.4) with steam reference efficiencies 5 percentage points lower than those of hot water (except for the waste heat, solar thermal and geothermal categories)
  - Making the reference efficiencies for the 'direct use of heat' category consistently 3 percentage points lower than those of steam (except for the waste heat, solar thermal and geothermal categories)

In summary the proposed reference values are:

Fuel Category		Description	Electrical efficiency %	Boiler efficiency, %		
				Hot Water	Steam	Direct Use
Solids (S)	1	Hard coal including anthracite, bituminous coal, sub-bituminous coal, coke, semi-coke, pet coke	44.2	88	83	80
	2	Lignite, lignite briquettes, shale oil	41.8	86	81	78
	3	Peat, peat briquettes	39.0	86	81	78
	4	Wood fuels, including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse	37.0	86	81	78
	5	Agricultural biomass including logs, round wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains, contaminated waste wood	30.0	80	75	72
	6	Municipal and industrial waste (non-renewable) and renewable/ bio-degradable waste	25.0	80	75	72
Liquids (L)	7	Heavy fuel oil, gas/diesel oil, other oil products	44.2	85	80	77
	8	Bio-liquids including bio-methanol, bioethanol, bio-butanol, biodiesel, other liquid biofuels	44.2	85	80	77
	9	Waste liquids including biodegradable and non-renewable waste (including pyrolysis oils, black and brown liquor, tallow)	29.0	75	70	67
Gases (G)	10	Natural gas, LPG and LNG	53.0	92	87	84
	11	Refinery gases hydrogen and synthesis gas	42.0	90	85	82
	12	Biogas produced from anaerobic digestion, landfill, and sewage treatment	42.0	80	75	72
	13	Coke oven gas, blast furnace gas and other recovered gases (excluding refinery gas)	35.0	80	75	72
Others	14	Waste heat (including high temperature process exhaust	30.0	100	100	100

(O)		gases, product from exothermic chemical reactions)				
	15	Nuclear	33.0	92	87	84
	16	Solar thermal	30.0	100	100	100
	17	Geothermal	30.0	100	100	100

Sub-section 5.5, supported by Appendices 1 and 2, provides the evidence and reasoning for the current list of reference values. The tables therein contained provide a description of the category, issues related to the fuel definition, issues related to the technology and our approach in recommending the reference values for electricity and heat.

Section 6 portrays the results of the review for the electricity and heat reference values.

Ambient conditions (e.g. temperature, pressure, relative humidity and cooling water temperature) can affect the efficiency of different thermal power or heat generation technologies through influencing the efficiency of the fuel combustion process and/or the efficiency of their corresponding thermodynamic cycles. In this regard, a literature review has been conducted to determine whether a revision of the correction factors for ambient conditions as given in Annex III of Decision 2011/877/EU is required.

As the fuel types used in gas turbines, CCGTs and engines are dominantly gaseous, the fuel types used in steam turbines are mainly solids and liquids, it is recommended applying ambient temperature correction to gaseous fuels only.

For the other ambient conditions (atmospheric pressure, altitude, relative humidity), qualitative relations between ambient conditions and efficiency are more limited and include specific technologies only. It is thus recommended to continue to not apply corrections for atmospheric pressure, altitude and relative humidity. Similarly, based on the review of available sources and literature, it has been decided to recommend to not include ambient correction factors for heat.

To account for the avoided grid losses, a distinction is made whether electricity produced in CHP plants is used on-site or off-site. For electricity used on-site, the cumulative losses at a given connection voltage level can be all saved due to the avoidance of transmission and distribution networks. For electricity used off-site, a discounting factor of 0.75 is used for the voltage levels below EHV and 0 for EHV, to account for the avoided cumulative losses due to the geographical proximity of CHP plants (see table below).

Connection voltage level	Correction factor (Off-site)	Correction factor (On-site)
EHV (>345kV)	1	0.976
HV (200 - 345kV)	0.972	0.963
HMV (100 - 200kV)	0.963	0.951
MMV (50 - 100kV)	0.952	0.936
LMV (12 - 50kV)	0.935	0.914
LV (0.45 - 12kV)	0.918	0.891
ELV (<0.45kV)	0.888	0.851

Finally, section 7 shares the outcomes of the analysis carried out in order to show the impact of the reference values on the amount of primary energy savings.

For this analysis 10 main fuel types were selected and linked to 27 typical CHP cases. Apart from differences in the fuel type, the cases vary with respect to capacity size and efficiencies (both related to technology type), grid connection level and type of heat produced (steam or hot water).

It is worth noting, that the electrical reference efficiencies have been corrected for avoided grid losses (see chapter 6). For the primary energy savings an average ambient temperature of 15°C have been assumed (standard ISO conditions), meaning that the natural gas electrical reference values do not need ambient temperature correction.

The results show that, apart from natural gas, all fuels achieve primary energy savings above 15% (see figure 20 in this section), which is well above the high-efficiency threshold value of 10%. The high PES values for some of the fuels is explained by a relative small difference between the CHP electrical efficiency and the reference electrical efficiency. For natural gas the situation is different. Reference electrical efficiency values for natural gas are very high compared to the values of other fuels. This puts a challenge on natural gas fired CHP schemes with relatively low electrical efficiencies (<27%) to qualify as high-efficient. Calculation outcomes are however sensitive: where such small gas turbines would be able to realise an overall efficiency of 80% (electrical efficiency still 27%), the PES would increase to 11.6-12.9% (export versus onsite consumption).

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1 Introduction

This report provides the results and recommendations for the reference values for high efficiency Cogeneration. The review of these efficiencies is required in order to comply with Article 14(10) of the Energy Efficiency Directive (Directive 2012/27/EU). The report summarises the findings of the project led by Ricardo-AEA, supported by University of Utrecht and Challoch Energy.

According to the Energy Efficiency Directive (EED), in order to be judged as High Efficiency CHP, cogeneration plants must, when compared with the separate generation of electricity and heat, provide primary energy savings (PES) ≥ 10% for plants with a capacity of 1MWe or greater (≥ 0% for schemes with capacity less than 1MWe). This calculation of PES requires reference efficiencies for the separate generation of heat and electricity.

The 2004 EU Cogeneration Directive (Directive 2004/8/EC) stated that the Commission is responsible for commissioning work to estimate these values based on operational data. In 2006 the Commission established the first set of harmonised efficiency reference values for separate production of electricity and heat. The rationale was the need to be able to compare the impacts of Member States' cogeneration policies on a like-for-like basis. The EED continued with this approach as it replaced the Cogeneration Directive in June 2014.

In order to account for technological developments and changes in the distribution of energy sources, the Commission plans to review these harmonised efficiency reference values for separate production of electricity and heat every 4 years. This was done for the first time in February 2011.

The Cogeneration Directive required the reference efficiency values for electricity and heat to be harmonised so that the reference value for a given fuel and given year of construction applies to all Member States across the EU. This requirement is maintained under the EED.

In addition, reference values should be based on operational data under realistic conditions for plants built by the market, not on information provided by manufacturers, design data or research projects. These data should also be normalised (depending on climatic conditions) to ISO conditions (15°C ambient temperature, 1.013bar, 60% relative humidity), so that a single system is applicable and fair to all Member States. Experience shows that there can be significant differences between design data and actual operational data due to a number of factors such as fluctuations in load profile, degradation of performance over time, etc.

According to the Directive, in establishing new reference values, a number of important issues need to be considered including but not limited to:

- The technological progress;
- Changes in the fuel mix;
- Applied CHP technologies;
- Climatic conditions;
- Cross border exchange of electricity;
- Changes in the applications and changes in the relevant operating characteristics of plants; and
- Changes in technical and economic conditions.

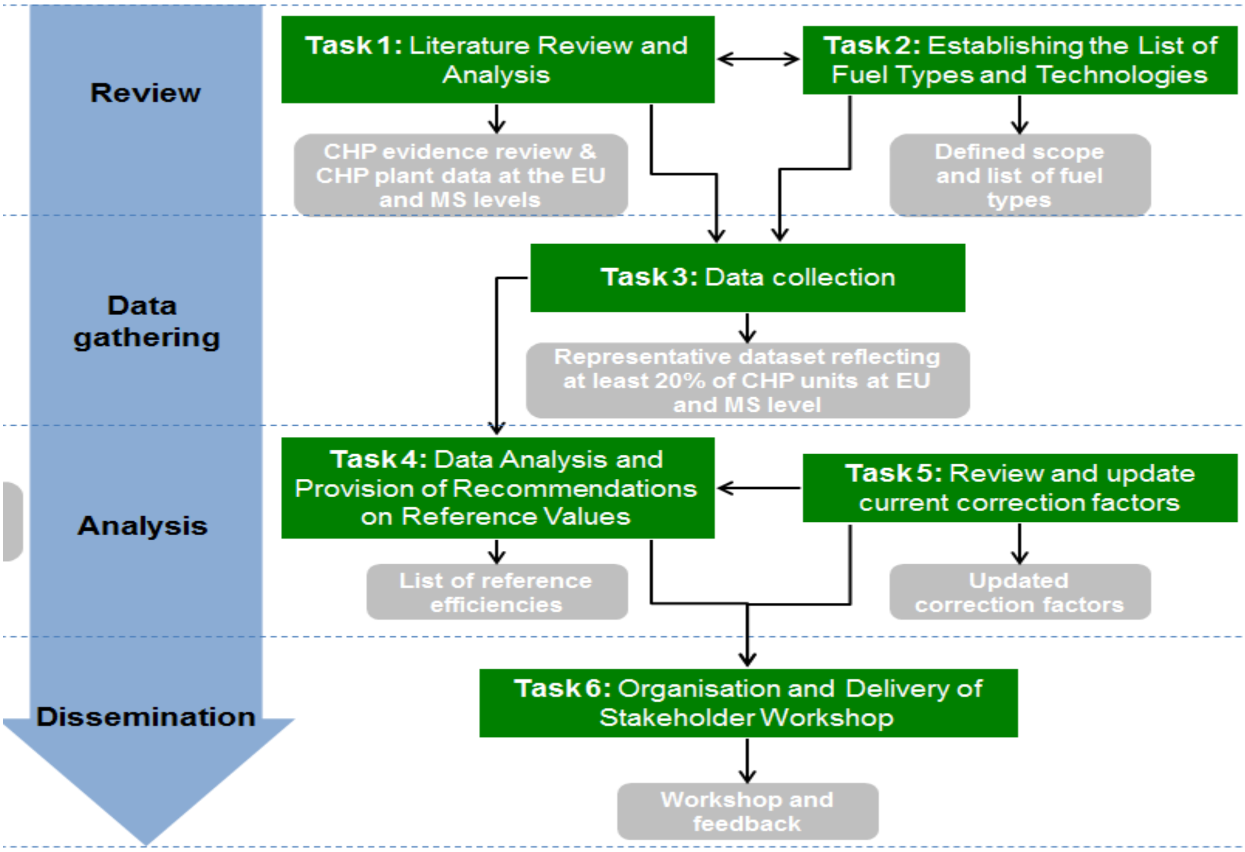
1.1 Objectives and approach

The overall objective of the current study is to develop a list of harmonised reference values for the separate production of electricity and heat for the period 2016 – 2019.

In order to achieve this objective, we have taken a comprehensive and versatile approach that encompassed consultation with the relevant stakeholders and industry in the power generation, heat generation and cogeneration industries. In addition, we drew upon a full overview of the existing relevant scientific literature and other evidence, including best available technologies.

The key tasks and how they relate to each other are shown in Figure 1.

Figure 1: Overall Approach



2 Review of the Current and Future Cogeneration Market in Europe

In order to develop the list of reference values and what technologies and fuels to consider, an understanding of the current status of cogeneration technologies and fuels is required. This section provides a review of historic trends, the current status of cogeneration and future projections of cogeneration in Europe.

2.1 Current state of play in the European CHP market

2.1.1 Overview of data sources

The current situation of the CHP market in Europe has been reviewed through data collection and detailed analysis of CHP data extracted from Eurostat and IEA databases and CHP operational data provided by contacts in a number of countries.

Eurostat and IEA databases contain data on fuel inputs and heat and electricity outputs in CHP Plants by fuel type for each Member State. This data are available for all countries for the period 2000 - 2012 (IEA as of 1990) which facilitates comparison across countries; therefore, after careful evaluation of several sources of information, we consider that Eurostat and IEA are the best available sources to understand the trends in fuel types used in CHP Plants in all countries.

The Eurostat database contains capacity data (2008 – 2012) for CHP and power-only plants aggregated as Conventional Thermal Power Stations and split by technology and fuel type. Eurostat data is not disaggregated for CHP or power-only plants. Since IEA provides this disaggregation, IEA data is thought to be a more useful source for the analysis of historic trends of fuel and technology types of Conventional Thermal Power Stations. Other national sources have been reviewed to understand the most used CHP technologies in the countries with more CHP installed capacity.

Information has also been drawn from the CODE project, a project that was developed for policy purposes and required each Member State to provide a report on the status of the transposition of the Directive 2004/8/EG. Each Member State should include in their National reports an update of their national CHP legislation and identify the barriers for the development of CHP. Submission date of these reports varies across countries from 2004 - 2008. The second progress reports of the CODE project were submitted in 2010. This set contains a report and a table with data on the CHP and technical and economic potentials of fossil fuel CHP for each Member State. The most complete country reports present capacities by fuels and technologies; however the complete set is not available for the countries. The quality and availability of information in these reports varies as each country developed a different methodology to estimate the CHP capacity.

Additional data sources, such as the Joint Research Centre (JRC) implementation report, National Energy Institutes and National Statistical Centres, have also been consulted as required

The JRC Implementation Report analyses the potential for high-efficiency cogeneration in the EU based on national reports and templates provided by Member States in 2010. The baseline figures used in the national reports and templates are different from the statistics recorded in Eurostat annual reports, since the national reports and templates deal with high-efficiency cogeneration only. The methodology used to calculate the high efficiency CHP capacity is not consistent across all countries.

Availability and quality of the data and information collected varied across countries and sources. Our analysis thus draws upon our experience to identify the most appropriate sources.

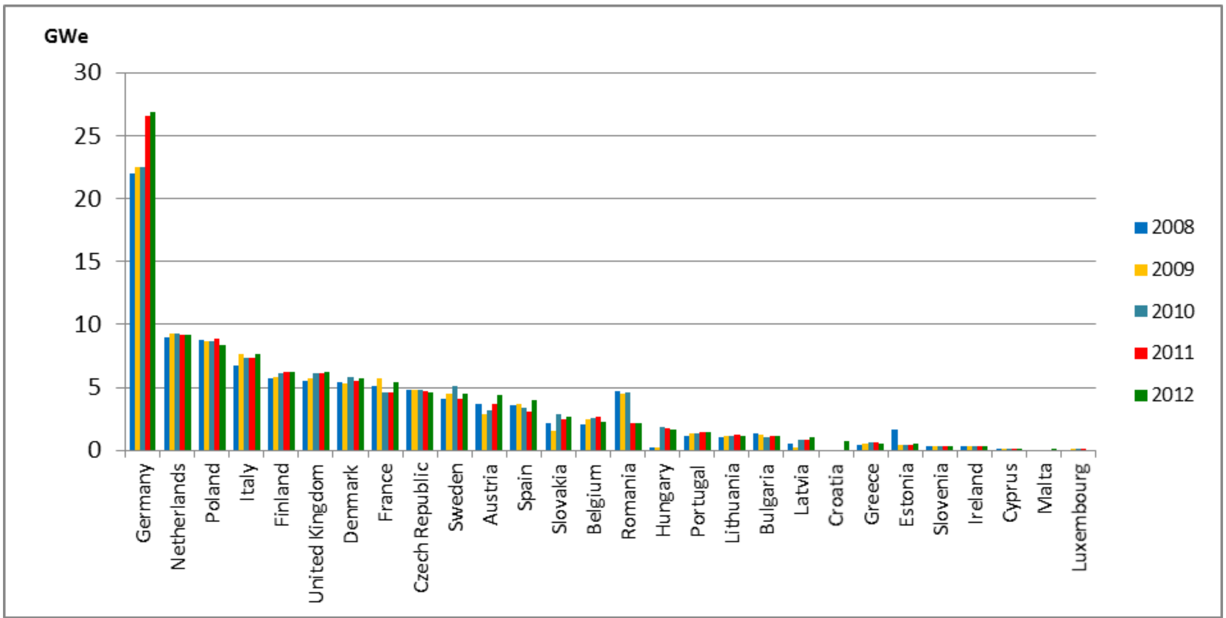
2.1.2 Evolution of CHP installed capacity in the EU

At present, the total installed capacity of conventional power plants in Europe is around 500GW, of which around 20% is CHP capacity[1]. According to Eurostat, the total installed CHP capacity across the EU increased from 102GW in 2005 to 109GW in 2012. Figure 2 shows the evolution of installed

[1] http://setis.ec.europa.eu/system/files/Technology%20Information%20Sheet%20-%20Cogeneration.pdf

CHP capacity in the EU-28 since 2008. 11 countries (Germany, Netherlands, Poland, Italy, Finland, UK, Denmark, France, Czech Republic, Sweden and Spain) make up more than 85% of the total installed CHP capacity in EU-28.

Figure 2: Evolution of installed CHP electrical capacity by country 2008 – 1012 (Source: Eurostat annual reports)



According to the Platts 2013 database it is seen that the technology trends of new CHP installed capacity in the last 8 years in Europe are Combined Cycle Gas Turbine (CCGT), Pass Out Condensing steam turbines (POCO), Gas Turbines (GT) and Reciprocating Engines (RE). CHP Organic Rankine Cycle plants (ORC) have been installed in Italy, Germany, Finland, UK and Czech Republic.

2.1.3 CHP output by Member State

The production of electricity from CHP in Europe has been steadily increasing in recent years. Analysis of IEA historic data for the EU-28 shows an increase of 60% in electricity produced from CHP plants since 1990 and 1.2% since 2005[2] (Figure 3). It should be noted that the figure below does not differentiate between CHP and non-CHP operation or between high efficient (HE) CHP and non-HE CHP. Heat produced from CHP in the EU-28 has also increased by 1.1% since 1990 but decreased by 7.2% since 2005 (Figure 4).

Figure 5 shows that power efficiencies and overall efficiencies have been steadily increasing since 1990 while heat efficiencies have been decreasing, which is a reflection of changes in the manufacturing processes, i.e. increasing electricity demands and reducing heat demands, changes of technologies mix used in CHP plants and improvements made to generating technologies.

Table 1(part b) shows that 11 Member States seen a decrease in electricity production from CHP in the period 2005-2012. Malta, Luxembourg, Ireland and Cyprus show significant increase since 2005 in electricity produced from CHP plants. Germany, Belgium and Italy are the Member States showing the greatest increase in absolute terms as shown in
Table **1**(part a).

[2] Note that IEA Statistics distinguish between main activity production and auto-producer. Percentages relate to the total electricity product ion in CHP plants

Figure 3: EU-28 electricity production by CHP (derived from IEA)

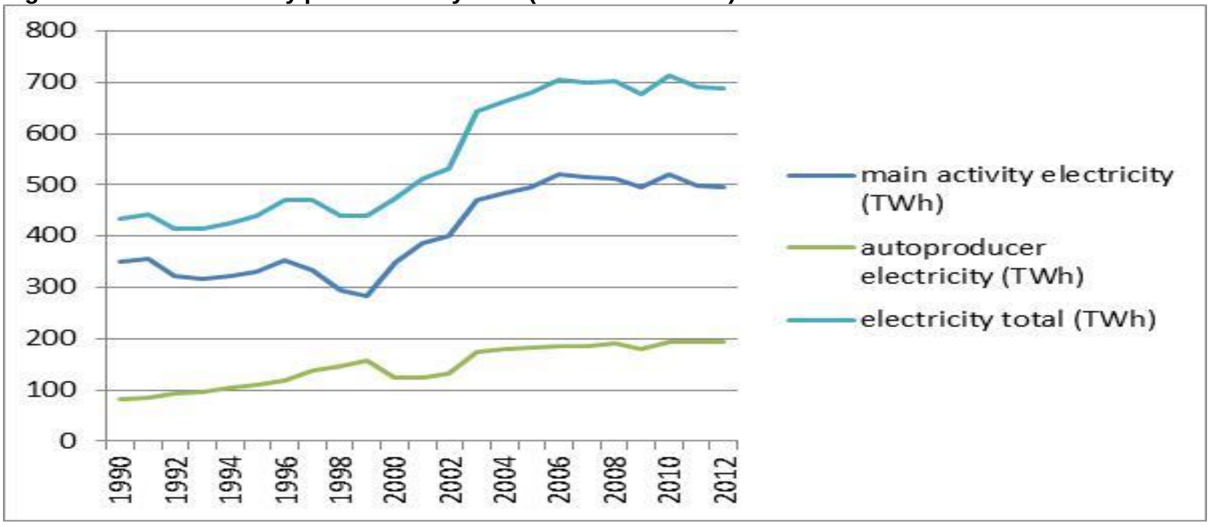


Figure 4: EU-28 heat production by CHP (derived from IEA)

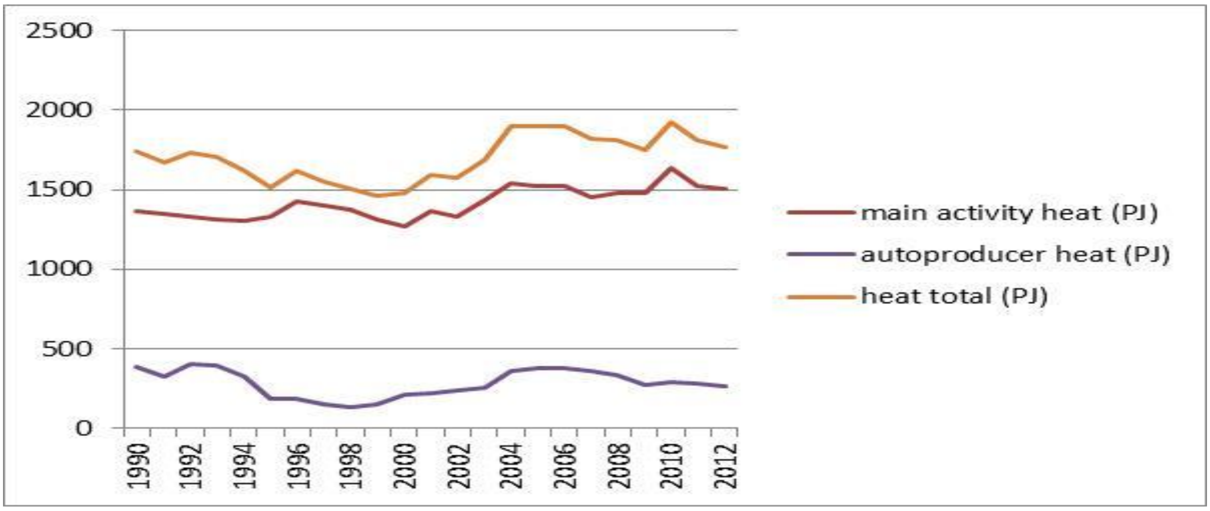


Figure 5: EU-28 CHP efficiencies

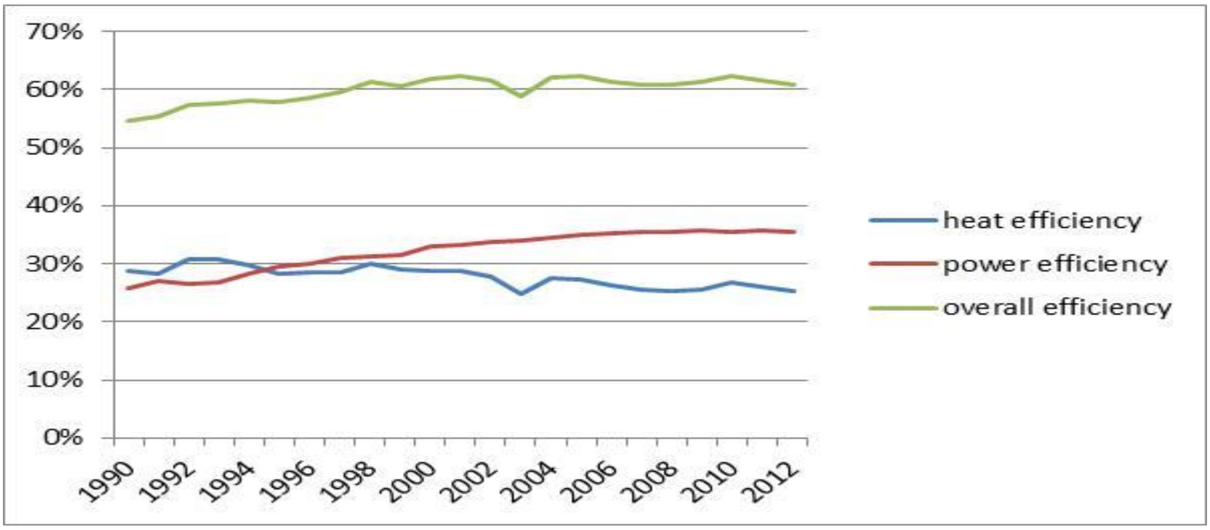


Table 1: Ranking of EU MS based on (a) absolute growth of CHP electricity production (2005 to 2012) and (b) relative growth (2012 in comparison to 2005) of CHP electricity production

Part a		Part b	
Member State	Absolute growth of CHP electricity between 2005 and 2012 in GWh	Member State	Relative growth in CHP power production between (2012 in comparison to 2005)
Germany	24,669	Malta	6.0
Belgium	7,699	Luxembourg	5.5
Italy	6,427	Ireland	3.3
Sweden	4,394	Cyprus	2.1
Greece	3,454	Belgium	2.0
Austria	2,960	Latvia	1.5
Luxembourg	2,000	Greece	1.4
Poland	1,903	Austria	1.4
Portugal	1,744	Sweden	1.4
Ireland	1,490	Portugal	1.3
Latvia	809	Germany	1.3
Spain	564	Croatia	1.2
Croatia	529	Estonia	1.1
Slovenia	208	Italy	1.1
Estonia	128	Slovenia	1.0
Cyprus	30	Spain	1.0
Malta	12	Poland	1.0
Bulgaria	-850	Netherlands	1.0
Czech Republic	-1,381	Czech Republic	0.9
Netherlands	-2,419	Finland	0.9
Hungary	-2,661	France	0.9
Romania	-3,126	Bulgaria	0.9
Finland	-3,249	United Kingdom	0.9
France	-3,252	Romania	0.8
United Kingdom	-4,714	Slovak Republic	0.7
Slovak Republic	-7,480	Hungary	0.7
Denmark	-9,320	Denmark	0.7
Lithuania	-10,209	Lithuania	0.3

2.1.4 CHP output by fuel type in the EU-28

Table 2 below shows the ranking of fuels used in CHP plants in the EU-28. This shows that natural gas being the most dominant fuel followed by solid fossil fuels, these representing over 85% of fuels used in CHP plants in the 28 MS. Whilst some countries show increasing utilisation of natural gas in CHP plants (e.g. Belgium, Germany, Spain, and Italy), others (e.g. UK, Netherlands and France) are showing less gas-fired CHP production. Overall, the consumption of natural gas shows no significant change while the consumption of coal, peat, lignite and oil as well as refinery gases and blast furnace gases show a decreasing trend. Nuclear CHP is also showing a significant decrease in comparison to 2005.

Renewable fuels, mainly biomass (used in steam turbine-based CHP), but also biogas (from AD plants and mainly used in reciprocating engine-based CHP) and combustible waste (used in steam turbine-based CHP), are becoming increasingly important[3] as shown by the last column in Table 2. These fuels, while small in absolute terms, have shown significant growth in recent years and are expected to continue to grow as fuels in CHP plants. The countries utilising most renewable fuels (in MWh) in CHP plants are Germany[4], Italy, France, UK, Denmark, Netherlands, Czech Republic, Finland and Romania. It is noted that solid biomass and biogas are found in most Member States, with almost all showing increasing production figures. The growth of “other” liquid biomass is almost solely due to Italy (and, to a smaller extent, Germany).

Table 2: CHP fuel ranking EU-28

Fuel ranking (2012)	Fuels	CHP electricity 2005 [TWh]	CHP electricity 2012 [TWh]	Change (2012 in comparison to 2005)
1	Natural gas	295.7	303.1	+2%
2	Other bituminous coal	140.1	120.7	-14%
3	Lignite	94.5	91.0	-4%
4	Solid biomass	29.9	54.2	+81%
5	Biogas	4.3	30.1	+609%
6	“Other” oil	13.8	14.1	+2%
7	Nuclear	28.1	11.2	-60%
8	Fuel oil	26.1	10.5	-60%
9	Municipal waste Re	5.0	9.8	+96%
10	Municipal waste non-Re	5.0	8.2	+62%
11	Refinery gas	7.0	6.6	-6%
12	Blast furnace gas	6.3	4.9	-22%
13	Peat	3.8	3.4	-10%
14	Industrial waste	1.9	2.0	+4%
15	“Other” liquid biofuels	0.2	1.2	+583%

2.1.4.1 Biomass-based CHP

Biomass-fired CHP plants have capacities ranging from a few MWe up to 350MWe. Small and medium-size CHP plants are usually sourced with locally available biomass. State-of-the-art biomass plants can achieve high-performance steam parameters and electrical efficiencies above 37% (net

[3] http://setis.ec.europa.eu/technologies/Cogeneration-of-heat/info
[4] The growth of biomass-based CHP in Germany amounted to 23% per year in the period 2004-2008 (IEA Energy Technology Network, Technology Brief E05, 2010:http://www.iea-etsap.org/web/E-TechDS/PDF/E05-Biomass%20for%20HP-GS-AD-gct.pdf).

output, GCV). Large CHP plants and coal/biomass co-firing power plants require biomass sourcing from a wide region and/or imported wood or forestry residues. Operating Biomass fuelled CHP plants are based on mature technologies with increasing generation efficiencies, while other technologies such as biomass integrated gasification combined cycles (BIGCC), which offer high technical and economic performance, are currently in the process of entering the market, following the industrial demonstration phase.

2.1.4.2 Biofuels

Conventional biofuels (commonly referred to as first generation biofuels) include sugar- and starch-based ethanol, oil crop-based biodiesel, and straight vegetable oil, as well as biogas derived through anaerobic digestion.

Advanced biofuels (commonly referred to as second generation) are conversion technologies that are still in the R&D, pilot or demonstration phase. This category includes hydro-treated vegetable oil, which is based on animal fat and plant oil, as well as biofuels based on lignocellulose biomass, such as cellulosic-ethanol, biomass-to-liquids-diesel and bio-synthetic gas. Furthermore novel technologies such as algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts are included. Advanced biofuels, produced from lignocellulose biomass, algae and other innovative feed stocks, have progressed more slowly than expected in recent years. The recent opening of the first commercial-scale production units, such as the Beta Renewables 60 million-litres-per-year cellulosic-ethanol plant in Italy. More commercial-scale plants are needed to reach economy of scale and bring down costs.

2.1.4.3 Anaerobic digestion CHP

Anaerobic digestion in combination with CHP plant is being increasingly applied throughout Europe. The digesters in AD plants and the pasteurisation tanks require maintaining at elevated temperatures. This heat demand can be satisfied by CHP plants (internal combustion engines) operating on biogas from the AD plant. AD plants are economically viable for the generation of heat and power using internal combustion gas engines. Thermal efficiencies of AD CHP plants can be around 55% with overall efficiency of more than 85%.

2.1.4.4 Nuclear CHP

District heating from nuclear power plants is common in some Eastern European countries including Hungary, Slovakia and Bulgaria. Nuclear power plants have the potential to also deliver industrial process heat as in Switzerland[5]. In Finland the Lovisa 3 nuclear plant was put forward as a CHP plant to provide heat to Helsinki's district heating system but was rejected by the government. The plant was around 100km from Helsinki. Studies show that the fact that nuclear power plants are far from residential areas and cities does not make them unsuitable for district heating as the transmitted hot water can still reach cities at high temperatures.

2.1.4.5 Solar thermal CHP

Concentrating solar CHP systems concentrate the solar rays to generate steam which is the used to generate power with the remaining heat used for useful purposes. The solar energy falling on the concentrator dish is focused on the hot end of a Stirling generator and is converted, through the Stirling energy cycle, into electricity that can be injected into the grid with the excess energy from the Stirling cycle (rather than rejected to the air through a closed loop cooling system) captured for water and air heating.It is expected that solar CHP will become more popular in the coming years and so it is recommended that solar thermal is included as a reference in the reference values against which solar CHP can be compared.

2.1.4.6 Geothermal CHP

Geothermal resources (which are mainly constitute low-grade heat) have long been used for direct heating applications (e.g. district heating, industrial processing, domestic hot water, space heating, etc.). However, some high-grade heat (e.g. high-temperature natural steam at less than 2-km depth, mainly available in areas with volcanic activity), have also been used for power generation. On a global scale, geothermal-based heat and power amount to 2 EJ/year (IEA, 2008).

[5] http://setis.ec.europa.eu/system/files/4.Efficiencyofheatandelectricityproductiontechnologies.pdf

In 2008, with a global capacity in operation of approximately 9 GWe (out of a total installed capacity of about 10 GWe), geothermal power plants generated approximately 60 TWh, that is some 0.25% of the global electricity generation. Geothermal heating plants produced some 63 TWh of heat, with an installed capacity of approximately 18 GW_{th}.

In geothermal CHP, heat passes through a turbine (organic rankine cycle, ORC) generating power with the remaining heat used for useful purposes (e.g. district heating). Geothermal CHP using ORC technology and a low-temperature boiling process fluid is cost effective if there is sufficient demand for heat production (e.g. district heating). In general, CHP plants are economically viable and largely used in (Northern) Europe where heating demand space is significant and constant over the year. It is expected that geothermal CHP will become more popular in the coming years and so it is recommended that geothermal is included as a reference in the reference values against which geothermal CHP can be compared.

2.2 Future projections of the cogeneration market in Europe

2.2.1 Overview of data sources

Several sources were reviewed for information on future CHP capacity in Europe. The most comprehensive and consistent (between Member States) source of information was found to be the CHP projections in the PRIMES-2013 scenario and so the results reported in this section are based on this.

According to PRIMES:

- CHP capacity shows a modest growth from 101GWe in 2010 to 114GWe in 2020 and 116GWe in 2030 (Figure 6).
- In the period 2010-2030, 80GWe of new CHP capacity is expected to be installed (42GWe up to 2020).
- This 80GWe is 41% of total new fossil fuel based thermal power capacity.
- Much of the new investments (GWe) consider replacement of existing capacity (net growth figure is small compared to the investment figure).
- Fuel shares are not specified for CHP, but for power capacity in general (including CHP) 59% is gas-fired, 23% is coal-fired and 11% is biomass/waste-fired. This suggests that at least 75% of the CHP investments will be gas-fired (assuming that new coal-fired CHP will be rare whereas biomass and waste will be preferable in CHP mode).
- As shown in Figure 7, some countries (Germany, Italy, Poland, UK, France, Spain, and Belgium) are expecting considerable growth whereas other countries (Netherlands, Finland, Sweden, Denmark and Austria) show a decline of CHP capacity.

Figure 6: Installed CHP capacity (GWe) and net CHP investment (GWe) in the EU-28

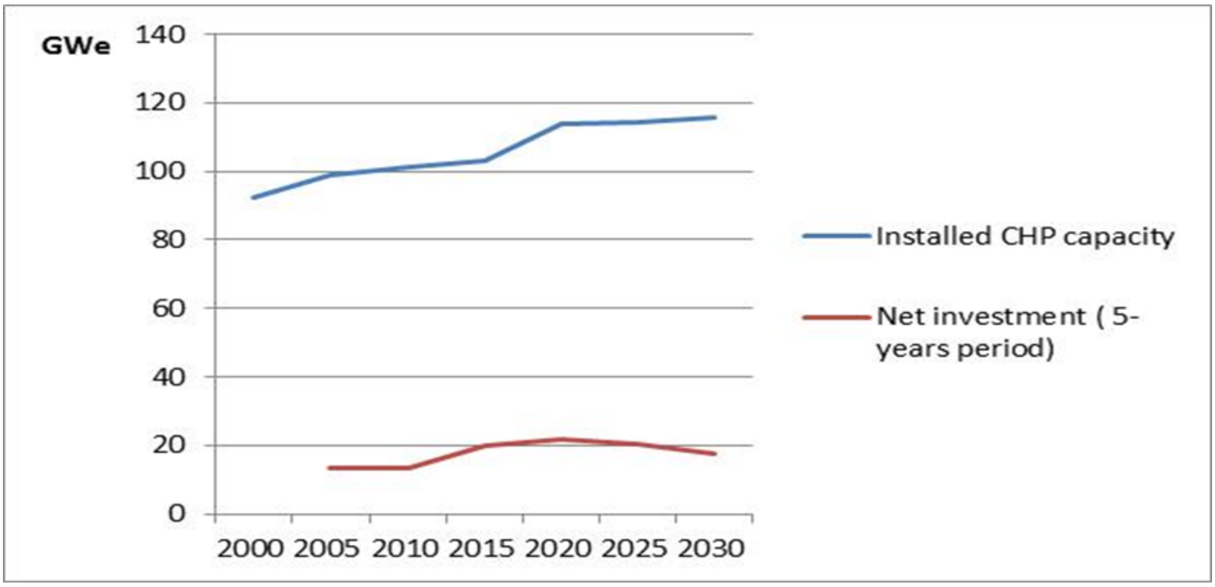


Figure 7: Installed CHP capacity in 2020 and 2030 by Member State

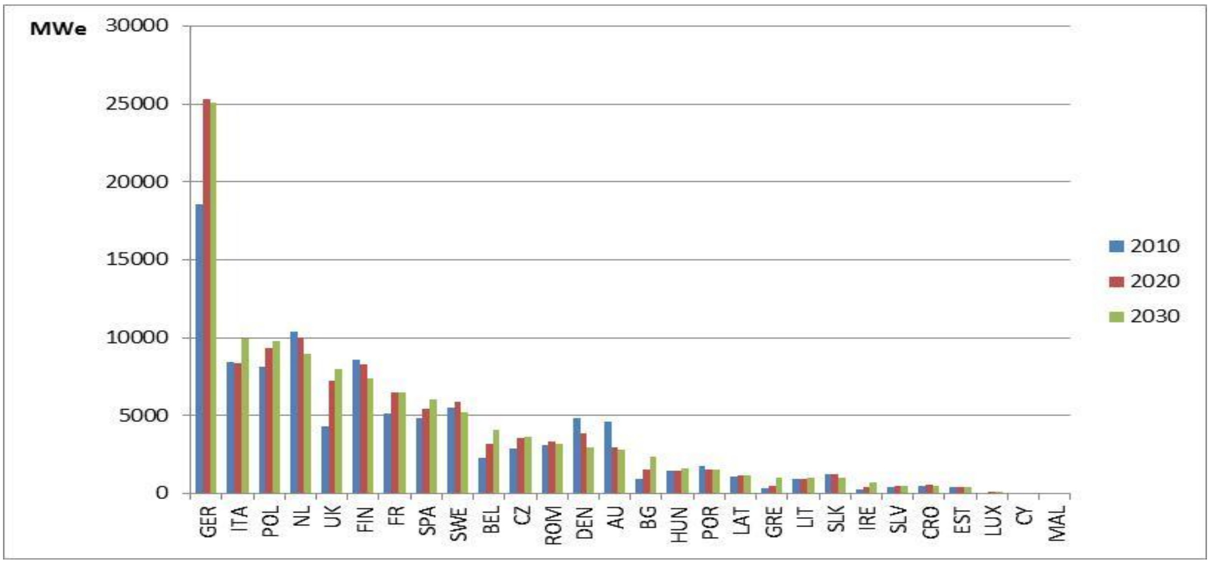
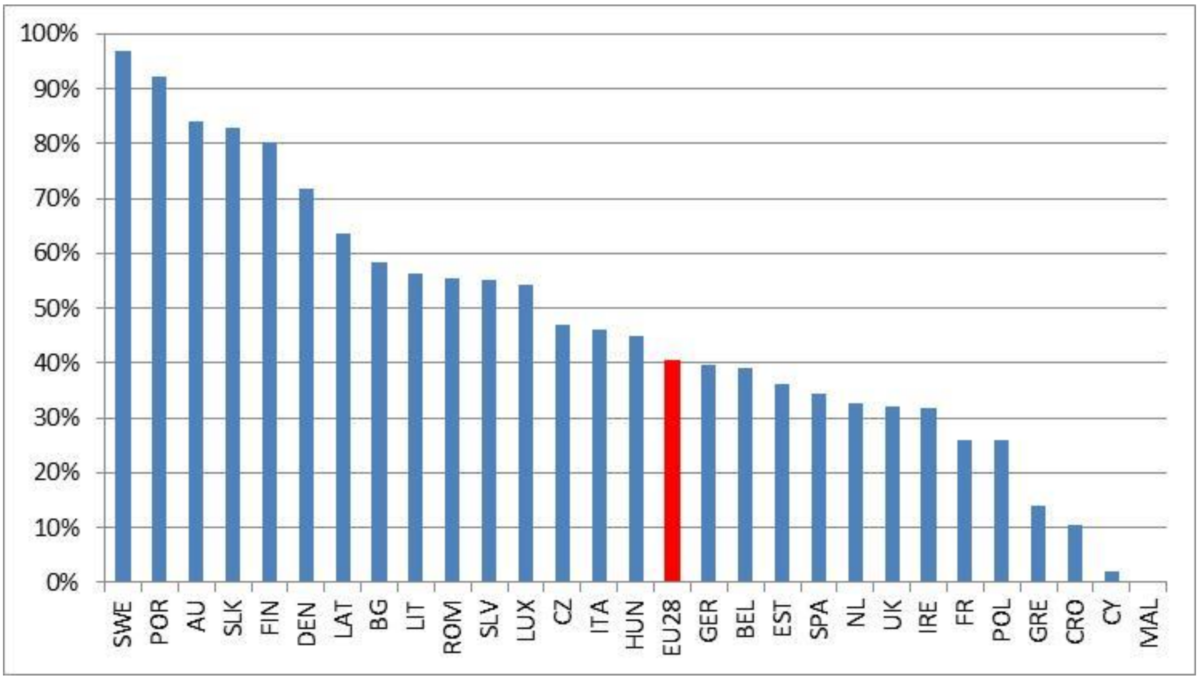


Figure 8 shows the share of CHP in the total net cumulative fossil fuel based thermal plants capacity investment (excluding nuclear) in the period 2010 - 2030. This figure shows that in the period to 2030, more than 95% of the Swedish investment in fossil thermal power plants will be dedicated to CHP plants. Since Sweden is showing a decrease in installed CHP capacity in the period to 2030 (Figure 7), it can be concluded that the majority of thermal power plants that will be built in Sweden likely to be CHP. Similar conclusions can be made for Austria and Denmark. It is noted from Figure 8 that Germany, which shows the biggest CHP growth in Figure 7, will have 60% of its thermal power investments (to 2030) in non-CHP. This is also observed for UK, Italy, Poland, France, Spain, and Netherlands.

Figure 8: Share of CHP in net cumulative thermal power capacity (excluding nuclear) investment 2010 - 2030


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
SWE
POR
AU
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ITA
HUN
EU28
GER
BEL
EST
SPA
NL
UK
IRE
FR
POL
GRE
CRO
CY
MAL

3 Recommendations for the List of Fuels

3.1 Introduction

The Commission Implementing Decision 2007/74/EC on 'establishing harmonised efficiency reference values' currently lists 16 fuel categories (Table 3). One of the objectives of the current project is to review the list of fuels currently used in CHP plants in order to establish whether additional categories need to be added to Table 3.

Table 3: Current list of fuels

Fuel type	No.	Fuel
Solid (S)	1	Hard coal/coke
	2	Lignite/lignite briquettes
	3	Peat/peat briquettes
	4	Wood fuels
	5	Agricultural biomass
	6	Biodegradable (municipal) waste
	7	Non-renewable (municipal and industrial) waste
	8	Oil shale
Liquid (L)	9	Oil (gas oil + residual fuel oil), LPG
	10	Biofuels
	11	Biodegradable waste
	12	Non-renewable waste
Gas (G)	13	Natural gas
	14	Refinery gas/hydrogen
	15	Biogas
	16	Coke oven gas, blast furnace gas, other waste gases, recovered waste heat

Many CHP plants utilise both conventional fossil fuels and renewable fuels, either via co-firing or via flexibility to switch between fuels depending on availability. As discussed in Section 2, the use of renewable fuels in CHP plants has shown significant increase in recent years. Table 4 gives an indication of the number of CHP plants which were constructed in Europe since 2006 by fuel type. It is seen that most of these CHP plants are utilising natural gas, biomass and biogas.

Table 4: Summary of development and historic trends on fuels used for CHP

Fuel	Construction of new sites (Platts)
Coal (lignite and bituminous coal)	++
Peat	+
Biomass	+++

Municipal waste	+
Oil shale	+
Fuel oil	+
Liquid biodegradable waste	++
Liquid non-renewable waste	+
Natural gas	+++
Refinery Gas	+
Biogas	+++
Blast-furnace gas	+

Key: +: New sites account less than 10,
++: 10-30 new sites,
+++: More than 30 new sites

Table 5 shows the CHP technologies where the fuels listed in Table 3 are used. This is based on analysis of European CHP plant data obtained from the Platts database. The organic rankine cycle (ORC) is an emerging technology which mainly uses wood fuels and agricultural biomass.

Table 5: Fuels matched to CHP technologies based on current practice

Fuel	Reciprocating engine	Simple cycle gas turbine	Back-pressure Steam turbine	Pass out Steam turbine	Combined cycle gas turbine	Organic rankine cycle
Coal				✓		
Lignite			✓	✓		
Peat				✓		
Wood fuel			✓	✓		✓
Agricultural biomass				✓		
Solid waste (Re and non-Re)			✓	✓		
Oil shale			✓	✓		
Oil	✓	✓	✓		✓	
Biofuels	✓					
Liquid waste (Re and non-Re)	✓		✓	✓		
Natural gas	✓	✓	✓	✓	✓	
Refinery gas		✓			✓	
Biogas	✓	✓		✓		
Coke oven gas, etc.				✓	✓	

3.2 Recent developments in CHP fuels

A comprehensive analysis of the type of fuels and technologies used by cogeneration plants has been conducted in order to investigate the need for updating the fuel categories in Table 3. Table 2 in Section 2 shows that all the top-ranking CHP fuels, except for 'nuclear' belong to the list above. A comprehensive list of fuels, based on Eurostat, Platts and CHP operational data from a number of MS, has been collated, as shown in Table 6 below. As all fuels currently used in CHP plants in Europe can be matched to one of the existing categories, it is recommended to keep the same categories as in Table 3.

Table 6: Comprehensive list of current CHP fuels matched to the existing 'reference values' list

Fuel	Matched category from Table 3	Fuel	Matched category from Table 3
Solids		**Liquids**	
Coking coal, bituminous coal, anthracite	S1	Oil	L9
Lignite	S2	Vegetable oil	L10
Peat	S3	Bio methanol	L10
Municipal solid waste	S6	Bioethanol	L10
Industrial waste	S6	Tallow	L11
Clinical waste	S6	Used cooking oil	L11
Refuse derived / solid recovered fuel	S6, S7	Fatty acids	L11
Poultry litter	S5	Pyrolysis oil	L11, L12
Sewage sludge	S6	**Gas**	
Paper sludge	S6	Natural gas	G13
Logs	S5	Coke oven gas	G16
Round wood	S5	Blast furnace gas	G16
Agricultural residues	S5	Refinery gas	G16
Pruning	S5	Biogas from AD plants	G15
Milling residues	S5	Biogas from landfills	G15
Distillers grain	S5	Sewage gas	G15
Contaminated waste wood	S5	Syntheses gas from gasification	G13
Energy crops	S4	Synthesis gas from pyrolysis	G13
Wood pellets, Dry wood chips	S4	**Other categories**	
Straw	S4	Waste heat	None[1]
Bagasse, nut shells, husks, olive stones	S4	Nuclear	None[2]
Clean waste wood	S4	Solar thermal and geothermal	None[2]

[1] Waste heat is currently included under the G16 category. It is recommended that this is dealt with as a separate category under 'Other'.
[2] Nuclear, solar thermal and geothermal are currently not included under any of the categories. It is recommended that 'nuclear' is added under the 'Other' category.

3.3 Recommended changes to the list of fuels

Whilst it is recommended that the fuel categories remain broadly the same, some changes to the grouping of the individual fuels is proposed as **summarised in Table 7 below** with further justification given **in Section 5. The** finalised **recommended list of fuels is shown in**
Table **9.**

Table 7: Recommended changes to the fuel list

Recommendations	Justification
Anthracite, coking coal, semi coke and pet coke should all be included with coal under category S1	This is justified on the grounds of similar technologies being used with similar efficiencies
Shale oil (S8) should be included under the same category as lignite (S2). This reduces the number of solid fuel categories by one	This is justified considering the same efficiency range.
It was initially recommended that the wood fuel (S4) and natural gas (G10) categories are split based on a capacity threshold (25MWe for wood fuel and 100 MWe for natural gas). **However, following the stakeholder meeting this recommendation was abandoned and decision deferred to the next review. More details are given in Section 5.3.1 and 5.3.2.**	Table 8 shows CHP fuels grouped according to the maximum efficiency[6]. It is noted that wood pellets, dry woodchip and other wood fuels (which can be grouped under category S4 in Table 3) have a wide range of maximum efficiencies (31% - 37%) depending on the size of the plant. It was thus recommended initially to split category S4 into two categories depending on a capacity threshold of 25MWe. In addition, technologies used in smaller biomass plants have lower efficiencies and so if the reference efficiencies are set high, such plants will be discriminated against and will struggle to qualify as HE CHP, despite the fact that they are much more efficient than power only plant, thus dis-incentivising the market for smaller units. Justification for the split in the natural gas category are given in detail in Section 5.3.1. **However, this recommendation has been abandoned in the final version of the report. It is recommended that consideration of splitting the biomass (S4) and natural gas (G10) categories depending on size of plant is considered for the next review.**
The bio-degradable and non-renewable waste categories (S6/S7 and L11/L12) should be combined into a single category	This is justified considering the similar efficiency range for these fuels
Syngas should be included under the same category as refinery gases	This is justified on the grounds of similar technologies being used. It should be noted that the boundary for syngas-based CHP plants should be drawn around the prime mover at the point of syngas being supplied, and should exclude the gasifier or the syngas-producing plant. The CHP plant boundary should include the engine firing the syngas and so the fuel in this case is the syngas rather than the solid fuel used in the gasification or pyrolysis plant
Waste heat should be separated into a separate category	Such as the exhaust gas from high temperature processes, or as a product of exothermic chemical reactions. So very different to 'coke oven/ blast

[6] The efficiencies shown thus represent efficiency of the most efficient prime mover technology in which the fuels can be used.

	furnace gases' and should be treated differently.
Nuclear should be added as a new separate category	Nuclear based CHP exist in Europe, but currently there isn't any reference values for such plants. It is proposed to keep this in a category on its own.
Solar thermal and geothermal should be added as a new separate category	Solar thermal and geothermal plant are believed to be under development in Europe and it is proposed to put these in categories of their own. No reference values exist for such plants.

Table 8: Renewable fuels categorised according to maximum power efficiency that can be delivered

Fuels included	Maximum power efficiency
Biogas from AD, landfills and sewage gas	37% – 39%
Syngas from gasification and pyrolysis	32% - 34%
Fatty Acid, Biomass To Liquid fuels, Virgin vegetable oil, Pyrolysis oil, Bio methanol, Bioethanol,	39%
Tallow, Used cooking oil	39%
Municipal solid waste, Industrial waste, Clinical waste, Refuse derived fuel, Solid recovered fuel, Poultry litter, De-watered sewage sludge, Paper sludge	25% - 27%
Logs, Round wood, Agricultural residues, Pruning, Milling residues, Forestry residues, Distillers grain	27% - 28%
Contaminated waste wood	28% - 29%
Wood pellets, Dry wood chips, Straw, Bagasse, Nut shells, Husks and Cobs, clean waste wood	31% - 37% 31% for smaller plants (<25MWe) and 37% for larger plants (>25MWe)

Table 9: Recommended list of fuels

Fuel Category		Description
Solids (S)	1	Hard coal including anthracite, bituminous coal, sub-bituminous coal, coke, semi-coke, pet coke
	2	Lignite, lignite briquettes, shale oil
	3	Peat, peat briquettes
	4	Wood fuels <25MWe including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse
	5	Agricultural biomass including logs, round wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains, contaminated waste wood
	6	Municipal and industrial waste (non-renewable) and renewable/ bio-degradable waste
Liquids (L)	7	Heavy fuel oil, gas/diesel oil, other oil products
	8	Bio-liquids including bio-methanol, bioethanol, bio-butanol, biodiesel, other liquid biofuels
	9	Waste liquids including biodegradable and non-renewable waste (including pyrolysis oils, black and brown liquor, tallow)
Gases	10	Natural gas, LPG and LNG <100MWe

(G)	11	Refinery gases hydrogen and synthesis gas
	12	Biogas produced from anaerobic digestion, landfill, and sewage treatment
	13	Coke oven gas, blast furnace gas and other recovered gases (excluding refinery gas)
Others (O)	14	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)
	15	Nuclear
	16	Solar thermal
	17	Geothermal

3.4 Required operational data

In order to establish the electrical and heat reference efficiency values, power-only (i.e. from power stations) and heat-only (i.e. boiler) operational data for each of the fuels listed in
Table **9** were required. Data from power plant and boilers installed after 2006 were required. It should be noted that in some cases this was not possible. For example, peat and ethane were identified as CHP fuels but, according to the Platts database, there are currently no power plant operating on these two fuels.

Table 10 shows CHP fuel consumption in 2012 as a percentage of total fuel consumption for each of the 11 major countries mentioned in Section 2.1.2[7].

Table 10: CHP fuel consumption as a percentage of total fuel in Europe for the top 11 countries in terms of CHP capacity

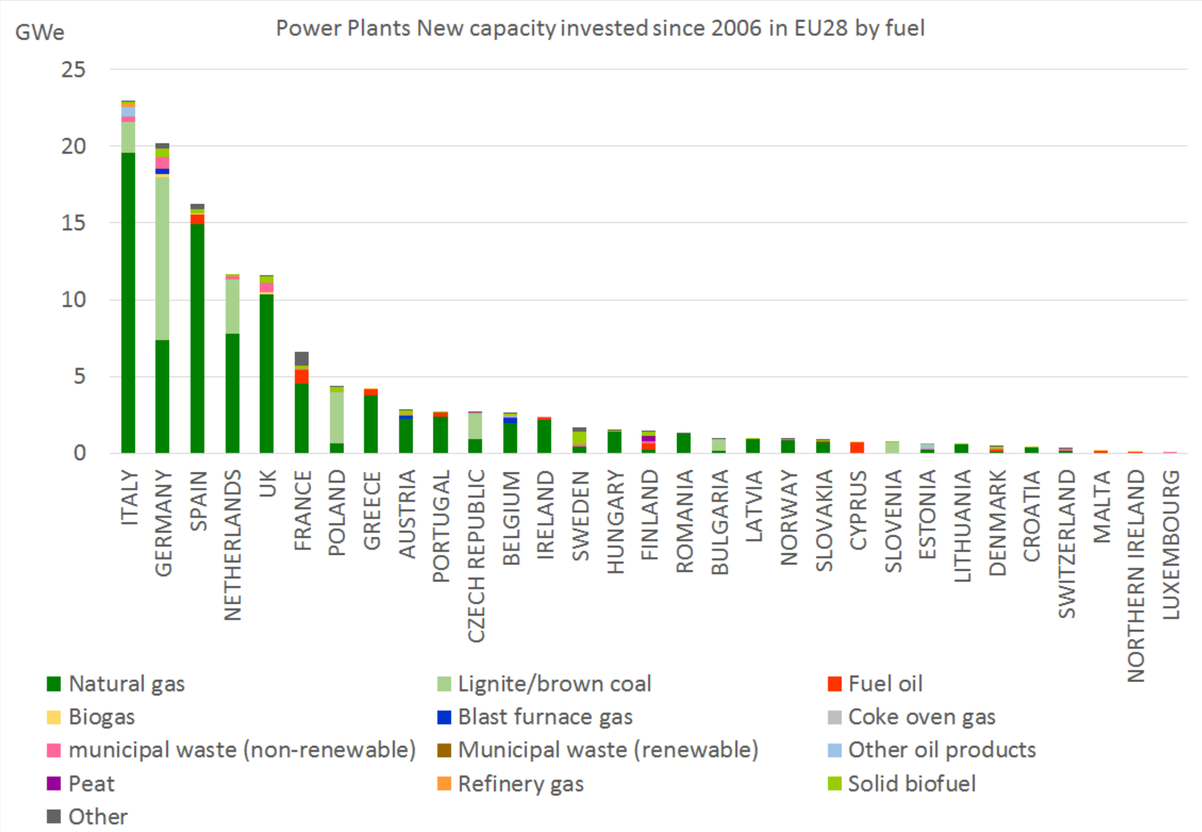
	Coking Coal	Other Bituminous Coal	Lignite/Brown Coal	Peat	Refinery gas	Total fuel oil	Other Oil Products	Natural gas	Coke Oven Gas	Blast Furnace Gas	Municipal waste (non-renewable)	Industrial wastes	Solid biofuels	Biogas	Municipal waste (renewable)
Germany	98%	11%	6%		1%	3%	0.1%	18%	1%	4%	25%	43%		63%	22%
Netherlands		4%			24%		0.1%	12%	0.4%	12%	19%			3%	21%
Poland		64%	44%			6%		2%	46%	17%	0.2%	2%		2%	
Italy		0.2%			58%	21%	91%	25%	29%	29%	9%	1%		12%	8%
Finland		4%		79%		2%		2%	0.1%	1%	2%	2%		0%	3%
United Kingdom		0.5%				3%		5%	1%	2%	2%	26%		4%	3%
Denmark		8%			2%	2%		2%			9%			2%	9%
France		1%			5%	1%	6%	7%	1%	2%	11%			2%	10%
Czech Republic		4%	13%			2%		1%	13%	11%	1%	1%		5%	1%
Sweden		1%		18%		6%		1%	0.4%	9%	12%	3%		0.2%	16%
Spain		0.1%				16%		6%	2%					0.4%	
Total	**98%**	**96.8%**	**63%**	**97%**	**90%**	**61%**	**98%**	**79%**	**94%**	**87%**	**91%**	**79%**	**0%**	**92.4%**	**93%**
EU28 %of total fuel consumed	**1%**	**19%**	**17%**	**1%**	**1%**	**1%**	**2%**	**36%**	**1%**	**1%**	**2%**	**1%**	**0%**	**3%**	**3%**

[7] These 11 countries make up more than 85% of the installed CHP capacity in Europe

Platts provides data on the new installed power plant capacity for the period 2006 – 2013 split by fuel (

Figure 9). It is noted that most of the installed capacity of new power plants is in Italy, Spain, UK, Germany, France, Netherlands, Portugal, Ireland, Greece and Belgium. Figure 9 also shows most of the new capacity is natural gas-based. Thus it is expected that most operational data will be obtained from these countries and will be for natural gas plants, mainly CCGT based plants.

Figure 9: New installed power plant capacity (2006 – 2013) by fuel



4 Data Collection

A major requirement for this project was the collection of operational data.

Collection of operational data from power stations and boilers operating with the fuels identified in Section 3 (

Table 9) was facilitated by creating a website (www.cogeneration-reference-values-review.eu). An e-mail address was also created: EU.ref-values@ricardo-aea.com enabling those accessing the website to contact the project team if they have any queries.

This website enabled stakeholders to learn about the project, register for workshops and provide some contact details, confirm attendance at the briefing event and access the appropriate questionnaires to provide the required power-only, heat-only and CHP data.

Key stakeholders, namely Member State Representatives and also the main relevant Trade Associations' bodies were contacted directly and briefed on the project. These communications provided the rationale for the study, the process that was put in place to gather data, primarily through a web-based questionnaire and to ask if they would promulgate this information and data request through the appropriate routes to plant operators.

Separate questionnaires for power generation and heat generation data collection were developed and distributed via a link on the project website and inserted as direct links to e-mails sent to targeted trade associations and plant operators.

The power-only questionnaire covered the requirement for the operational data for each of the years (2006 - 2013 as applicable) and requested data on:

- fuel consumption (for main fuel used on site),
- % of the main fuel used on site,
- total electricity generated and delivered to the grid and
- the electricity supplied to customers (if available).

For plants which operate in CHP mode, the heat output was also required. A boiler data collection questionnaire was sent to MS representatives (via the Commission) to collect data on a country-by-country basis.

Questionnaires were also developed in Survey Monkey format to allow operators to complete the necessary data online. Copies of these questionnaires are shown in the Appendix to this report.

4.1 Summary of questionnaire responses

In the attempt of gathering as much operational data as possible from power-only and heat-only plants, the developed questionnaires were sent to MS representatives and to Trade Associations.

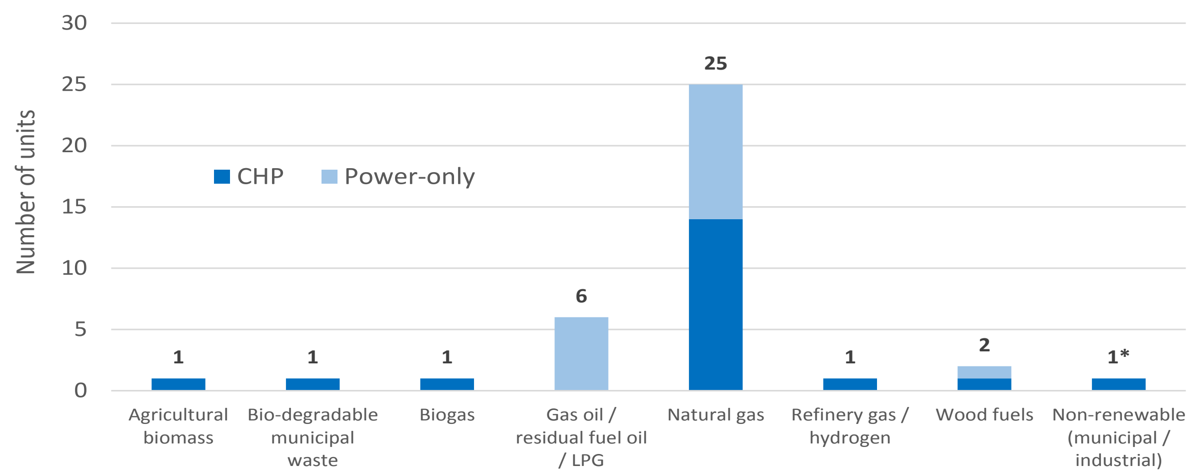
Initially planned for 31 October 2014, the closing date for completing the questionnaire was extended to 21 November 2014. Despite this, insufficient data were collected both in terms of range and quantity.

Ideally, to formulate accurate reference values, operational data from several units/plants are required for each fuel type and/or heating application. However the data collected did not cover all of the fuels listed in

Table 9 or all of the heating applications of interest.

Power related operational data was received from 37 plants in seven different countries, 18 of which are power-only and 19 are CHP. There is, however, a data gap which is visible in Figure 10. For five fuel types, gathered data originate from single sources (one plant per fuel type), whereas only three fuel types had data for two or more plants. The latterly mentioned fuel types are: Natural gas, Gas oil/residual fuel oil/LPG and wood fuels (only two plants).

Figure 10: Questionnaire responses in number of units and sorted by fuel type used in CHP and power only plant



(*) data point taken from a unit mosty using natural gas (75%). With stable power/heat ratios, the non-renewable waste efficiency can be estimated by assuming a natural gas efficiency equal to that when the unit runs solely on natural gas.

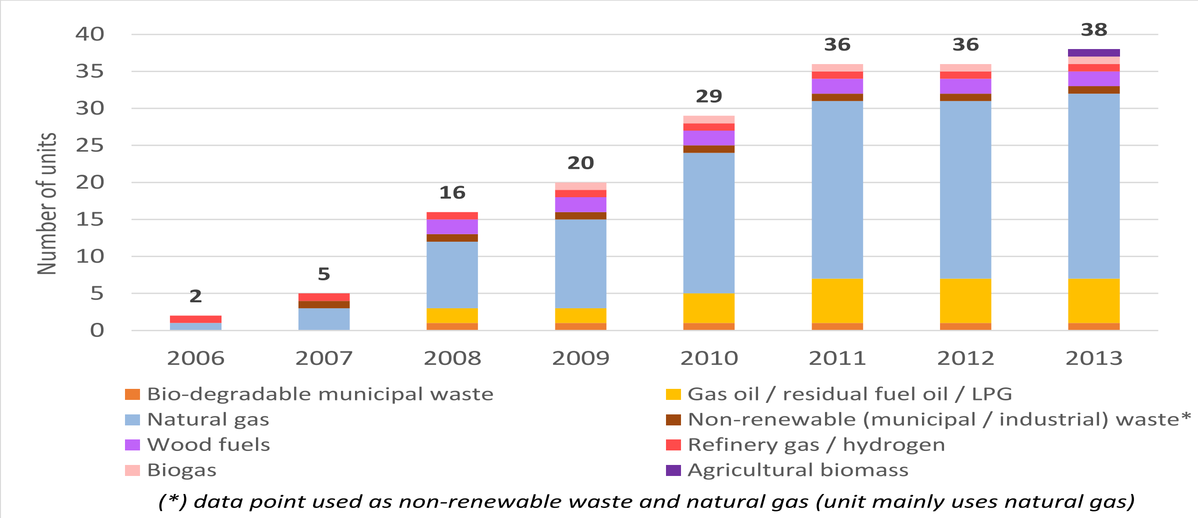
Based on submitted operational data for natural gas, gas oil/residual fuel oil/LPG and wood fuels, the *highest* (not average) electrical efficiencies achieved by these plants were 59% (for one of the plant), 47% and 33% respectively.

Figure 11 shows an overall picture of the collected data from CHP[8] and power-only plants, which is sorted by fuel type and by year of operation. It should be noted that in certain plants, two fuels are used. The share of primary fuel usage in each case varies but remains above 96%, with the exception of one plant running on 75% natural gas and 25% non-renewable waste. In this case, the fuels can be separated and efficiencies for both scenarios can be estimated.

It is noted that, as expected, the majority of the available data are for natural gas. Data for renewable fuels, on the other hand, is limited.

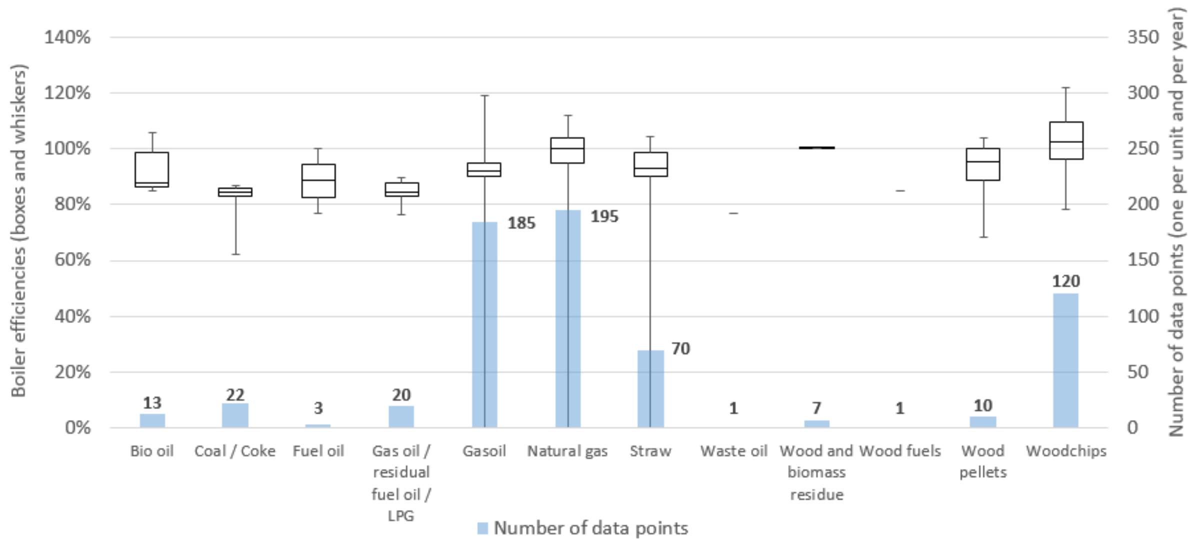
Figure 11: Collected data sorted by number of units, fuel type and year

[8] Even though the main interest is in data for power-only and heat-only plants, CHP data remain useful. Indeed, it is possible to determine the electrical efficiency of a CHP unit if it were to run in power-only mode from CHP data (fuel, power and heat). To calculate the power-only efficiency of a CHP unit which is not running in condensing mode, the power loss coefficient, which is a function of the grade of heat extracted, can be used. In order to calculate the electrical output at full condensing mode, the power loss coefficient is multiplied by the actual thermal output (in CHP mode) and the product is added to the actual electrical output (in CHP mode). The electrical efficiency at full condensing mode can then be calculated.



Despite a greater number of data points with regards to heat-only operational data, all fuel categories are still not covered and nor are all heating applications. As shown in Figure 12, 12 fuel categories are present, however two of them consist of single data points. In order to analyse boiler efficiencies for given fuels, only single fuel data points were considered, each data point representing one year of operation of a plant or of a unit within a plant. As it can be seen in the figure, a few data points exhibit implausibly high boiler efficiencies, questioning the accuracy of the data.

Figure 12: Boiler efficiencies for single fuel data points (one per year) – operational data from heat-only plants



The 647 data points gathered in Figure 12 originate from 177 plants and represent yearly boiler efficiencies between 2006 and 2013 inclusive. The heating application is known for 169 of these plants: 167 of them generate hot water, 1 plant generates steam, and another uses heat directly from the exhaust gases.

As a result, there is currently a lack of operational data for the majority of fuel types, necessitating that alternative approaches must be undertaken in order to establish future reference values.

5 Estimation of Cogeneration Reference Efficiencies for Electricity and Heat

5.1 Introduction

This section presents the methodology used in establishing the final recommended list of reference efficiencies (Section 5.2). It should be noted that a draft list of electrical and thermal reference efficiencies (Appendix 4) was developed and presented to stakeholders in a draft report and at the stakeholder meeting in Brussels on Feb. 10, 2015. Following additional analysis after the stakeholder meeting and following feedback from stakeholders (Appendix 3), a revised list of reference values has been produced as discussed in this Section. Key changes to the original list of reference values including those which have been originally recommended in the draft report but later abandoned are presented in Section 5.3.

The final recommended list is given in Section 5.4 with explanatory notes provided in Section 5.5. Detailed analysis of the data leading to the recommended values is given in Appendices 1 and 2.

As shown in Section 4, for most fuels, the amount of data and number of data points obtained through submitted questionnaires is not satisfactory to form a reliable representative dataset of operational data on which recommendations for the reference values can be based. As a result, as described below, alternative methods were considered in order to allow their estimation.

5.2 Methodology

As required by Annex II, f of the Energy Efficiency Directive, the harmonised efficiency reference values "must be based on a well-documented analysis taking, inter alia, into account data from operational use under realistic, fuel mix and climate conditions as well as applied cogeneration technologies." In the following subsections, the methods for establishing the reference efficiencies for electricity and heat are described.

5.2.1 Electricity

The approach for reviewing and updating the efficiency reference values is visualised in Figure 13. As stipulated by the Directive, the primary approach for each fuel is to collect operational data of power-only production. As outlined in section 4, requests were sent out, on behalf of the Commission, to stakeholders and Member States. Where operational data was received by the consultancy team, it has been scrutinised in order to assess whether it could be actually used for determining the electrical efficiency reference value. Criteria used for this assessment were

(i) Data reliability
(ii) Transparency (has sufficient detail been provided regarding location & size of the plant, the (lower or higher) heating value of the fuel, input and output data),
(iii) Representativeness of the data (data from old plants or demonstration plants e.g. do not qualify) and
(iv) The availability of time series (to ensure that the operational data does not only reflect and extremely good or bad year).

In case the operational data for an individual fuel passes all checks, they can be used for setting an efficiency reference value after normalisation of the data.

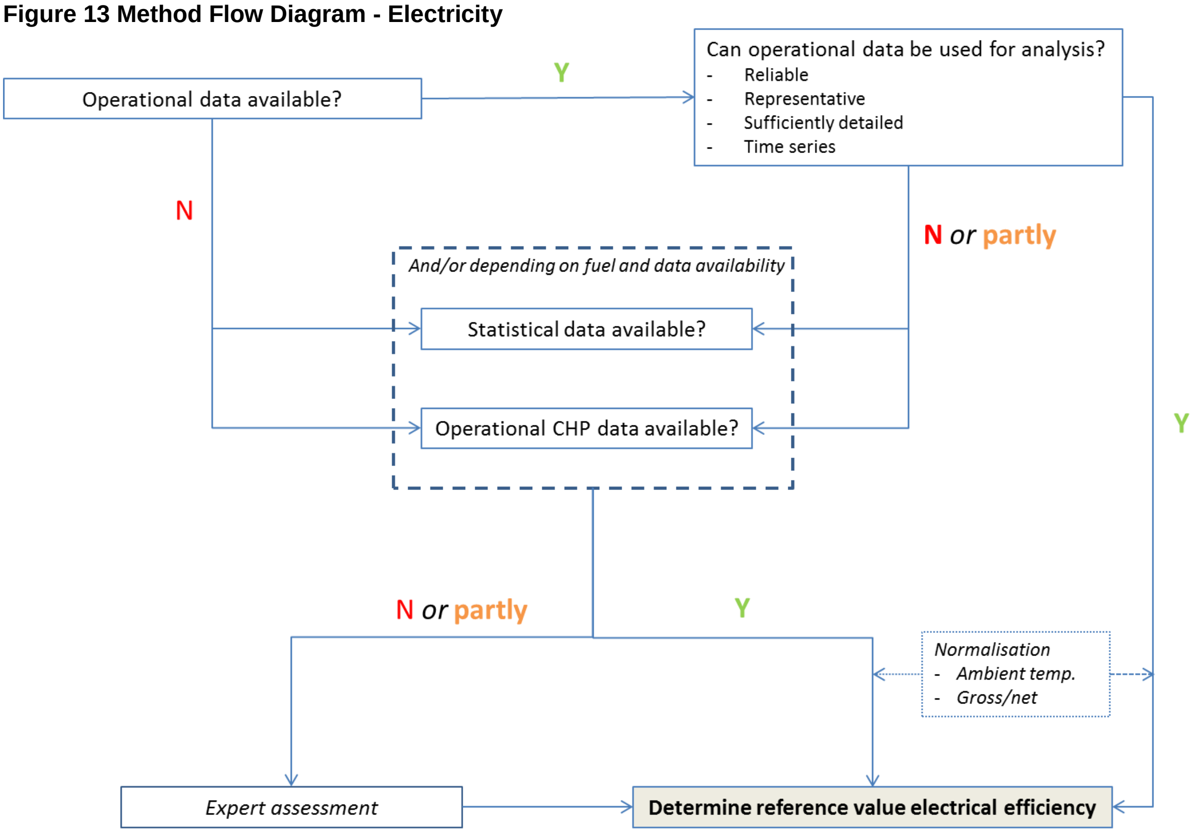
5.2.1.1 Data normalisation

For gaseous fuels the operational efficiency needs to be normalised for ambient temperature, i.e. 0.1 percentage point increase or decrease if the ambient temperature is lower or higher than standard ISO conditions (15°C). For the average ambient temperature the data from the capital cities are taken.

In the Directive the electrical efficiency of a CHP plant is a gross efficiency, i.e. without corrections for internal power consumption of the plant. As the reference efficiency values for electricity are not explicitly defined in the Directive in terms of gross or net, an approach has to be chosen:

- For most gas-fired CHP plants the internal consumption is comparable with the internal consumption of separate heat production in a boiler as long as the plant operates in CHP mode. In that case, the internal consumption (if any) for the cooling of the power plant is additional and should be accounted for in the reference value of gaseous fuels. A reasonable approach is to use the net efficiency of power-only production. Gross efficiencies of power-only production should be corrected downwards with a factor 1/1.022.
- For fuels, which need fuel and/or flue gas treatment (e.g. coal) the situation is slightly different. The internal consumption of a CHP plant for fuel and/or flue gas treatment is higher compared to separate power production since the power efficiency of a CHP plant is lower than the power efficiency of the best available separate production. When in this case net efficiencies for separate power production are applied as reference value the CHP plant is granted for its high internal consumption (especially when the CHP power efficiency is considerably lower than the power efficiency for separate production). The reference values of these fuel types will therefore have to be higher than net efficiencies (due to fuel and flue gas treatment) but lower than gross efficiencies (due to the avoided internal consumption for cooling). The proposed approach is to increase net efficiencies of these fuels by a factor of 1.035 or to decrease the gross efficiency by a factor of 1.035 (assuming a 7 percentage-points difference between gross and net efficiencies).

Figure 13 Method Flow Diagram - Electricity



5.2.1.2 Alternative approaches

In cases where the operational data does not pass or only partially passes the checks, alternative approaches had to be adopted in order to determine the electrical efficiency reference value. Depending on fuel type and data availability, either statistical data and/or data from CHP plants were used to determine the reference values:

- **Statistics**: This approach was based on the analysis of the statistical trend development of electricity efficiencies of plants using various fuel types with focus on the period 2008 –

2012 (or newer data when available). Focussing on this period helped get appropriate insight into the current average operational efficiencies over a longer period and avoiding possible misinterpretation of the data in case of untypical years. Statistics may be useful as a source for those fuels that are sufficiently big in size (quality of statistics tend to decrease for smaller plants) and represent a unique fuel type rather than a set of heterogeneous fuel types that have been split in separate fuel categories in the proposed reference value matrix. Natural gas meets both criteria whereas solid biomass, for example, is often just one fuel category in statistics which makes them less useful for determining reference values for this particular group of fuels.

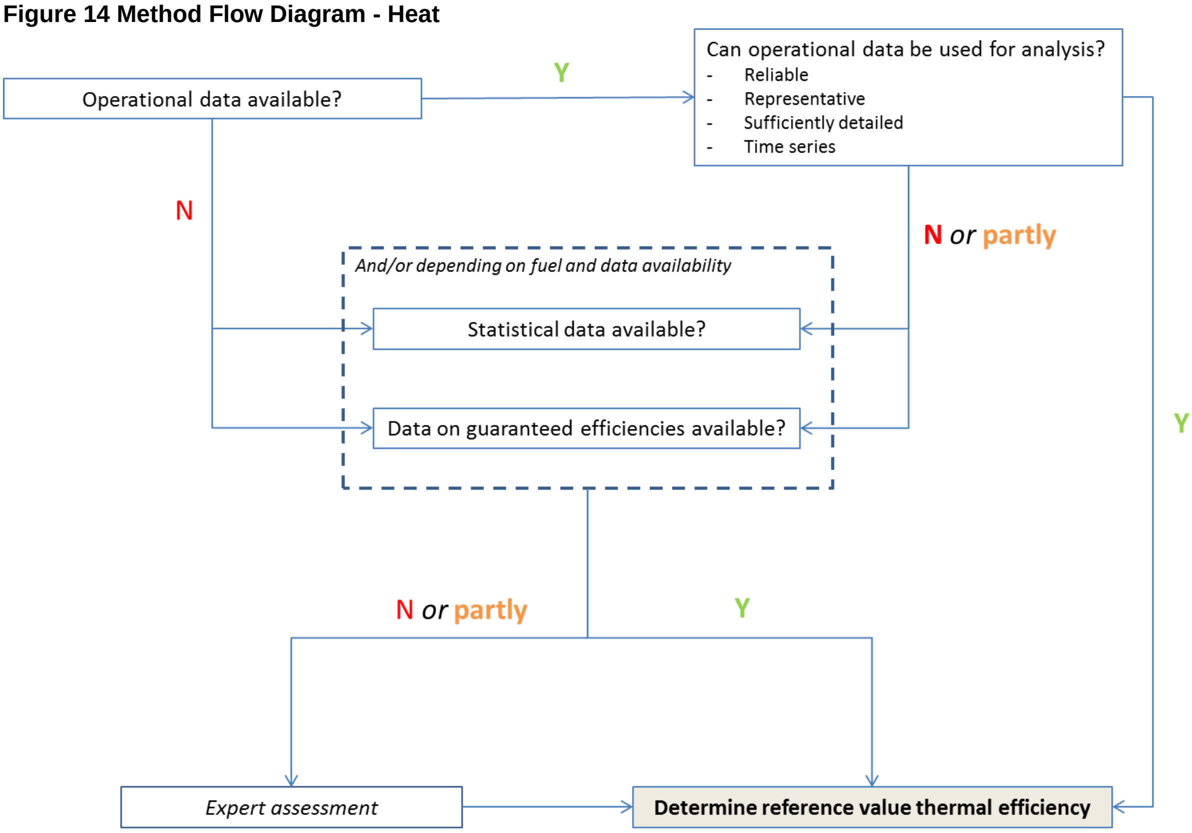
- **CHP data**: This approach was based on operational and statistical data for CHP plants that have the ability to run in condensing mode. This means that the CHP data can be normalised to power-only data using a power loss coefficient (based on steam conditions, plant size and steam extraction pressure).

In cases where the two approaches above still provided insufficient proof for determining the reference values (efficiency values often come in ranges: the higher end of the range is not necessarily the most appropriate reference value), expert knowledge and feedback from stakeholders has been used to come to a final decision.

5.2.2 Heat

The approach for reviewing and updating the efficiency reference values is visualised in Figure 14. As for electricity, the primary approach for each fuel is to collect operational data of heat-only production. As discussed in Section 4, requests were sent out, on behalf of the Commission, to stakeholders and Member States. Where operational data was received by the consultancy team, it has been scrutinised in order to assess whether it could be actually used for determining the heat efficiency reference value. The criteria used for this assessment were as described in Section 5.2.1 for 'Electricity'. However, unlike electricity reference values, heat values should not be normalised for ambient conditions (see Section 6.1.2).

Figure 14 Method Flow Diagram - Heat



5.2.2.1 Alternative approaches

The alternative approaches for heat are based on statistical data and/or data on efficiencies from boiler manufacturers. It should be stressed that the statistical data concerns sold heat-only (for example district heating) since statistics report the deliveries to the end-user (which is the boiler fuel) rather than the secondary energy produced (heat).

Table 11: Fuel ranking EU-28 based on power-only (main activity + auto-producer) and heat-only boilers

Power-only production ranking			Heat-only production ranking		
Ranking Fuels (2012)	Fuel	Electricity production (2012) [TWh]	Ranking Fuels (2012)	Fuel	Heat production (2012) [PJ]
1	Nuclear	871.2	1	Natural gas	289.4
2	Other bituminous coal	377.8	2	Other bituminous coal	134.9
3	Natural gas	278.6	3	Solid biomass	130.4
4	Lignite	247.2	4	Municipal waste (Re and non-Re)	37.5
5	Solid biomass	26.2	5	Fuel oil	20.7
6	Fuel oil	25.1	6	Gas oil/diesel	9.5
7	Coking coal	20.9	7	Peat	7.3
8	Municipal waste	17.8	8	Coking coal	6.6
9	Blast furnace gas	17.4	9	Industrial waste	5.0
10	Biogas	16.3	10	Other liquid bio	4.9
11	Anthracite	15.2	11	Lignite	4.0
12	Gas oil/diesel	8.6			

5.3 Changes to the previous list of reference values

5.3.1 Consideration of a capacity threshold for natural gas

In the draft version of the reference values, a capacity threshold for natural gas (100 MWe) with two values of reference electrical efficiency (for capacities ≤ and > 100 MWe) was suggested. The reasoning behind this recommendation is given below. While there was wide support for this approach from stakeholders, it was decided, as explained below, to abandon this approach for the 2016-2019 set of values and to recommend for consideration in the next review.

5.3.1.1 Current situation

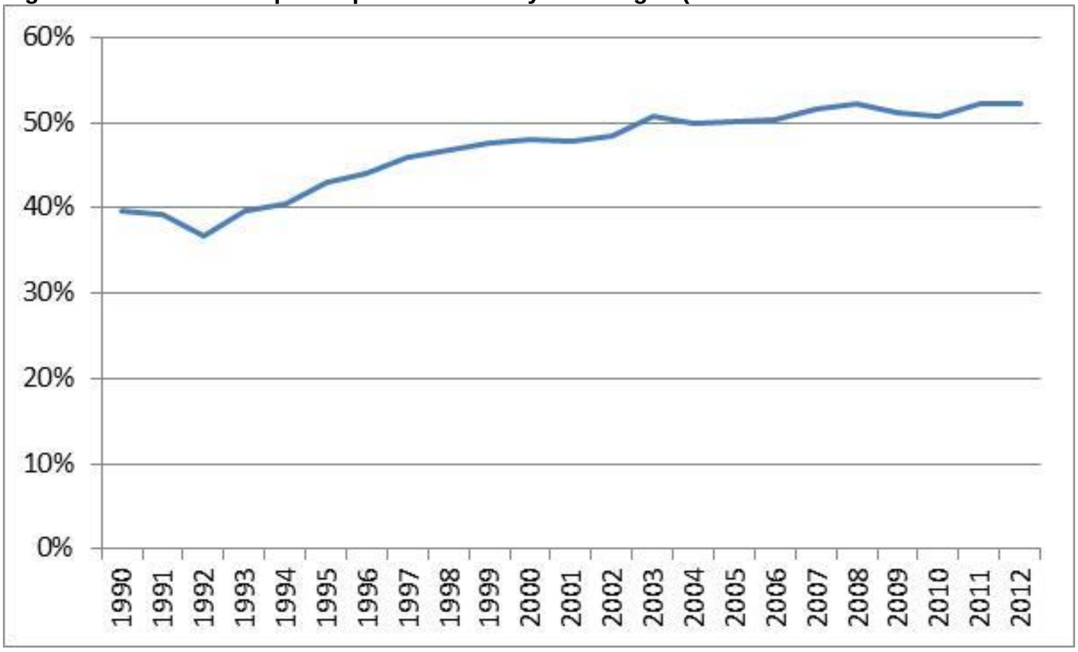
The reference value for electricity for natural gas has been previously based on large Combined Cycle Gas Turbine (CCGT) power plants. These plants have traditionally been the technology of choice for gas power stations. However, there is evidence that the electricity market has been driving change in plant choice, with an increasing number of smaller gas-fired power plants being installed.

Analysis of the Platts database of power plant investments in Europe shows that 64 gas-fired plants of more than 100MWe were installed from 2006 to 2013. At the same time 48 gas-fired plants in the size range of 25 and 100 MWe and a further 61 plants in the size range of 5 and 25MWe were installed. Note that all of these are power plants and not cogeneration plants. This reflects a shift in the market to smaller, quicker to install projects demanded by the electricity market for flexibility. As a result, the previous natural gas reference value for electricity is not completely representative of the current shift in the market as it is based on larger CCGT power plants.

5.3.1.2 Considerations on the efficiencies of natural gas power plant

For large CCGT plants, there is a slight increase in efficiency since 2006, though the rapid improvements in plant efficiencies of earlier years (prior to 2006) have not continued. This reflects that CCGT technologies have matured and increasing efficiency is based on small improvements. Figure 15 shows that since 1990 the average efficiency of gas-fired power capacity (IEA category: main activity) in the EU28 has increased from about 40% to more than 52% (gross efficiency, LHV).

Figure 15: Trend development power efficiency natural gas (derived from IEA statistics – main activity)



For smaller plants, there is not a suitable suite of data. Manufacturers' datasheets for sub-100MWe CCGTs show that the efficiency is on average 51%. As we have seen from experience with larger CCGTs, the difference between manufacturers' datasheets and operating efficiency is around 6 percentage points and so for small CCGTs this would imply an operating efficiency of 45%. This efficiency value is supported by analysing data set of cogeneration plants in a number of EU countries, recalculated to power only/condensing efficiency.

However, the vast majority of small gas-fired plants installed are not CCGTs, but open-cycle gas turbines. These have a much lower operating efficiency. For plants in the size range of 25 to 100MWe, from manufacturers' datasheets, the average efficiency is 39%, with the range 45% down to 29%. Operating efficiencies will be lower. Again using the cogeneration data set the efficiency in power only mode for OCGT plants below 100MWe gives an average of 40%.

Both of these sets of considerations would result in a reference value efficiency for small gas plants below the one proposed for larger plants. If this is based on the higher of the two, the one for CCGTs, then this would be 45.0%. As these plants would be embedded in the network and not connected at the highest grid levels, the efficiency should be corrected upwards to give parity to large CCGTs. Assuming these plants are connected at the MMV level the correction factor is 0.952 (refer to Section 6), resulting in a reference value of 47.3%.

5.3.1.3 Proposal to the Commission

We believe there is a need to propose that the Commission considers two reference electrical efficiencies for natural gas depending on the size of plant (100 MWe based on evidence). However, we believe that splitting the natural gas category into two reference values will add complexity to the existing reference values table. Evidence shows that for smaller plants (≤100 MWe), the reference electrical efficiency should be reduced below the existing 52.5%. As a result, if a split in the natural gas category is implemented now, the existing table will show that the reference electrical efficiency for the new '≤ 100 MWe' sub-category has been gradually increasing since 2001 and suddenly decreasing for the period 2016 – 2019. This is inaccurate and so historic reference efficiencies for the '≤ 100 MWe' should be scaled down for all previous years showing a gradual increase and leading to the new recommended value (50% as was originally recommended in the draft report as shown in Appendix 4).

We thus recommend that the Commission does not consider this split for the period 2016-2019

but to revisit this in the next review.

5.3.2 Consideration of a capacity threshold for wood fuel

In the draft version of the reference values, a capacity threshold for wood fuels (25 MWe) with two values of reference electrical efficiency (for capacities ≤ and > 25 MWe) was suggested. The reasoning behind this recommendation is given below. There was support for this approach from some stakeholders. However, following the stakeholder workshop, it was decided to abandon this approach for the 2016-2019

set of values and to recommend consideration in the next review.

5.3.2.1 Current situation

The reference value for electricity for wood fuels has been previously defined at 33%. Most existing plants are smaller plants. Recent development in the power sector shows that many of the new wood fuel plants with generating capacities greater than 250 MWe.

5.3.2.2 Considerations on the efficiencies of wood fuel power plant

Analysis of biomass-CHP data, shows that, depending on capacity and the quality of the fuel, power-only efficiency ranges from 21% to 39%. This wide range of efficiencies is not observed for other types of fuels (including agricultural biomass). Analysis based on operational data received as part of this project (2 data points) and based on analysis of CHP data shows that the 33% efficiency level is reasonable for smaller plants (≤ 25 MWe) operating on wood fuel. It is, however, noted that, while larger wood fuel-based plants were not common a few years ago, plants with large capacities (>250MW) are now in planning in Europe and, based on design data, these plants, using dried fuel and more efficient combustion technologies such as fluidised-bed combustion (FBC), normally have efficiencies closer to 37% (NCV) which are achievable under certain innovative boiler designs. As a result, it was originally recommended to split the wood fuel category into two categories to highlight the fact that larger plants (> 25 MWe).

5.3.2.3 Proposal to the Commission

Whilst a split in this category may have merits, there is insufficient evidence to suggest that the market would build small power-only plant without subsidy regimes that support such projects. Thus we recommend keeping it as a single set of reference values.

5.3.3 Additional categories

5.3.3.1 Waste heat

Waste heat is currently treated a part of the 'coke over gases, blast furnace gases, etc.' category with reference electrical efficiency of 35% and reference heat efficiency of 85%. We recommend that waste heat is treated as a separate category. This refers to waste heat from industrial processes which is subsequently used for generating power (e.g. in an Organic Rankine Cycle, ORC) with the remaining heat (i.e. after passing through the power generation process) used for useful applications. It is recommended that the reference value for the waste heat category when extracted through waste heat recovery boilers to be 100% (as there is no heat losses in these circumstances and waste heat recovery boilers have efficiencies typically in the order of 100% or more). As for electricity generation from waste heat it is recommended to use the same reference values as that for Agricultural biomass of 30%.

5.3.3.2 Nuclear

As discussed in Section 2, nuclear CHP is currently in operation and many studies show that this could become increasingly common in the future. As a result, a new category is added to the list of fuels as discussed in section 2 and 3. A typical power generation efficiency for nuclear plants is 33% while a heat reference efficiency is not available and so the value for natural gas is used.

5.3.3.3 Solar thermal

As discussed in Section 2, solar CHP is increasingly becoming popular. This is the application where solar heat is used to generate power (e.g. using a Stirling engine) with the heat remaining from the power generation process used, through heat exchangers, for hot water and space heating. As such plants currently exist and likely to become more popular in the future, we recommend adding a new category for solar thermal to be used as reference against which solar CHP can be compared.

5.3.3.4 Geothermal

Geothermal CHP is increasingly becoming popular. This is the application where high or medium quality geothermal heat is used to generate power (e.g. using an Organic Rankine Cycle) with the heat remaining from the power generation process used for useful purposes (e.g. district heating). As such plants currently exist and likely to become more popular in the future, we recommend adding a new category for solar thermal to be used as reference against which solar CHP can be compared.

5.3.4 Consideration of hot water and steam Reference Efficiencies

5.3.4.1 Current situation

The Commission Decision 2007/74/EC determined the reference efficiency values of steam and hot water were only considered the same when the condensate return to the boiler was neglected in the calculations. This was formulated, in French, in a footnote to the heat reference table:

“Il faut retrancher 5 points de pourcentage absolus au rendement vapeur lorsque les États membres qui appliquent l'article 12, paragraphe 2, de la directive 2004/8/CE prennent en compte le retour du condensat dans les calculs de rendement d'une unité de cogeneration”

The English translation:

“For Member States that use an alternative calculation method via Article 12.2, heat only steam efficiencies should be lowered by 5 percentage points if condensate return is subtracted from the useful heat production of a CHP plant.”

In the revision to the reference values completed in 2011 (Commission Decision 2011/877/EU), this adjustment footnote was omitted. It is not clear whether this omission was deliberate or by mistake.

5.3.4.2 Considerations on the efficiencies of heating plant

The efficiency of operating boiler plants varies depending on many factors. Whereas in hot water applications these variations include the load factor on the boiler, the actual condensing capability and the variability of heat demand. For steam systems there are more factors to consider, these include the pressure of the steam demand, the variability of steam demand (which can be very rapid), the lack of use of low temperature heat and the contamination or live use of the steam preventing condensate return, etc.

In hot water boilers the efficiencies will vary from design conditions and the reference values considered take these factors into account. However, these factors do not present a large range of variations from the efficiencies given from the analysis.

In steam boilers the various factors have a far greater influence and in turn range of efficiencies and so it is necessary to understand these and account for this variation in setting the reference efficiency values. It is important to recognise that these factors are a function of the heat demanding site and not necessarily due to a poor boiler design. These issues are:

- Condensate return: on industrial sites the level of condensate return can vary from as much as 95% of steam flow (5% is typically unavailable due to steam distribution factors such as steam traps and inefficiencies in steam use) to zero condensate return where the steam is consumed by the process or is contaminated and is sent directly to an effluent treatment plant. In addition the condensate may be returned in the form of either hot water or low pressure steam. If the maximum condensate is returned then the boiler plant efficiency will match that of a hot water boiler (before taking into account other factors that may reduce efficiency). It is good practice to return as much as possible of the condensate. Returned condensate is usually hot so, besides reducing the quantity of fresh treated water make-up that is required to compensate for losses, it reduces the heat (steam) requirements of the deaerator. This in turn results in a fuel saving either at the CHP plant or at the site boilers.
- Steam variation: in steam systems the use of steam can be steady and vary slowly, which occurs in continuous process industrial applications, or it may vary considerably and with rapid ramp-ups and ramp-downs. The greater the variability of the steam supply, especially rapid variations in volumes, the less efficient the boiler's annual operation will be.
- Lack of low temperature heat demand; many industrial sites have no use for low-grade heat and so the use of economisers and especially condensing economisers is not possible. In these cases the boiler will operate without being able to recover a proportion of the heat in the boiler exhaust. The use of an economiser may lower the boiler exhaust to below 100°C, but where this cannot be used the exhaust temperature may be 170°C or more.
- The grade of steam required: the higher the steam pressure and temperature the lower the boiler operating efficiency will be. There is not a straight-line correlation and for example there are step changes due to transition from shell boilers to water tube boilers.

As each industrial site using steam will have a different mix of these factors, it is not practical to have a complete range of options to adapt the reference values for steam. The range of efficiencies can be from equally as high as the efficiency of a hot water boiler, to 12 percentage points below that efficiency.

In order to determine the true thermal efficiency of the reference boiler plant the quantity (and temperature) of returned condensate, the steam conditions, variability and steam use must be taken into consideration. In practice this may present a number of problems (metering complexity being just one factor). Thus it is necessary to use a simplified convention to cover the range of possibilities.

Ultimately, in future reviews of the reference values and the assessment of CHP efficiencies it may be beneficial to properly account for these factors. However, at the present time, even dealing with one factor, such as condensate return, is complex and the consultant team recommends a simple and transparent approach.

Finally, the reference values associated with the direct use of heat also account for the zero return of condensate/hot water to the boiler feedwater. This accounts for the lower reference values.

5.3.4.3 Proposal to the Commission

We therefore propose reference values for steam be lowered by five percentage points from the hot water reference values for each of the fuels. This reflects a mid-point in the range of efficiencies for the factors discussed above.

5.4 Proposed Reference Efficiency Values

As discussed above, during the consultation process of this study, a set of proposed reference efficiency values were presented to stakeholders in the Stakeholder Report and at the accompanying workshop (in February 2015). These draft values are shown in Appendix 4. Following feedback from stakeholders (Appendix 3), further consideration was given to the proposed reference values and, following further analysis, the list of reference values was revised as shown in Table 12 below. The key changes from the draft version presented in Appendix 4 are as follows (discussed above in Section 5.3)

- the proposals for splitting the natural gas (G11) and wood fuel (S4) categories according to capacity were abandoned (recommended for consideration as part of the next review)

- solar thermal and geothermal categories were added as two new categories under 'Other'

The key changes in the reference values are

- **For reference electrical efficiencies**
  - Maintaining the reference efficiency for
    - the coal, lignite and peat categories at the previous levels
    - the solid waste category at 25%
    - Oil and biofuel (categories L7 and L8) at 44.2%
    - biogas at 42%
    - coke over gas, blast furnace gas, etc. at 35%
  - Increasing the reference efficiency for
    - wood fuels from 33% to 37%
    - agricultural biomass from 25% to 30%
    - the liquid waste category from 25% to 29%
    - natural gas from 52.5% to 53%
  - Decreasing the reference efficiency for
    - Refinery gas from 44.2% to 42%
  - Setting the reference efficiency for
    - Nuclear at 33%
    - Waste heat, solar thermal and geothermal at 30%

- **For reference heat efficiencies**
  - For the Hot water category
    - Maintaining the reference efficiencies for all solid fuels the same as previously
    - Deceasing the reference thermal efficiencies in the liquid fuel category as follows
      - For oil and biofuel (categories L7 AND l8), from 89% to 85%
      - For waste liquids, from 80% to 75%
    - Increasing the reference thermal efficiencies
      - For natural gas, from 90% to 92%
      - For refinery gas from 89% to 90%
      - For Biogas, from 70% to 80%
      - For coke over gas, etc., from 80% to 85%
    - Setting the reference heat efficiency for
      - Nuclear at 92%
      - Waste heat, solar thermal and geothermal at 100%
  - Splitting the hot water / steam categories into two separate categories (as discussed in Section 5.3.4) with steam reference efficiencies 5 percentage points lower than those of hot water (except for the waste heat, solar thermal and geothermal categories)
  - Making the reference efficiencies for the 'direct use of heat' category consistently 3 percentage points lower than those of steam (except for the waste heat, solar thermal and geothermal categories)

Evidence and additional details and reasoning for the recommendations above are given in Section 5.5 below and in Appendices 1 and 2.

Table 12: Proposed final electricity and heat reference values

Fuel Category		Description	Electrical efficiency %	Boiler efficiency, % Hot Water	Steam	Direct Use
Solids (S)	1	Hard coal including anthracite, bituminous coal, sub-bituminous coal, coke, semi-coke, pet coke	44.2	88	83	80
	2	Lignite, lignite briquettes, shale oil	41.8	86	81	78
	3	Peat, peat briquettes	39.0	86	81	78
	4	Wood fuels, including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse	37.0	86	81	78
	5	Agricultural biomass including logs, round wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains, contaminated waste wood	30.0	80	75	72
	6	Municipal and industrial waste (non-renewable) and renewable/ bio-degradable waste	25.0	80	75	72
Liquids (L)	7	Heavy fuel oil, gas/diesel oil, other oil products	44.2	85	80	77
	8	Bio-liquids including bio-methanol, bioethanol, bio-butanol, biodiesel, other liquid biofuels	44.2	85	80	77
	9	Waste liquids including biodegradable and non-renewable waste (including pyrolysis oils, black and brown liquor, tallow)	29.0	75	70	67
Gases (G)	10	Natural gas, LPG and LNG	53.0	92	87	84
	11	Refinery gases hydrogen and synthesis gas	42.0	90	85	82
	12	Biogas produced from anaerobic digestion, landfill, and sewage treatment	42.0	80	75	72
	13	Coke oven gas, blast furnace gas and other recovered gases (excluding refinery gas)	35.0	80	75	72
Others (O)	14	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)	30.0	100	100	100
	15	Nuclear	33.0	92	87	84
	16	Solar thermal	30.0	100	100	100
	17	Geothermal	30.0	100	100	100

5.5 Changes to the current reference values

This section, supported by Appendices 1 and 2, provides the evidence and reasoning for the current list of reference values. The tables below provide a description of the category, issues related to the fuel definition, issues related to the technology and our approach in recommending the reference values for electricity and heat.

5.5.1 Solid fuels

Category	Solid Fuel, S1
Description	Hard coal including anthracite, bituminous coal, sub-bituminous coal, coke, semi-coke, petcoke
Introduction	Fuel category S1 covers hard coal and includes anthracite, sub-bituminous coal, pet coke and semi-coke. Bituminous coal (second place after nuclear), coking coal (seventh) and anthracite (tenth) are all top 10 fuels for power-only production in the EU-28. It should be stressed that electricity production from bituminous coal (378 TWh in 2012) is much greater than the 21 TWh from coking coal and the 15 TWh from anthracite. Bituminous coal (second place after natural gas) and coking coal (ninth) are also top 10 fuels for heat only production (sold heat only). Also for heat, heat production from bituminous coal (135 PJ in 2012) is much greater than the heat production from coking coal (7 PJ).
Current reference efficiency	The existing reference efficiency for category S1 is 44.2% for electricity and 88% for hot water / steam.
Commentary on Approach Adopted	The consulting team did not receive sufficient data and so the alternative approaches discussed in sections 5.2.1.2 were used to set the reference electrical efficiencies for solid fuels. The same is true for heat reference efficiencies as insufficient operational data was received. Based on statistical data, the average EU-28 efficiency for the period 2008-2012 is 39.3% for bituminous coal and 40.1% for coking coal. These values are lower than the current value of 44.2%. According to Platts, the data are dominated by relatively old plants and so the efficiency of operational plants is influenced heavily by the older plants and consequently the efficiency is slightly below the current value of 44.2%. There is no evidence to suggest that there is a need to change the existing reference electrical efficiency. Furthermore, due to lack of operational data, we propose to maintain the heat reference efficiency from the existing reference set for hot water.
Recommendation for Electricity Efficiency	44.2%
Recommendation for Heat Reference Efficiency	Hot Water: 88% Steam: 83% Direct Use: 80%

Category	Solid Fuel, S2
Description	Lignite, lignite briquettes, shale oil
Introduction	Fuel category S2 is lignite and lignite briquettes. Shale oil, which was in the previous list included as a separate category, is also included under the lignite category due to lack of data and as it has similar efficiencies. Lignite ranks 4th in terms of electricity production with 247 TWh and 11th in terms of heat production with 4 PJ.
Current reference efficiency	The existing reference efficiency for category S2 is 41.8% for electricity and 86% for hot water / steam.
Commentary on Approach Adopted	As with the cola category, the consulting team did not receive sufficient data and alternative approaches discussed in sections 5.2.1.2 were used to set the reference electrical efficiencies for solid fuels. The same is true for heat reference efficiencies as insufficient operational data was received. Based on historic statistical data, the average efficiency for lignite for the period 2008-2012 for the EU-28 is 36.4%. The 2008-2012 average efficiencies for highest ranking country (Germany) is 38.1% (only country scoring above EU average). It is not clear from the IEA data to what extent these figures are dominated by old or new technology. Checking the Platts database shows that the majority of these plants are old plants. As a result, the efficiency calculated from statistical data is slightly lower than the existing 41.8% reference efficiency. As there is no evidence to suggest that there is a need to change the existing reference electrical efficiency, it is recommended to maintain the reference electrical efficiency for lignite at 41.8%. Trend development boiler heat efficiency (main activity includes 93% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 85.7%). Thus we propose to maintain the heat reference efficiency from the existing reference set for hot water. We propose to reduce the reference efficiency for steam by 5 percentage points and that for direct use of heat by 8 percentage points.
Recommendation for Electricity Efficiency	41.8%
Recommendation for Heat Reference Efficiency	Hot Water: 86% Steam: 81% Direct Use: 78%

Category	Solid Fuel, S3
Description	Peat, peat briquettes
Introduction	This category includes peat and peat briquettes. This category is not one of the top ranking categories for power-only production but ranks 7th for heat-only production but representing in the order of 1% of total heat used.
Current reference efficiency	The existing reference efficiency for category S3 is 39.0% for electricity and 86% for hot water / steam.

Commentary on Approach Adopted	The consulting team did not receive sufficient data and so alternative approaches (as described in Section 5.2.1.2) were used to set the reference electricity efficiency for S3 fuels. The same is true for heat reference efficiencies as insufficient operational data was provided. Statistical data shows that the average electricity efficiency for peat for the period 2008-2012 for the EU-28 is 39.9% which is slightly higher than the current value of 39%. Peat power-only data is just a small data sample dominated by Finland and Ireland. It is not clear from the IEA data to what extent these figures are dominated by old or new technology. However, the Platts database shows that while many plants operating on peat in these countries are older plants, new plants are being designed and built. Trend development boiler heat efficiency (main activity includes 98% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 84.6%, with the 4 of these years achieving 86%). Thus we propose to maintain the heat reference efficiency from the existing reference set for hot water. We propose to reduce the reference efficiency for steam by 5 percentage-points and that for direct use of heat by 8 percentage-points.
Recommendation for Electricity Efficiency	39.0%
Recommendation for Heat Reference Efficiency	Hot Water: 86% Steam: 81% Direct Use: 78%

Category	**Solid Fuel, S4**
Description	Wood fuels including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse
Introduction	This category mainly refers to high quality biomass fuels. This includes wood fuels with relatively high energy content and low moisture content. The list of fuels falling under this category is not exhaustive but is thought to represent fuels which are naturally of high quality without further processing. The determining factor for including these fuels in the same category is the fact that they are associated with similar electrical efficiencies when combusted. Another approach would be top group fuels in categories S4 and S5 according to moisture content but this would significantly add to the complexity of applying the reference values to CHP plants by Member States.
Current reference efficiency	The existing reference efficiency for category S4 is 33% for electricity and 86% for hot water / steam.
Commentary on Approach Adopted	As discussed in Section 5.3.2, we have considered dividing this category into two sub-categories (S4A and S4B) depending on a capacity threshold of 25 MWe. The justification for this is that, as observed from power-only efficiencies obtained from CHP data, plants with lower capacities (<25MW) have lower efficiencies (31%-33%) while larger plants have efficiencies which could reach 37% (NCV). This wide range of efficiencies is not observed for other types of fuels (including agricultural biomass, category S5). As a result, this argument supports assigning two efficiency values to plants operating on wood fuels, a lower value for smaller plants and another for larger plants. Evidence shows that he most reasonable capacity threshold is 25 MWe. However, whilst a split in this category may have merits, there is

	insufficient evidence to suggest that the market would build small power only plant without subsidy regimes that support such projects. Thus we recommend keeping it as a single set of reference values. Limited operational data was provided for plants operating on wood fuels (2 plants). These were with capacities of 25 and 50MW and reported efficiencies of 26% and 36% (NCV) respectively. In comparison to design data, the 26% seems to be on the lower end for 25MW plants. A 36% for the 50 MW plant indicates that higher efficiencies are achievable for larger plants as has been observed for plants > 250 MWe. Additional operational data would be required in order to establish the correct reference efficiency. Based on IEA historic data, average efficiency for the period 2008-2012 for the EU-28 is 32% (main activity power-only) or 44.9% (autoproducer CHP in Sweden – representing 56% of total electricity production in Swedish solid biomass CHP). It should be noted that the Swedish figures might be higher due to the fact that Swedish biomass CHP plants have capacities up to 130MW with an average capacity of 30MW while the EU-average might be dominated by smaller scale installations. Design data for larger biomass plants in some European countries show that efficiencies (NCV) as high as 37% are achievable. Analysis of biomass-CHP data, shows that, depending on capacity and the quality of the fuel, power-only efficiency range from 21% to 39%. It is noted that plants with large capacities (>250MW) are now in planning in Europe and, based on design data, these plants, using dried fuel, normally have efficiencies closer to 37% (NCV) which are achievable under certain innovative boiler designs. Due to a lack of operational data, we propose to base our recommendation for the heat reference efficiency on statistical data. The trend development for boiler heat efficiency (main activity includes 94% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 81.1%). When taking the best performing member states in the Statistics (Denmark, Finland, Hungary, Luxembourg, Poland, Lithuania), which represent 33% of total fuel use for main activity sold heat production in the EU-28, the average 2008 - 2012 heat efficiency = 87.9**%.** Since, based on IEA statistics, the average heat-only efficiency for biomass boilers (wood fuel) are close to the current reference efficiency of 86%, and due to the lack of operational data, we recommend that the current value of 86% for wood fuels is maintained for hot water and a reference for steam that is 5%-points lower than for hot water. It should be noted that, as shown in Section 7, the increase of the electrical reference efficiency to 37% does not significantly influence the HE CHP performance of cogeneration plants operating on wood fules which can still deliver PES (above 30%) using the higher reference electrical efficiency.
Recommendation for Electricity Efficiency	37%
Recommendation for Heat Reference Efficiency	Hot Water: 86% Steam: 81% Direct Use: 78%

Category	Solid Fuel, S5
Description	Agricultural biomass including logs, round wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains, contaminated waste wood
Introduction	This category mainly refers to low quality biomass fuels. This consists of agricultural biomass (which is used as it is harvested without treatment to increase its energy content), including logs, wound wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains. These fuels tend to have a higher moisture content than similar biomass fuels covered by category S4, and consequently combustion technologies are modified accordingly.
Current reference efficiency	The existing reference efficiency for category S5 is 25.0% for electricity and 80% for hot water / steam.
Commentary on Approach Adopted	While one submission was received for agricultural biomass, no operational data was provided for this plant. The consulting team did not receive sufficient operational data and so the alternative approaches in Section 5.2.1.2 were used. IEA statistics do not provide a separation between wood fuels and agricultural biomass. As discussed above, based on IEA historic data, average electrical efficiency for biomass plants for the period 2008-2012 for the EU-28 is 32.0% (main activity power-only) and 44.9% (auto-producer CHP in Sweden – representing 56% of total electricity production in Swedish solid biomass CHP). It is not clear from the IEA data what proportion of these plants use 'agricultural biomass' rather than 'wood fuels'. Using CHP data from the UK shows that, power-only efficiency for plants using agricultural biomass (as defined under category S5) can reach 30%. Design data for newly installed CHP schemes also shows that efficiencies as high as 30 % (based on fully condensing mode) are achievable. Therefore, it is proposed to increase the reference efficiency value from the current level of 25% to 30%. Due to lack of operational data, we propose to maintain the heat reference efficiency from the existing reference set for hot water and direct use, and a reference for steam that is 5%-points lower than for hot water. It should be noted that, as shown in Section 7, the increase of the electrical reference efficiency from 25% to 30% does not significantly influence the HE CHP performance of cogeneration plants operating on agricultural biomass which can still deliver PES (above 25%) using the higher reference electrical efficiency.
Recommendation for Electricity Efficiency	30%
Recommendation for Heat Reference Efficiency	Hot Water: 80% Steam: 75% Direct Use: 72%

Category	**Solid Fuel, S6**
Description	Municipal and industrial waste (non-renewable) and renewable/ bio-degradable waste
Introduction	This includes solid waste, both bio-degradable and non-renewable including industrial waste, municipal waste and clinical waste. The bio-degradable and renewable waste categories are treated separately under the existing reference values. However, due to similar efficiencies and for simplicity, it is proposed to combine the two in one category.
Current reference efficiency	The existing reference efficiency for category S6 is 25.0% for electricity and 80% for hot water / steam.
Commentary on Approach Adopted	The primary purpose for waste-to-Energy (WtE) plants is the treatment of waste through incineration and thus the recovery of energy for electricity, heat or CHP is a secondary activity. The requirement to combust the waste especially the secondary (gaseous) combustion at high temperatures and for a substantial residence time (850°C and 2s) reduces the ability to recover energy. The fuel can be sourced from unsorted waste, all the way to refuse derived fuel (RDF). Unsorted waste-based WtE plants are generally less efficient than RDF or SRF-based WtE plants. Based on statistical data, the average electricity efficiency for the years 2008-2012 for the EU-28 is 25.8%. This average is similar to the current reference efficiency of 25% but some countries (Finland, Germany, Hungary, Spain) have efficiencies >30%. This has been validated by CHP data (efficiencies at full condensing mode), which show efficiencies in the range 20%-31%. In addition, the consulting team has access to a dataset consisting of information on 44 heat-only plants and 83 power-only plants. However this data cannot be validated as it does not specify the fuel used, the technology deployed and does not have enough granularity to perform efficiency calculations. Nevertheless it does provide a population of plant and a spread of size ranges and efficiencies. Results from this dataset support the conclusions obtained from the statistical data and CHP data. The current reference electrical efficiency for both bio-degradable and non-renewable municipal waste is 25%. Some evidence from CHP plant data suggests that reference efficiencies for plants operating on municipal waste could be increased to 30%. However, based on the operational data of power-only plants and the IEA data available, we recommend that the reference efficiency for both bio-degradable and non-renewable fuels remains the same at 25%. For heat references the operational data shows that a number of plants achieve 80% efficiency and the trend development boiler heat efficiency from IEA (main activity includes 75% of total sold heat production; average heat efficiency main activity 2008-2012 = 59.0% for bio-degradable waste and 63% for industrial waste) suggests that the current reference of 80% for hot water should be maintained.
Recommendation for Electricity Efficiency	25%
Recommendation for Heat Reference	Hot Water: 80% Steam: 75%

Efficiency	Direct Use: 72%

5.5.2 Liquid fuels

Category	**Liquid Fuel, L7**
Description	Heavy fuel oil, gas/diesel oil, other oil products
Introduction	This category includes heavy fuel oil, diesel oil and other oils. LPG should be removed out of this category and included under natural gas.
Current reference efficiency	The existing reference efficiency for category L7 is 44.2% for electricity and 89% for hot water / steam.
Commentary on Approach Adopted	Operational data was submitted for plants in the capacity range 50 to 220 MW. Efficiencies ranged from 40.8-42.6%, slightly lower than the current reference value. Based on IEA statistical data, the average efficiency for 2008-2012 for the EU28 for fuel oil is 37.3%. Countries show high fluctuations in efficiency. For gas diesel, the average power-only efficiency is 45.2% (auto-producer power only) and 35.0% (main activity power only). Average efficiencies for highest ranking countries are 42.8% for France and 40.5% for Austria. No CHP data for plants operating on oil and diesel was available and so this approach was not applied here. The current reference electrical efficiency for fuel oil is 44.2%. Due to conflicting evidence and due to lack of data, we propose to keep the reference electrical efficiency at 44.2%. There is a lack of operational data on heat efficiencies. Based on IEA statistical data, an efficiency of 84.3% is obtained. Based on this data, the heat reference efficiency should be reduced from the current 89% to about 85%. Therefore, we recommend that the heat reference efficiency be set at 85% for hot water.
Recommendation for Electricity Efficiency	44.2%
Recommendation for Heat Reference Efficiency	Hot Water: 85% Steam: 80% Direct Use: 77%

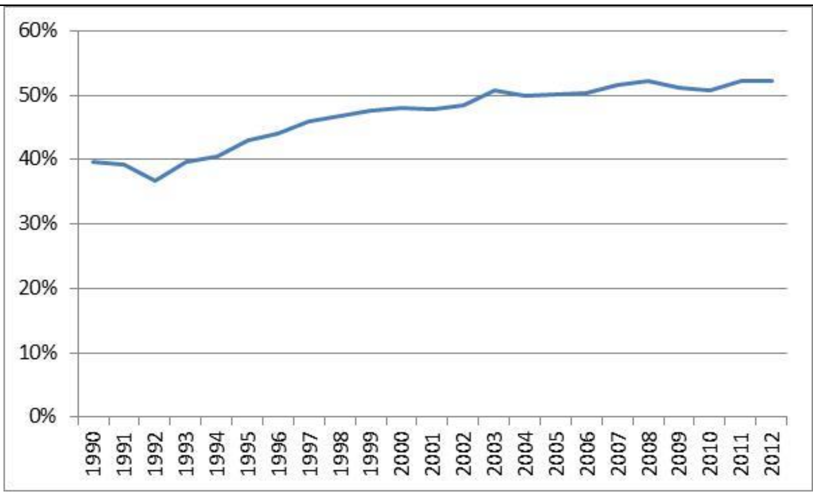
Category	**Liquid Fuel, L8**
Description	Bio-liquids including bio-methanol, bioethanol, bio-butanol, biodiesel, other liquid biofuels
Introduction	This category include Bio liquids including bio methanol, bioethanol, bio butanol, biodiesel, and other liquid biofuels. This is a very broad set of fuels and with the increasing use of renewable sources is likely to increase in scope.
Current reference efficiency	The existing reference efficiency for category L8 is 44.2% for electricity and 89% for hot water / steam.
Commentary on Approach Adopted	Submissions were made for two plants (4 MW and 24 MW) operating on biofuel (both CHP plants). Data was available for one of the plants with power-only efficiency of 44.7%. This compares well with the current value of 44.2%.

	Statistical IEA data was not available for biofuels. Based on CHP design data and using limited operational data, the average power-only efficiencies for bio-liquids were calculated as 35-40%. This is below the current reference efficiency of 44.2%. Due to the limited operational data and the evidence that operational plants can achieve efficiencies as high as 44.7%, we recommend that for now this reference efficiency is kept at 44.2%. Based on IEA statistical data, trend development boiler heat efficiency is in the range 82%-85%. We therefore propose to use the same heat references as for category L7 at 85% for hot water and a reference for steam that is 5%-points lower than for hot water.
Recommendation for Electricity Efficiency	44.2%
Recommendation for Heat Reference Efficiency	Hot Water: 85% Steam: 80% Direct Use: 77%

Category	**Liquid Fuel, L9**
Description	Waste liquids including biodegradable and non-renewable waste (including pyrolysis oils, black and brown liquor, tallow)
Introduction	This category includes liquid waste from bio- biodegradable and non-renewable sources.
Current reference efficiency	The existing reference efficiency for category L9 is 25% for electricity and 80% for hot water / steam.
Commentary on Approach Adopted	The consulting team did not receive sufficient operational data. In addition, no IEA statistical data was available for plants operating on liquid waste. However, CHP design and operational data are available and these were used to determine full-condensing efficiencies showing power efficiencies in the range 28-29%. Based on CHP data, the reference power efficiency for liquid waste is slightly higher than the current value of 25%. We thus recommend that this figure is increased to 29%. Due to lack of operational and IEA data, we propose to maintain the heat reference efficiency from the existing reference set at 80% for hot water.
Recommendation for Electricity Efficiency	29%
Recommendation for Heat Reference Efficiency	Hot Water: 75% Steam: 70% Direct Use: 67%

5.5.3 Gaseous fuels

Category	Gaseous Fuel, G10
Description	Natural gas, LPG and LNG
Introduction	The reference value for electricity for natural gas has historically been based on large Combined Cycle Gas Turbine (CCGT) power plants. These plants have traditionally been the technology of choice for gas power stations. However, there is evidence that the electricity market has been driving change in plant choice, with an increasing number of smaller gas-fired power plants being installed. Analysis of the Platts database of power plant investments in Europe shows that 64 gas-fired plants of more than 100 MWe were installed from 2006 to 2013. At the same time 48 gas-fired plants were installed between 25 and 100 MWe and a further 61 plants between 5 and 25 MWe. Note that all of these are power plants and not cogeneration plants. This reflects a shift in the market to smaller, quicker-to-install plants demanded by the electricity market for flexibility, and so these plants should be taken into account when establishing the reference efficiencies.
Current reference efficiency	The existing reference efficiency for category G10 is 52.5% for electricity and 90% for hot water / steam.
Commentary on Approach Adopted	For this category there is sufficient operational data, which is supported by IEA data. For the large CCGT plants there seems to be evidence showing a slight increase in efficiency since 2006, though the rapid improvements in plant efficiencies of earlier years (prior to 2006) have not continued. This reflects that the CCGT technologies have matured and increasing efficiency is based on small improvements. Based on operational data, peak / maximum efficiencies of 58-60% (NCV) can be achieved for CCT plants. On an annual basis, this corresponds to 52-54%. The figure below shows clearly that since 1990 the average efficiency of gas-fired power capacity (IEA category: main activity) in the EU28 has increased from about 40% to about 53% (gross efficiency, LHV). Our recommendation is thus to increase the current natural gas reference electrical efficiency from 52.5% to 53%. This is supported by operational data as well as data calculated (at full condensing mode) from CHP plants. This recommendation is applicable for larger CCGT plants.

<table>
<tr><td></td><td>

As discussed above, it was initially recommended to split the natural gas category into two sub-categories: one for large plants (> 100 MW) with a reference efficiency of 53% and another for smaller plants (≤100 MWe) with a lower efficiency. For smaller CCGT plants (< 100 MW), there is not a suitable suite of data. Manufacturer’s datasheets for sub-100 MWe CCGTs show that the efficiency is on average 51%. As we have seen from larger CCGTs, the difference between manufacturer’s datasheets and operating efficiency is around 6%-points and so for small CCGTs this would imply an operating efficiency of 45%. This efficiency value is supported by analysing the data set of the UK of cogeneration plants recalculated to power- only/condensing efficiency.
However, the vast majority of small gas-fired plants installed are not CCGTs, but open-cycle gas turbines (OCGT). These have a much lower operating efficiency. In the range, 25 MWe to 100 MWe, from manufacturer’s datasheets the average efficiency is 39%, with the range 45% down to 29%. Operating efficiencies will be lower. Again using the UK cogeneration data set available to the consulting team, the efficiency in power-only mode for OCGT plants below 100 MWe gives an average of 40%.
Both of these sets of considerations would result in a reference value efficiency for small gas plants below the proposed one for larger plants of 53.0%. If this is based on the higher of the two, the one for CCGTs, then this would be 45.0%. As these plants would be embedded in the network and not connected at the highest grid levels, the efficiency needs to be corrected upwards to give parity to large CCGTs. Assuming these plants are connected at the MMV level the correction factor is 0.952, resulting in a reference value of 47.3%.
However, as discussed in Section 5.3.1.3, whilst the consulting team acknowledges this situation and there is merit in further analysis, the recommendation is not split the category by size. As a result, a single reference efficiency of 53% should be adopted for natural gas.
For the reference heat efficiency, IEA data shows an efficiency of 92% for hot water boilers operating on natural gas. This is supported by operational data received as part of this project which show average efficiencies in the range 90-96%. </td></tr>
<tr><td>Recommendation for Electricity Efficiency</td><td>53%</td></tr>
<tr><td>Recommendation for Heat</td><td>Hot Water: 92%</td></tr>
</table>

Reference Efficiency	Steam: 87% Direct Use: 84%

Category	Gaseous Fuel, G11
Description	Refinery gases, hydrogen and synthetic gas
Introduction	This includes refinery gas / hydrogen gas. In addition, syngas is also added to this category. Syngas (mainly hydrogen and carbon monoxide) results from the gasification and pyrolysis of solid fuels or from the reforming of natural gas. In CHP plants, it should be noted that the boundary for the CHP plant should exclude the gasifier or the syngas-producing equipment and should be defined around the engine using the syngas. So the fuel input to the CHP plant is syngas rather than solid fuel or solid waste for example.
Current reference efficiency	The existing reference efficiency for category G11 is 42% for electricity and 89% for hot water / steam.
Commentary on Approach Adopted	The consulting team did not receive sufficient operational data. In addition, IEA data and CHP data are also not available. Due to lack of data, we recommend that this value is kept at 42%. Due to lack of operational data, we also propose to maintain the heat reference efficiency from the existing reference set for hot water.
Recommendation for Electricity Efficiency	42%
Recommendation for Heat Reference Efficiency	Hot Water: 90% Steam: 85% Direct Use: 82%

Category	Gaseous Fuel, G12
Description	Biogas produced from anaerobic digestion, landfill, and sewage treatment
Introduction	This category includes biogas whether from AD plants, landfill gas or from wastewater treatment plants. It should be noted that for biogas-based CHP plants, the boundary should be drawn around the CHP plant with biogas as the fuel to the CHP engine rather than the feedstock used to produce the biogas.
Current reference efficiency	The existing reference efficiency for category G12 is 42% for electricity and 70% for hot water / steam.
Commentary on Approach Adopted	The consulting team did not receive sufficient operational data. Based on IEA statistical data, the average efficiency for 2008-2012 for biogas for the EU-28 is 37.0% (main activity, power only), 53.0% (main activity CHP) and 44.6% (auto-producer CHP) (Note: main activity CHP is much bigger than auto producer CHP. Data highly dominated by Germany.) Based on CHP plant data, power-only efficiencies for plants > 1 MW are above 40% (design data). The current reference electrical efficiency for biogas is 42%. Due to lack of operational data, we recommend that this value is kept the same. The current reference heat efficiency for biogas is thought to be low, at 70%. The number of plants utilising biogas from AD plants and wastewater treatment plants has been increasing recently. However, no

	operational data was received as part of this project. Design and suppliers data suggest that efficiencies of boilers operating on biogas can reach 80%. Our recommendation is thus to increase the current heat efficiency (for hot water) of 70% to 80%.
Recommendation for Electricity Efficiency	42%
Recommendation for Heat Reference Efficiency	Hot Water: 80% Steam: 75% Direct Use: 72%

Category	Gaseous Fuel, G13
Description	Coke oven gas, blast furnace gas and other recovered gases (excluding refinery gas)
Introduction	This category covers coke oven gas and blast furnace gas. Both are with similar efficiencies and so are kept in the same category as in previous list of fuels.
Current reference efficiency	The existing reference efficiency for category G13 is 35% for electricity and 80% for hot water / steam.
Commentary on Approach Adopted	The consulting team did not receive sufficient operational data. Based on IEA statistical data, the average electrical efficiency for blast furnace gas for the period 2008-2012 for the EU28 is 40.2%. The 2008-2012 average efficiencies for highest ranking countries: France 42.8%, Austria 40.5% Coke oven gas is a much smaller fuel for power only production. Based on CHP data, however, power-only efficiencies for plants operating on coke oven and blast furnace gases is 21-23%. Due to conflicting evidence at this stage, we recommend that the current reference value of 35% is kept the same. Due to lack of operational and IEA data, we propose to maintain the heat reference efficiency from the existing reference set at 80% for hot water and a reference for steam that is 5%-points lower than for hot water.
Recommendation for Electricity Efficiency	35%
Recommendation for Heat Reference Efficiency	Hot Water: 80% Steam: 75% Direct Use: 72%

5.5.4 Other fuels

Category	Other Fuel, O14
Description	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)
Introduction	This category covers waste heat such as the exhaust gas from high temperature processes, or as a product of exothermic chemical reactions. It should be noted that only waste heat that is used to generate electricity and then supply heat is included. It is not for either the generation of power or the supply of heat not in CHP mode.
Commentary on Approach Adopted	There is no reference data available for waste heat CHP, or power generation, or heat production. The team have adopted the approach used in the UK, as the only one currently available.
Recommendation for Electricity Efficiency	30%
Recommendation for Heat Reference Efficiency	Hot Water: 100% Steam: 100% Direct Use: 100%

Category	Other Fuel, O15
Description	Nuclear
Introduction	This category covers nuclear CHP. There is little CHP using nuclear, but there is a small amount
Commentary on Approach Adopted	The default power efficiency applied in statistics is 33%. The consulting team recommends to adopt this value as reference value for power production as it provides a transparent base for comparing the statistics of high-efficient CHP with the statistics of power only production. For the reference heat efficiency, we recommend that the reference efficiencies for natural gas are used.
Recommendation for Electricity Efficiency	33%

Recommendation for Heat Reference Efficiency	Hot Water: 92% Steam: 87% Direct Use: 84%

Category	**Other Fuel, O16**
Description	Solar Thermal
Introduction	This category covers solar thermal used in CHP mode. This is a new category and is included as the consulting team recognise that there is a potential for this technology in the near future as discussed in Section 5.3.3.
Commentary on Approach Adopted	As there is no direct data available, we have adopted the same references as for waste heat.
Recommendation for Electricity Efficiency	30%
Recommendation for Heat Reference Efficiency	Hot Water: 100% Steam: 100% Direct Use: 100%

Category	**Other Fuel, O17**
Description	Geothermal
Introduction	This category covers geothermal used in CHP mode. This is a new category and is included as the consulting team recognise that there is a potential for this technology in the near future as discussed in Section 5.3.3.
Commentary on Approach Adopted	As there is no direct data available, we have adopted the same references as for waste heat.
Recommendation for Electricity Efficiency	30%
Recommendation for Heat Reference Efficiency	Hot Water: 100% Steam: 100% Direct Use: 100%

6 Correction Coefficients

6.1 Correction for ambient conditions

Ambient conditions (e.g. temperature, pressure, relative humidity and cooling water temperature) can affect the efficiency of different thermal power or heat generation technologies through influencing the efficiency of the fuel combustion process and/or the efficiency of their corresponding thermodynamic cycles. Depending on the characteristics of different technologies, the direction and magnitude of impacts of ambient conditions on electric and heat efficiency performance may differ from each other. A literature review has been conducted to determine whether a revision of the correction factors for ambient conditions as given in Annex III of Decision 2011/877/EU is required.

This section present the results of the review for the electricity reference values (up to now corrected for ambient temperature only) and for the heat reference values (up to now not corrected for ambient conditions).

6.1.1 Correction for ambient conditions - electricity

Ambient temperature is currently the only ambient condition for which the electricity reference values are corrected (cf. Annex III of Decision 2011/877/EU): for each one degree Celsius above or below 15°C, the reference efficiency is decreased/increased with 0.1 percentage point. Our literature review shows that this correction is consistent with the empirical values found for gas turbines, combined cycle gas turbines and engines. For steam turbines (not in CCGT configuration) the impact of ambient conditions is much smaller. Moreover, whether the efficiency increases or decreases with an increase of ambient temperature is linked to the type of cooling system applied (open or closed).

As the fuel types used in gas turbines, CCGTs and engines are dominantly gaseous, the fuel types used in steam turbines are mainly solids and liquids, we recommend applying ambient temperature correction to gaseous fuels only.

For the other ambient conditions (atmospheric pressure, altitude, relative humidity), qualitative relations between ambient conditions and efficiency are found in literature. Quantitative relations are more limited and include specific technologies only. As the quantitative relations found are much smaller than those for ambient temperature, we recommend to continue to not apply corrections for atmospheric pressure, altitude and relative humidity.

Regarding cooling water temperature quantitative relations have been found for steam turbines and CCGT. Empirical data shows that for nuclear power plants and CCGT, the impact of cooling water temperature is comparable to the impact of ambient temperature. Cooling water temperature correction may therefore be relevant for the normalisation of the operational efficiency of power plants which serve as reference for the reference efficiency values. This can only be done if site specific conditions are known. Cooling water temperature correction should not be applied to correct the harmonised reference efficiency values when calculating the primary energy savings of specific CHP units.

Table 13: Summary of ambient conditions' impacts on the efficiency performance of different prototypical thermal power generation technologies

Power generation technology			Reciprocating engine	Gas turbine	Steam turbine			CCGT
ISO standard reference conditions	Ambient temperature (°C)		25	15	not avalable			15
	Atmospheric pressure (kPa)		101.3	101.3	not available			101.3
	Relative humidity (%)		30	60	not available			60
	Cooling water temperature (°C)		not available	not available	15			15
Impact of ambient conditions on efficiency performance	Ambient temperature	Qualitative correlation	Negative	Negative	Open-loop cooling system		Negative	Negative
					Closed-loop cooling		Positive	
		Quantitative correlation	-0.18% of rated efficiency per	-0.06 ~ -0.18 percentage point per 1°C increase	Open-loop cooling	Coal	-0.007 percentage point per 1°C	-0.09% of rated efficiency,

			1°C increase					increase	or -0.02 ~ -0.04 percentage point per 1°C increase
							NG	-0.003 percentage point per 1°C increase	
						Closed-loop cooling	Coal	+0.004 percentage point per 1°C increase	
							NG	+0.009 percentage point per 1°C increase	
	Atmospheric pressure	Qualitative correlation	Positive	Positive		Not available			Positive
		Quantitative correlation	not available	not available		not available			not available
	Relative humidity	Qualitative correlation	Negative	Without inlet air cooling	Positive	Open-loop cooling system	not available		not available
				With inlet air cooling	Negative	Closed-loop cooling system	Negative		
		Quantitative correlation	not available	Without inlet air cooling	+0.04 percentage point per 10% point increase in relative humidity	not available			not available
				With inlet air cooling	not available				
	Altitude	Qualitative correlation	Negative	Negative		Negative			Negative
		Quantitative correlation	-1.2% per every 100m increase in altitude above 300m	not available		not available			not available
	Cooling water temperature	Qualitative correlation	Not available	Not available		Negative			Negative
		Quantitative correlation	Not available	Not available		Coal	-0.02 percentage point per 1°C increase		-0.14% of rated efficiency per 1°C increase
						NG	-0.01 percentage point per 1°C increase		
						Nuclear	-0.12 percentage point per 1°C increase		
	Additional remarks	Combined impact of ambient conditions can be determined through relevant formulas provided in ISO 15550: 2002 (E)	Not available	Not available		Based on correcting the independent efficiencies for the topping gas turbine and the bottoming steam turbine, efficiency change of the CCGT can be calculated through the formula: $\Delta\eta_{CCGT} = (1-\eta_{ST,r}) * \Delta\eta_{GT} + (1-\eta_{GT,r}) * \Delta\eta_{ST} + \Delta\eta_{GT} * \Delta\eta_{ST}$			

6.1.2 Correction for ambient conditions - heat

Currently, no corrections are applied to the heat reference efficiencies. The aim of this review is to explore whether arguments can be found justifying such correction.

The boiler is the mainstay and most common technology for separate heat production, where water is heated in a closed vessel to generate steam or hot water for space heating or (industrial) process heating. In boilers, a wide range of fuels such as NG, propane, fuel oil, coal and biomass can be combusted. The produced flue gases then pass through a heat exchanger, transferring heat to the feed water to generate steam or hot water with high energy content. Boilers are usually fuel-specific, depending on the design characteristics and auxiliaries of each boiler. In Europe, gas-fired boilers with a market share of 79% dominate the individual central heating sector. The type and quality (e.g. purity, hydrogen content and moisture content) of the fuel often produce a large impact on both the load and the efficiency of the boiler.

Ambient temperature can have a significant impact on boiler efficiency mainly through the heat transfer between the boiler and the ambient air in the boiler room. For every 1°C increase in ambient temperature, boiler efficiency increases by 0.05 percentage point. According to standard engineering practice, an 80°F (or 26.7°C) boiler room ambient temperature is assumed for most boiler efficiency calculations. Therefore, boiler efficiency at full load is less sensitive to outdoor atmospheric temperature, unless the boiler operates outside.

For other ambient conditions, limited information is available on the impact on boiler efficiencies.

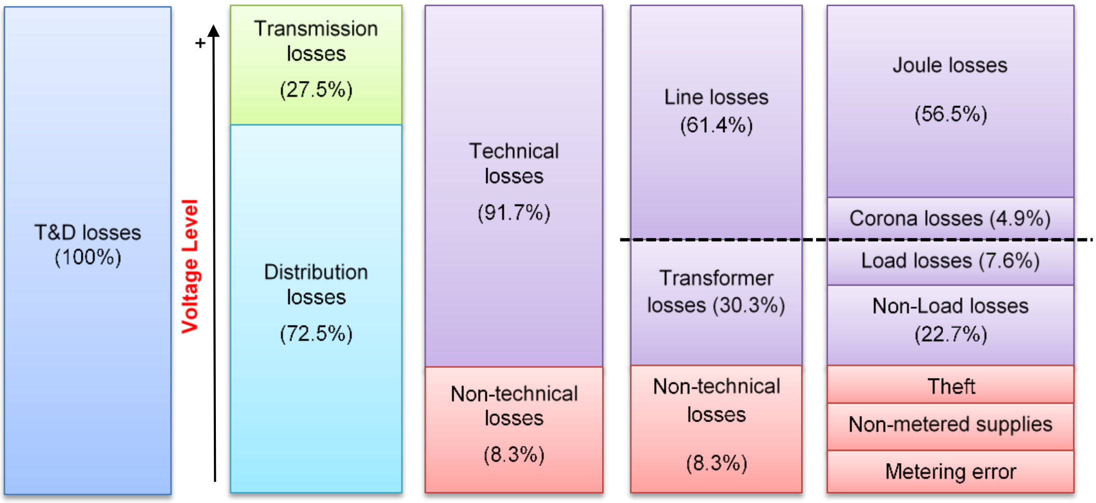
Based on the review of available sources and literature, we recommend to not include ambient correction factors for heat

6.2 Review of the grid loss correction factors

The purpose of this review is to calibrate and update the correction factors for grid losses set out in Annex III of *Decision 2011/877/EU* (EC, 2011). Transmission and distribution (T&D) losses refer to the amount of electric power consumed within the transmission and distribution network from electricity suppliers to end-users. They can be expressed as the percentage of losses out of the electricity output of power plants.

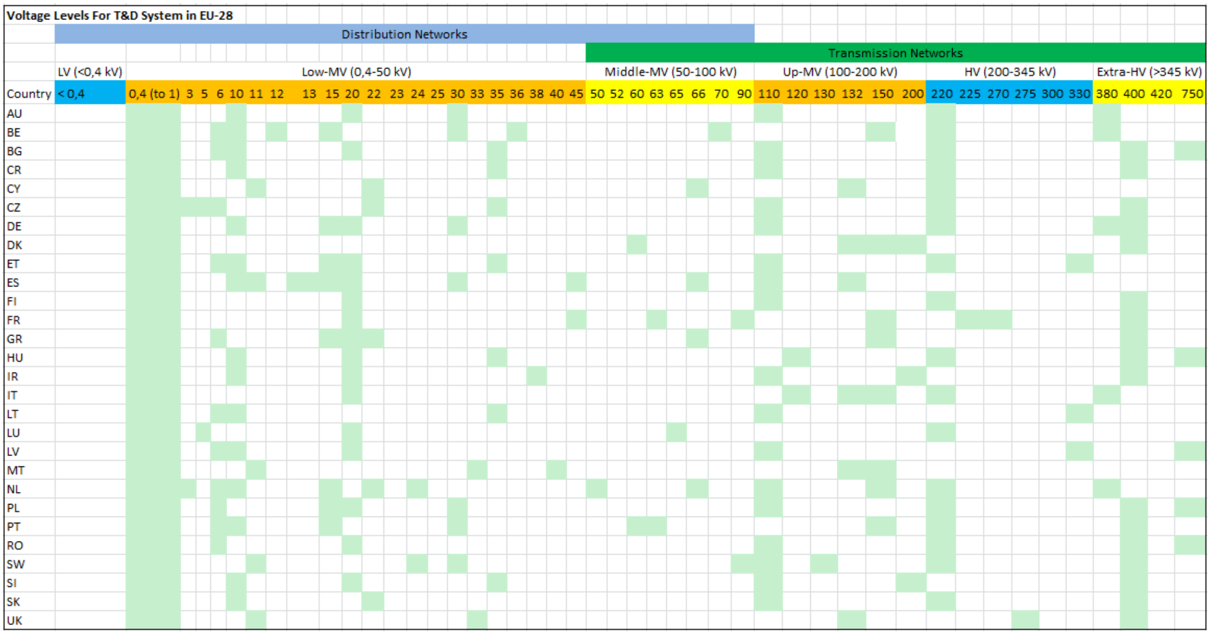
T&D losses can be mainly categorised into technical (or physical) losses and non-technical (or commercial) losses. Technical losses result from the resistances and electromagnetic properties of grid elements (e.g. transformers, underground cables, overhead lines) throughout the entire electrical network. Non-technical losses consist of electricity that is delivered and used, but not reflected in the sale records, such as electricity theft, non-metered supplies and metering errors compared to technical losses, non-technical losses are less significant. According to a survey by Ofgem in the UK, non-technical losses range from 3% to less than 20% of total losses within distribution networks. In this review we will focus on technical losses. An overview of the categorisation of grid losses, different grid loss components and their corresponding percentage contributions to total losses are presented in Figure 16. The percentage contributions of different grid loss components are calculated based on relevant parameters provided in a variety of literature.

Figure 16: Components of T&D losses and their percentage contributions to total losses



In Europe, the voltage levels for transmission grids range from 50 to 750kV, while most distribution lines (97% of the total grid) operate at a voltage level below 100kV, with 60% of distribution lines operating at less than 1kV. Approximately 70% - 75% of losses occur in the distribution grids. Detailed voltage levels for T&D lines of each Member State can be found in Figure 17.

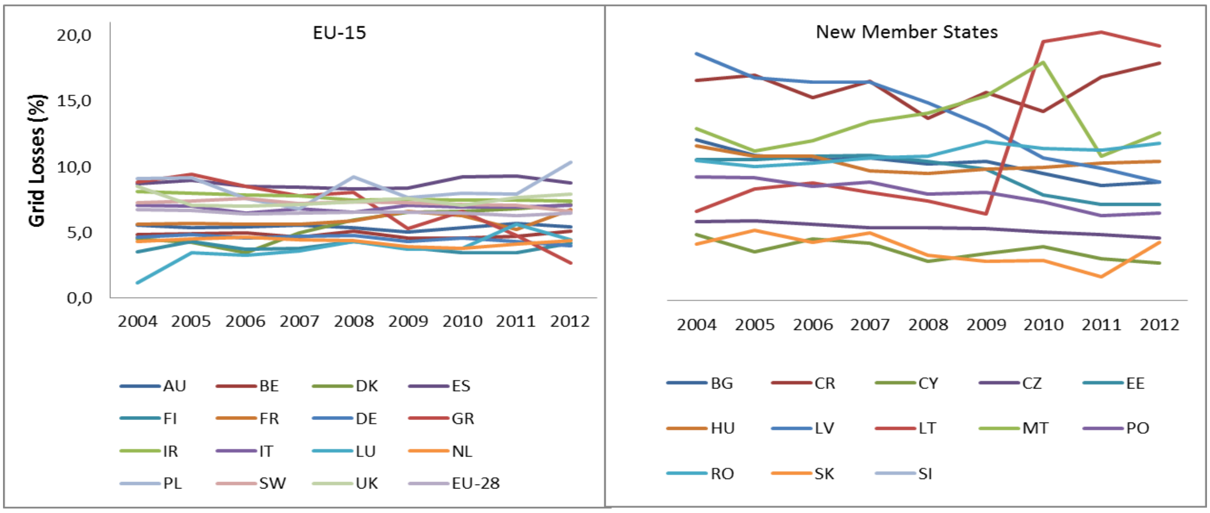
Figure 17: Detailed voltage levels for T&D lines of each Member States (derived from Eur-electric and the Grid Codes of individual Member States)



6.2.1 Development of correction factors for grid losses

System configurations and the corresponding grid losses of the electric power T&D system are heterogeneous across different EU Member States. The average grid losses at Member State level are presented in Figure 18.

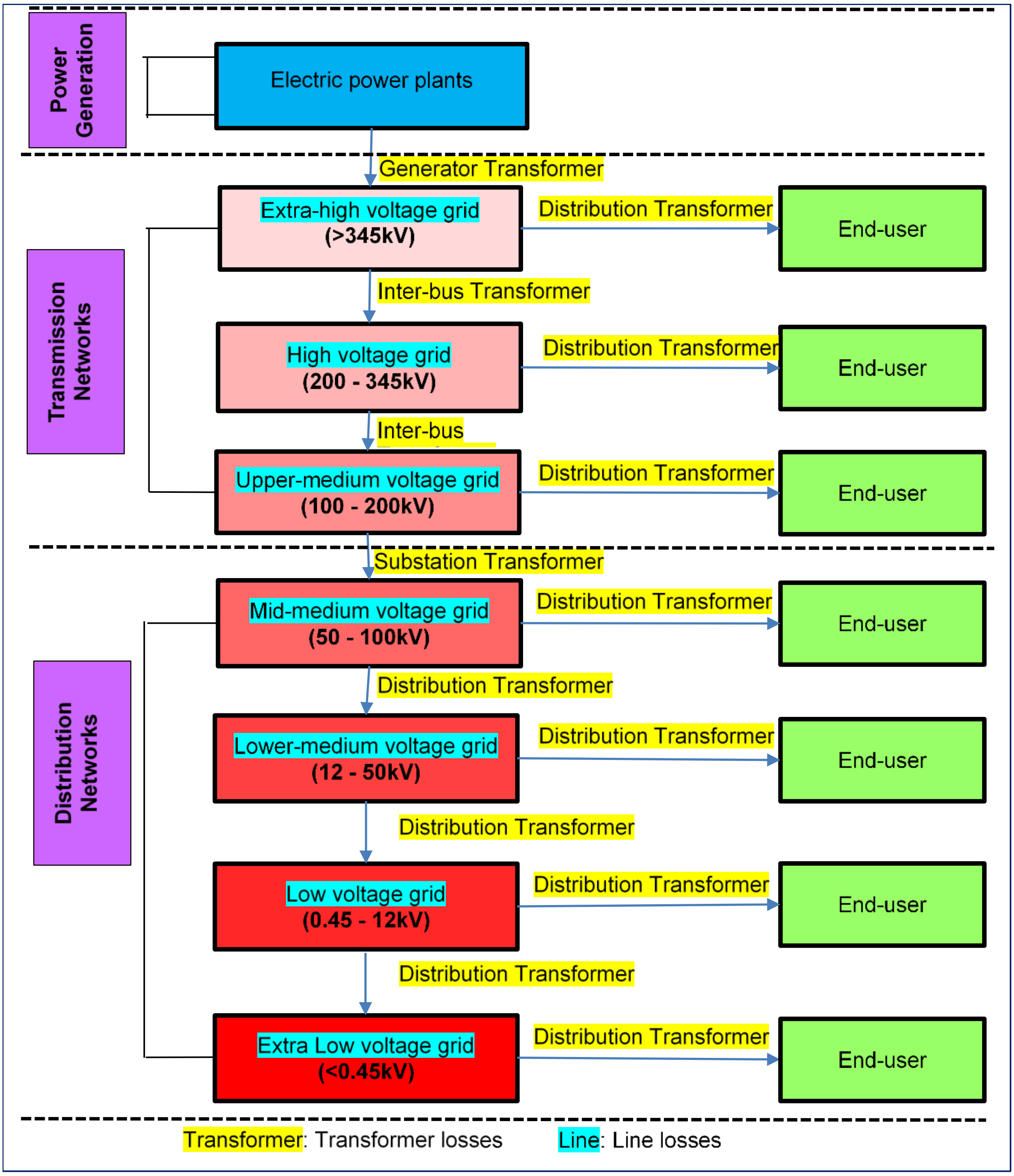
Figure 18: Average grid losses at Member State



Despite the difference and complexity in grid losses across different Member States, for the convenience of all stakeholders and regulators it is necessary to use a practical and easily-understandable generic approach for grid loss correction. Thus, we developed a one-size-fits-all simple system for modelling the transmission and distribution of electric power in EU (Figure 19), where voltage levels for the T&D network are divided into seven main bands. They are extra-high (>345kV), high (200 - 345kV) and upper-medium (100 - 200kV) voltages for the transmission network; middle-medium (50 - 100kV), lower-medium (12 - 50kV), low (0.45 - 12kV) and extra-low voltages (<0.45kV) for the distribution network[9]. Grid losses occur at each voltage line that electric power passes through and at each transformer that interconnects these voltage lines. The cumulative grid losses from power plants to end-users are dependent on the grid voltage level at which electric power is supplied to end-users. The lower voltage level of end-user grid connection, the more upstream lines and transformers electric power has to pass through, and thus the more cumulative grid losses

Figure 19: One-size-fits-all model of EU transmission and distribution system

[9] Compared with the voltage bands identified in Annex III of Decision 2011/877/EU (EC, 2011), a further voltage band (>345kV) is added to cover the extra-high voltage transmission grid that is increasingly common in most Member States. Meanwhile, we replaced the voltage level 0.4kV into 0.45kV as at the latter voltage level many CHP power plants are connected (according to personal communication with experts). In addition, the voltage band (0.45-50kV) is further divided into two bands (0.45-12kV and 12-50kV), because we found that there are two major clusters of voltage levels scattering notably surrounding 12kV in EU-28.



The marginal and cumulative losses for each connection voltage level in EU are presented in Table 14.

Table 14: Marginal and cumulative losses for each connection voltage level

Voltage level		Transmission Networks			Distribution Networks			
		EHV	HV	UMV	MMV	LMV	LV	ELV
		>345 kV	200-345 kV	100-200 kV	50-100 KV	12-50 kV	0.45-12 kV	<0.45 kV
Marginal line losses	Corona losses	0.005	0.002	0.000	0.000	0.000	0.000	0.000
	Joule losses	0.006	0.009	0.010	0.012	0.013	0.015	0.020
Marginal transformer losses		0.004	0.002	0.002	0.004	0.008	0.008	0.008
Non-technical losses		0.000	0.000	0.000	0.000	0.000	0.000	0.012
Marginal total losses (excluding last transformer)		0.015	0.013	0.012	0.015	0.021	0.024	0.040
Last transformer losses (to end-user)		0.009	0.009	0.009	0.008	0.008	0.008	0.008
Cumulative losses		0.024	0.037	0.049	0.064	0.086	0.109	0.149

Compared with conventional centralised large power plants, CHP plants are usually decentralised and they supply electricity closer to end-users. Thus, the avoided grid losses due to the geographical proximity of CHP plants should be corrected for reference electric efficiencies.

To account for the avoided grid losses, we distinguish whether electricity produced in CHP plants is used on-site or off-site. For electricity used on-site, the cumulative losses at a given connection voltage level can be all saved due to the avoidance of transmission and distribution networks. For electricity used off-site, we use a discounting factor of 0.75 for the voltage levels below EHV and 0 for EHV, to account for the avoided cumulative losses due to the geographical proximity of CHP plants. This means that 75% (0% in case of EHV connection) of the cumulative grid losses for electricity supplied by a conventional centralised large power plant can be avoided if the same amount of electricity is supplied by a CHP plant that exports electricity to the grid.

Table 15 presents avoided cumulative losses for on/off site electricity production of CHP plants at different connection voltage levels.

Table 15: Avoided cumulative grid losses for on/off site electricity production from CHP plant

Connection voltage level	Avoided cumulative losses (On-site)	Avoided cumulative losses (Off-site)
EHV (>345kV)	0.024	0
HV (200 - 345kV)	0.037	0.028
HMV (100 - 200kV)	0.049	0.037
MMV (50 - 100kV)	0.064	0.048
LMV (12 - 50kV)	0.086	0.065
LV (0.45 - 12kV)	0.109	0.082
ELV (<0.45kV)	0.149	0.112

Corresponding to avoided cumulative grid losses, the proposed correction factors for grid loss correction are presented in Table 16. Compared to the current grid correction factors, the main difference is the addition of the two voltage levels. For individual CHP plants this might result in a change of the correction factor to be applied.

Table 16: Correction factors for on/off site electricity production from CHP plant

Connection voltage level	Correction factor (Off-site)	Correction factor (On-site)
EHV (>345kV)	1	0.976
HV (200 - 345kV)	0.972	0.963
HMV (100 - 200kV)	0.963	0.951
MMV (50 - 100kV)	0.952	0.936

LMV (12 - 50kV)	0.935	0.914
LV (0.45 - 12kV)	0.918	0.891
ELV (<0.45kV)	0.888	0.851

7 Impact of Reference Values on Primary Energy Savings

An analysis has been carried out to show the impact of the reference values on the amount of primary energy savings (and the related qualification for high efficiency CHP or not). For this analysis 10 main fuel types have been selected and linked to 27 typical CHP cases. Apart from differences in the fuel type, the cases vary with respect to capacity size and efficiencies (both related to technology type), grid connection level and type of heat produced (steam or hot water). The case characteristics are summarised in Table 17.

Table 17 Characteristics of typical CHP cases

Case	Category	Fuel	Size	Voltage	Application heat	Electrical Efficiency %	Boiler Efficiency %	Overall Efficiency %
1a	S1	Coal	60 MWe	MMV	hot water	30%	45%	75%
1b	S1	Coal	60 MWe	MMV	10 bar steam	24%	51%	75%
2a	S4	Woodchip	20 MWe	LMV	hot water	31%	44%	75%
2b	S4	Woodchip	20 MWe	LMV	10 bar steam	25%	50%	75%
3a	S4	Clean Waste Wood	5 MWe	LMV	hot water	23%	52%	75%
3b	S4	Clean Waste Wood	5 MWe		10 bar steam	18%	57%	75%
3c	S4	Clean Waste Wood	40 MWe	LMV	hot water	32%	43%	75%
3d	S4	Clean Waste Wood	40MWe		10 bar steam	27%	48%	75%
4a	S5	Distillers Grains	10 MWe	LMV	hot water	27%	48%	75%
4b	S5	Distillers Grains	10 MWe		10 bar steam	22%	53%	75%
5a	S5	Logs	45 MWe	LMV	hot water	29%	46%	75%
5b	S5	Logs	45 MWe		10 bar steam	24%	51%	75%
5c	S5	Logs	6 MWe	LMV	hot water	21%	54%	75%
5d	S5	Logs	6 MWe		10 bar steam	16%	59%	75%
6a	S6	Municipal Waste	25 MWe	LMV	hot water	20%	55%	75%
6b	S6	Municipal Waste	25 MWe		10 bar steam	15%	60%	75%
7a	S6	SRF	25 MWe	LMV	hot water	25%	50%	75%
7b	S6	SRF	25 MWe		10 bar steam	20%	55%	75%
8a	L9	Black Liquor	20 MWe	LMV	hot water	22%	53%	75%
8b	L9	Black Liquor	20 MWe		10 bar steam	17%	58%	75%
9a	G10	Natural Gas	4 MWe	LV	hot water	27%	48%	75%
9b	G10	Natural Gas	4 MWe		10 bar steam	27%	48%	75%
9c	G10	Natural Gas	42 MWe	MMV	hot water	38%	37%	75%
9d	G10	Natural Gas	42 MWe		10 bar steam	38%	37%	75%
9e	G10	Natural Gas	140 MWe	HMV	hot water	40%	35%	75%
9f	G10	Natural Gas	140 MWe		10 bar steam	39%	36%	75%
10	G12	Biogas from AD	1.2 MWe	LV	hot water	36%	39%	75%

For each of the cases an overall efficiency of 75% has been assumed. This implies that a fair amount of the heat produced can be usefully applied. This 75% has been chosen since it is the minimum threshold value for all CHP technologies apart from combined cycle gas turbines with heat recovery and steam condensing extraction turbines for which the minimum threshold efficiency is 80% (see Annex I of the Energy Efficiency Directive). The general principles for the calculation of electricity from cogeneration dictate that in a CHP scheme with a lower overall efficiency than the threshold values so-called non-CHP electricity production takes places. This non-CHP electricity production should be removed from the total electricity production before calculating the primary energy savings.

For combined cycles and condensing steam turbines the choice for 75% overall efficiency for the defined cases can be considered conservative in terms of the related primary energy savings, i.e. using 80% overall efficiency would result in higher primary energy savings than reported below.

Primary energy savings have been calculated using the following formula:

$$PES = (1 - (1/(\eta_{heat\_CHP}/\eta_{heat\_ref} + \eta_{elec\_CHP}/\eta_{elec\_ref})) \times 100\%$$

Where the reference efficiency values are taken from Table 12.

The electrical reference efficiencies have been corrected for avoided grid losses (see chapter 6) distinguishing between two situations: all electricity produced exported to the grid versus all electricity produced used onsite. For the primary energy savings an average ambient temperature of 15°C have been assumed (standard ISO conditions), meaning that the natural gas electrical reference values do not need ambient temperature correction.

The results of the primary energy savings are given in Figure 20.

Figure 20 Primary Energy Savings calculations for typical CHP cases

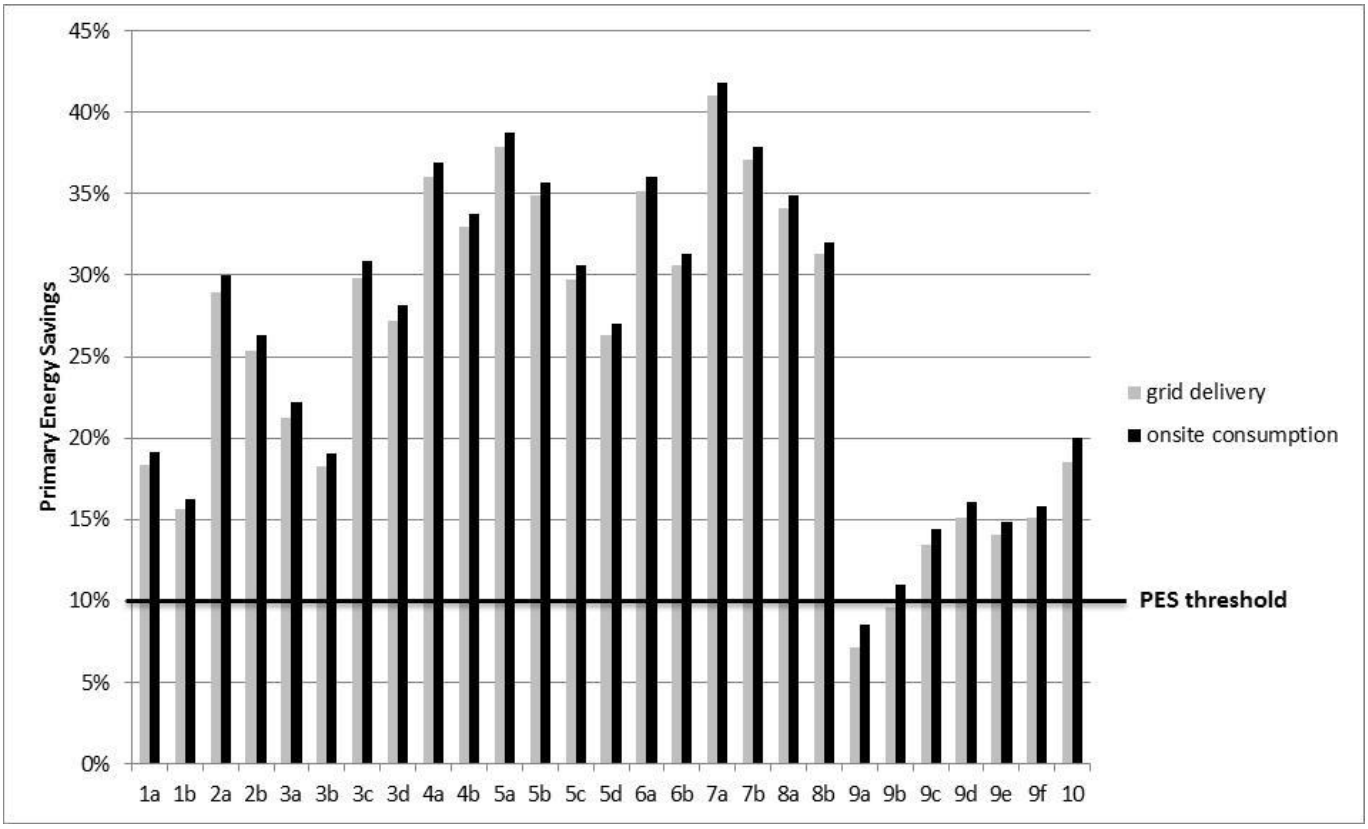


Figure 20 shows that, apart from natural gas, all fuels achieve primary energy savings above 15% which is well above the high-efficiency threshold value of 10%. The high PES values for some of the fuels is explained by a relative small difference between the CHP electrical efficiency and the reference electrical efficiency. For case 5 and 7 for example the CHP electrical efficiency is respectively 29% and 25% whereas the reference electrical efficiency is 27.4% and 22.9% after correction for grid losses, i.e. lower than the CHP electrical efficiency.

For natural gas the situation is different. Reference electrical efficiency values for natural gas are very high compared to the values of other fuels. This puts a challenge on natural gas-fired CHP schemes with relatively low electrical efficiencies (<27%) to qualify as high-efficient. Example case 9a (a small gas turbine exporting all its electricity to the grid) will not be able to qualify as high-efficient with given characteristics (27% electrical and 75% overall efficiency). Calculation outcomes are however sensitive: where such small gas turbines would be able to realise an overall efficiency of 80% (electrical efficiency still 27%), the PES would increase to 11.6-12.9% (export versus onsite consumption).

The above supports the argument presented in section 5.3.1 to split the natural gas category based on capacity with smaller plants (< 100 MWe) having lower reference electrical efficiency, which is supported by operational and design data. However, it should be noted that, as this recommendation has now been abandoned and deferred to the next review and a single reference value of 53% is recommended for all natural gas-based schemes regardless of size, smaller GT-based plants might find it easy to meet the overall efficiency threshold of 75% while failing the 10% PES threshold.

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Appendices

Appendix 1 – Initial recommendations for electricity reference efficiencies – supporting analysis

Four approaches were considered in the original analysis. These are as follows:

- **Approach 1:** based on submitted operational data
- **Approach 2:** based on the analysis of the statistical trend development of power and heat efficiencies of the various fuel types. Primary source for this analysis are the IEA statistics. Focus was on the period 2008-2012 to get appropriate insight into the current average operational efficiencies. Data for the individual Member States have been corrected for ambient temperature (0.1%-point increase or decrease if the ambient temperature differs from standard ISO conditions, i.e. 15 ^{0}C). For the average ambient temperature the data from the capital cities are taken. As the IEA data considers gross efficiencies (not accounting for parasitic load), net efficiencies (excluding parasitic load and internal consumption) have been calculated using a correction factor of 1.022.
- **Approach 3:** based on operational and statistical data for CHP plants that have the ability to run in condensing mode. This means that the CHP data can be normalized to power-only data using the so-called power loss coefficient. This analysis provides proxies for power efficiencies only and not for heat efficiencies.
- **Approach 4**: (for heat efficiencies only) is based on the analysis of the guaranteed efficiencies by boiler manufacturers.

The discussion below describes the results obtained for each of the fuels under each of the approaches described above as relevant.

Solids

Category S1

Fuel category S1 covers hard coal and includes anthracite, sub-bituminous coal, pet coke and semi-coke. Bituminous coal (second place after nuclear), coking coal (seventh) and anthracite (tenth) are all top 10 fuels for power-only production in the EU-28. It should be stressed that electricity production from bituminous coal (378TWh in 2012) is much greater than the 21TWh from coking coal and the 15TWh from anthracite.

Approach 1: Operational data

No data was provided for category S1 fuels.

Approach 2: Use of IEA statistics

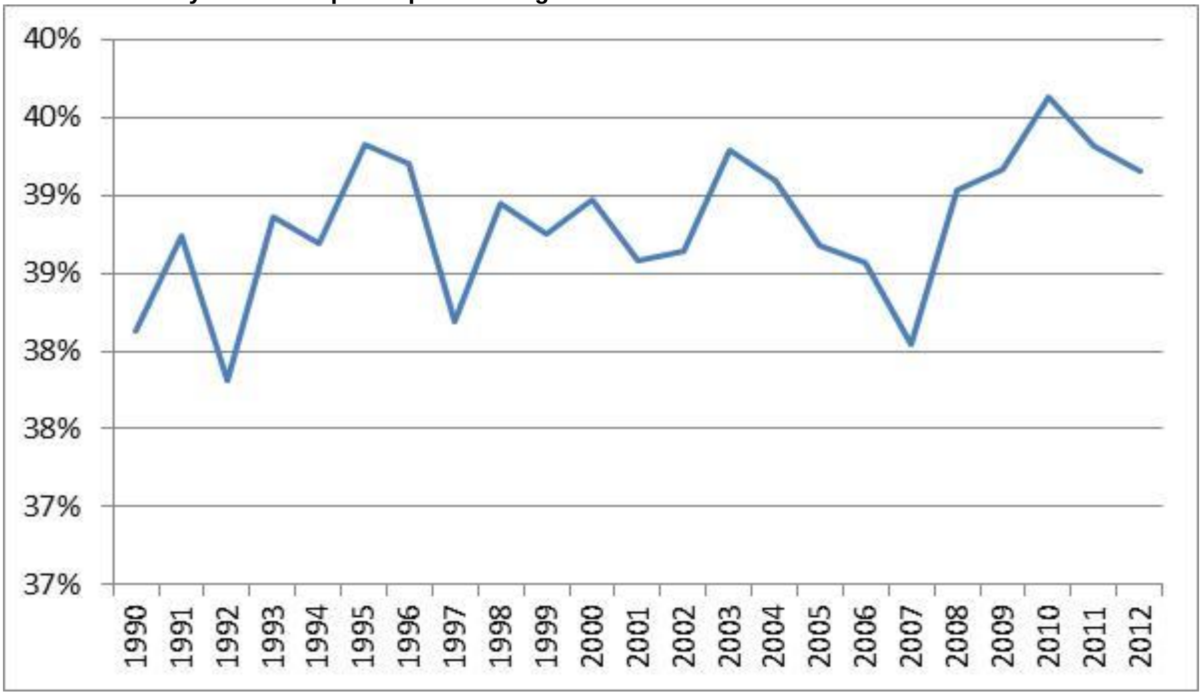
For 'other bituminous coal', the average EU-28 efficiency for 2008 - 2012 is 39.3%. Austria is the highest ranking country with 43.7% efficiency, followed by Finland (42.1%), the Netherlands (41.8%) and Germany (40.1%). According to Platts, these countries are dominated by relatively old plants which provides an argument to sticking to the existing reference value of 44.2%. No further operational data become available following the Stakeholders consultation.

For coking coal, average efficiency for the period 2008 - 2012 across the EU-28 is 40.1%. This is also the average for Germany which is the highest ranking country. Anthracite for power only production is only used in Germany, Bulgaria and Spain. Germany has the highest average 2008-2012 efficiency with 40.1%. According to Platts, the majority of the capacity in these countries is old and so it is justifiable to combine anthracite and coking coal in the same category as bituminous coal (S1) and apply a reference value of 44.2%. Again should operational data become available following the Stakeholders consultation, this will be reconsidered.

Approach 3: use of CHP data

This approach was not applied for this fuel category as Approach 2 provided a sufficient base for developing the reference values for electricity.

Annual efficiency of thermal power plants using bituminous coal



Category S2

Fuel category S2 is lignite and lignite briquettes. Shale oil is also included under this category due to lack of data and as it has similar efficiencies. Lignite ranks fourth in terms of electricity production.

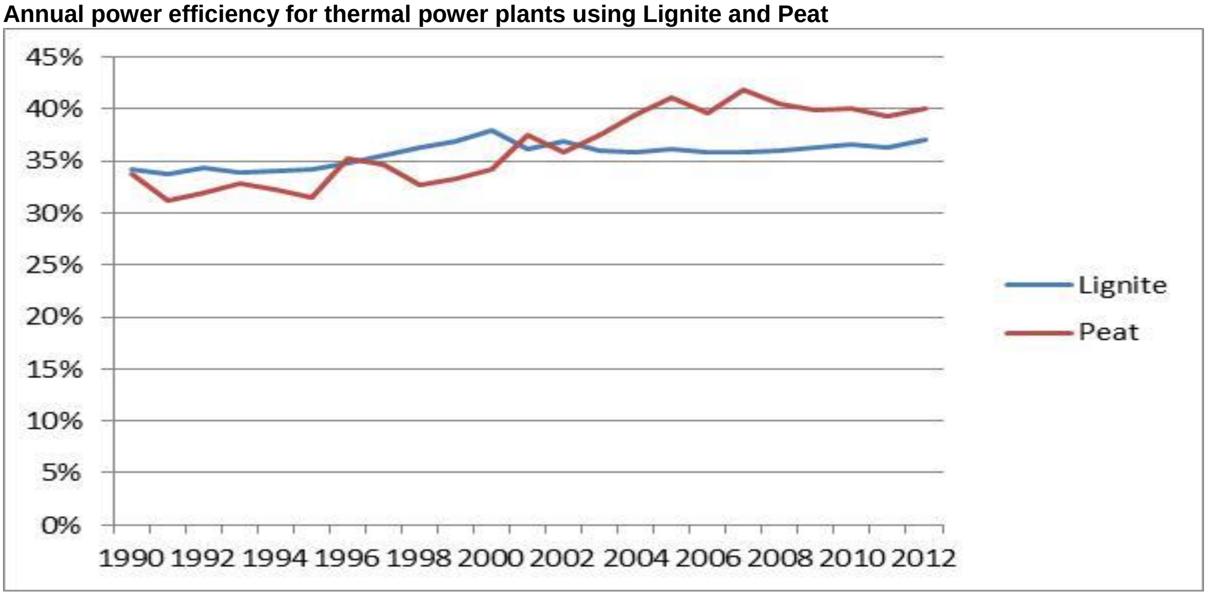
Approach 1: Operational data

No data was provided for category S2 fuels.

Approach 2: Use of IEA statistics

Based on IEA historic data, the average efficiency for lignite for the period 2008 - 2012 for the EU-28 is 36.4%. The 2008 - 2012 average efficiencies for highest ranking country (Germany) is 38.1% (only country scoring above EU average). It is not clear from the IEA data to what extent these figures are dominated by old or new technology. Checking the Platts database shows that the majority of these plants are old plants.

Annual power efficiency for thermal power plants using Lignite and Peat



Approach 3: use of CHP data
This approach was not applied for this fuel category as approach 2 provides a sufficient base for developing the reference values for electricity.

Category S3

This category includes peat and peat briquettes. This category is not one of the top ranking categories for power-only production.

Approach 1: Operational data
No data has yet been provided for peat.

Approach 2: Use of IEA statistics
Based on IEA historic data, the average efficiency for peat for the period 2008 - 2012 for the EU-28 is 39.9% (see figure above). Peat power-only data are just a small data sample dominated by Finland and Ireland. It is not clear from the IEA data to what extent these figures are dominated by old or new technology. However, the Platts database shows that most plants operating on peat in these countries are older plants.

Approach 3: use of CHP data
This approach has not been applied for this fuel category as approach 2 provides a sufficient base for developing the reference values for electricity.

Category S4

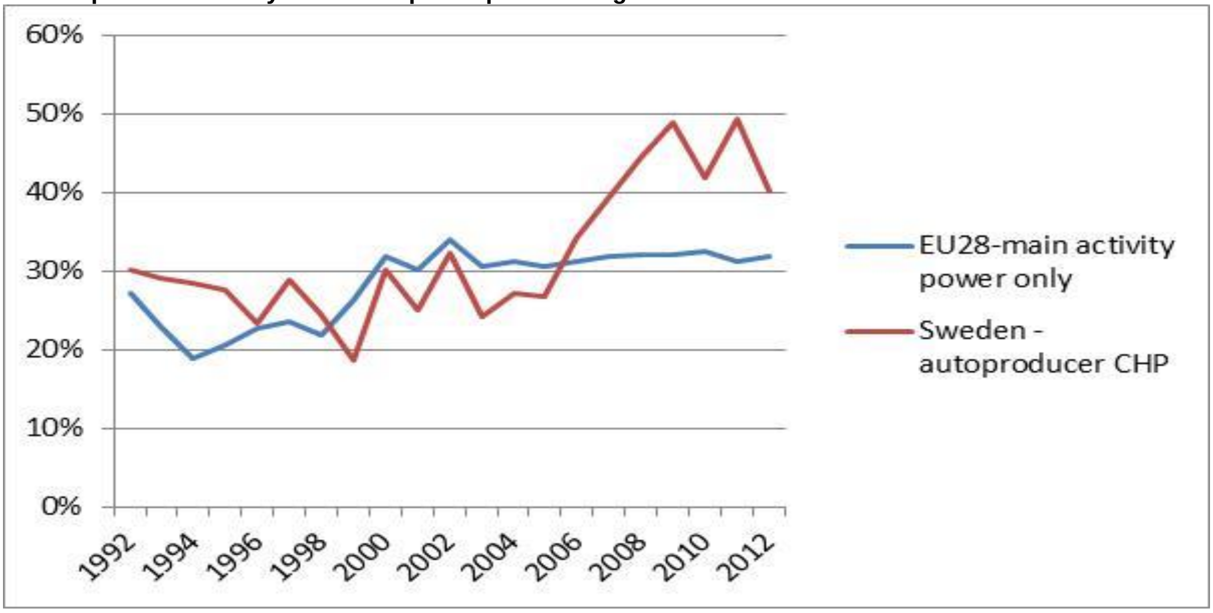
This includes wood fuels with relatively high energy content and low moisture content. These include wood pellets, dry woodchips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse. They can all be grouped into the same category as all can operate with similar efficiencies. Agricultural biomass, as the case currently in the existing reference values table, is a different category (S5) which includes fuels with a generally higher moisture level and mainly comprises agricultural waste and untreated wood. These two categories (S4 and S5) are usually combined together when it comes to reporting efficiencies as in IEA historic data.

Approach 1: Operational data
Limited operational data was provided for plants (two plants) operating on wood fuels. These were with capacities of 25 and 50MWe and reported efficiencies of 26% and 36%. In comparison to design data, 26% seems to be at the lower end for 25MWe plants. Additional operational data are required in order to establish the correct capacity threshold.

Approach 2: use of IEA statistics
Based on IEA historic data, average efficiency for the period 2008 - 2012 for the EU-28 is 32.0% (main activity power-only) or 44.9% (autoproducer CHP in Sweden – representing 56% of total electricity production in Swedish solid biomass CHP). It should be noted that the Swedish figures might be higher due to the fact that Swedish biomass CHP plants have capacities up to 130MWe with an average capacity of 30MWe while the EU-average might be dominated by smaller scale installations. Design data for larger biomass plants in some European countries show that efficiencies (NCV) as high as 37% are achievable.

Approach 3: use of CHP data
Analysis of biomass-CHP data, shows that, depending on capacity and the quality of the fuel, power-only efficiency range from 21% to 39%. It is noted that plants with large capacities (>250MWe) are now in planning in Europe and, based on design data, these plants, using dried fuel, normally have efficiencies closer to 37% (NCV) which are achievable under certain innovative boiler designs.

Annual power efficiency of thermal power plants using biomass



Category S5

This category includes biomass with typically high moisture content and lower energy content than wood fuels (category S4). This consists of agricultural biomass (which is used as it is harvested without treatment to increase its energy content), including logs, wound wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains. Unlike, wood fuels, design efficiency calculations show that agricultural biomass fuels have a narrow range of power efficiencies.

Approach 1: Operational data

While one submission was received for agricultural biomass (as in Section 4), no operational data was provided for this plant.

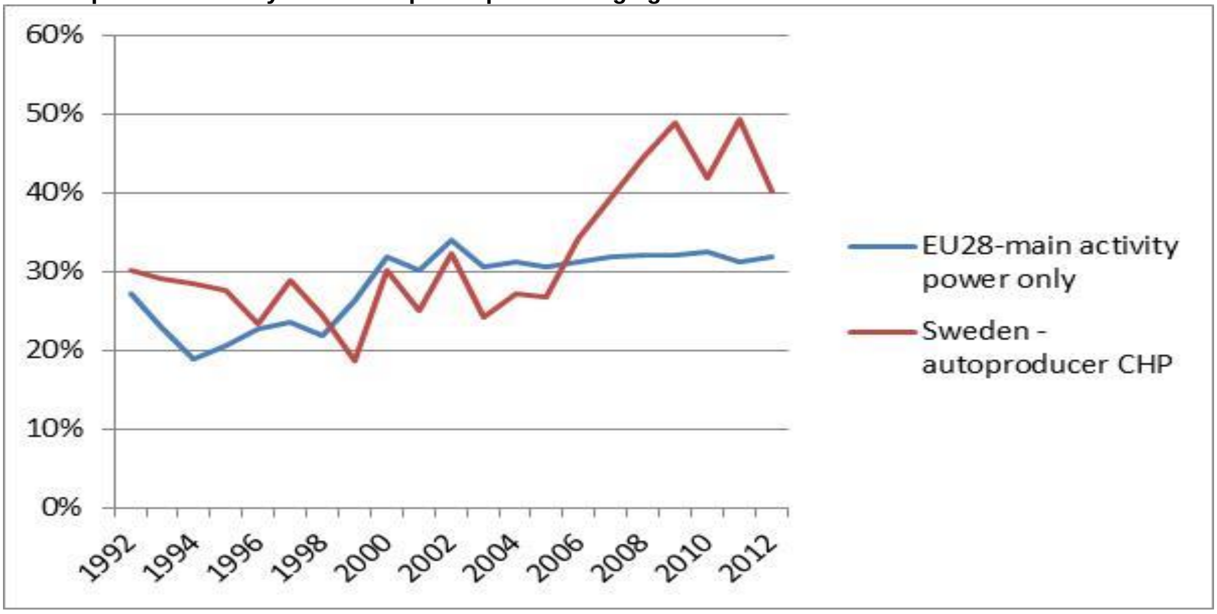
Approach 2: use of IEA statistics

IEA statistics do not provide a separation between wood fuels and agricultural biomass. As discussed above, based on IEA historic data, average electrical efficiency for biomass plants for the period 2008 - 2012 for the EU-28 is 32.0% (main activity power only) and 44.9% (auto-producer CHP in Sweden – representing 56% of total electricity production in Swedish solid biomass CHP). It is not clear from the IEA data what proportion of these plants use 'agricultural biomass' rather than 'wood fuels'.

Approach 3: use of CHP data

Analysis of agricultural biomass CHP data from the UK shows that, power-only efficiency can reach up to 30% and can be as low as 21%. The lower range of the efficiencies is for lower quality fuels with higher moisture content.

Annual power efficiency of thermal power plants using agricultural biomass



Category S6

This includes solid waste, both bio-degradable and non-renewable including industrial waste, municipal waste and clinical waste. The bio-degradable and renewable waste categories are treated separately under the existing reference values. However, due to similar efficiencies and for simplicity, it is proposed to combine the two in one category.

Approach 1: Operational data

Two submissions were made for solid waste, one for bio-degradable waste and another for non-renewable waste. The submission for bio-degradable waste did not provide data while for non-renewable waste, a 21% electrical efficiency was calculated for a 27MWe plant.

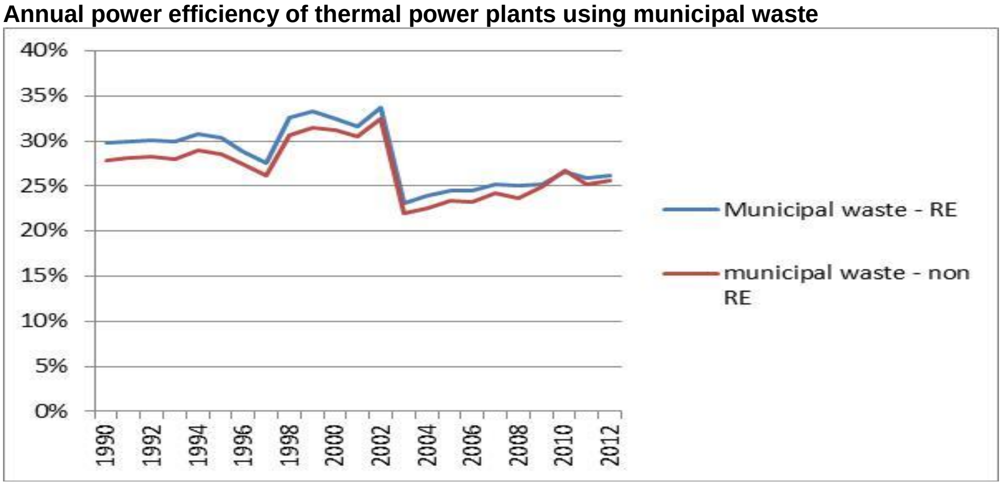
Approach 2: use of IEA statistics

The average efficiency for the years 2008 - 2012 for the EU-28 is 25.8%. This average is similar to the current reference efficiency of 25%. Finland, Germany, Hungary, Spain have efficiencies >30%.

Approach 3: use of CHP data

Based on analysis of CHP data for plants operating on municipal waste (11 – 22 MW), power-only fully condensing mode) efficiencies range from 20% to 31%.

Annual power efficiency of thermal power plants using municipal waste



Liquids

Category L7

This category includes heavy fuel oil, diesel oil and other oils. The current electrical efficiency is 44.2%. LPG should be removed out of this category and included under natural gas.

Approach 1: Use of operational data
Operational data was submitted for plants in the capacity range 50 to 220MWe. Efficiencies ranged from 40.8 - 42.6%, slightly lower than the current reference value.

Approach 2: use of IEA statistics
The average efficiency for 2008 - 2012 for the EU28 for fuel oil is 37.3%. Countries show high fluctuations in efficiency. For diesel, the average power-only efficiency is 45.2% (auto-producer power only) and 35.0% (main activity power only). Average efficiencies for highest ranking countries are 42.8% for France and 40.5% for Austria.

Approach 3: Use of CHP data
This approach was not applied for fuel oil due to lack of data.

Category L8

This category include Bio liquids including bio methanol, bioethanol, bio butanol, biodiesel, and other liquid biofuels.

Approach 1: use of operational data
Submissions were made for two plants (4MWe and 24MWe) operating on biofuel (both CHP plants). Data was available for one of the plants with power-only efficiency of 44.7%. This compares well with the current value of 44.2%.

Approach 2: use of IEA statistics
Data were not available.

Approach 3: use of CHP data
Based on CHP design and operational data, average power-only efficiencies for bio-liquids is in the range of 35% - 40%. This is below the current reference efficiency of 44.2%.

Category L9

This category includes liquid waste from bio- biodegradable and non-renewable sources

Approach 1: use of operational data
No operational data obtained.

Approach 2: use of IEA statistics
IEA data not available.

Approach 3: use of CHP data
Based on CHP design and operational data, average power-only efficiencies for liquid waste is about 28% - 29%.

Gases

Fuels in Category G10

This category includes natural gas, LPG and LNG.

Analysis of natural gas data, shows that, depending on the total power capacity, power-only efficiencies can range from 49% to 55%. Natural gas-based CHP plants with capacities above 100MWe can have efficiencies which reach the current reference value of 52.5%. However, some larger plant show efficiencies which exceed the 53.0% and can exceed, based on operational data, 55%.

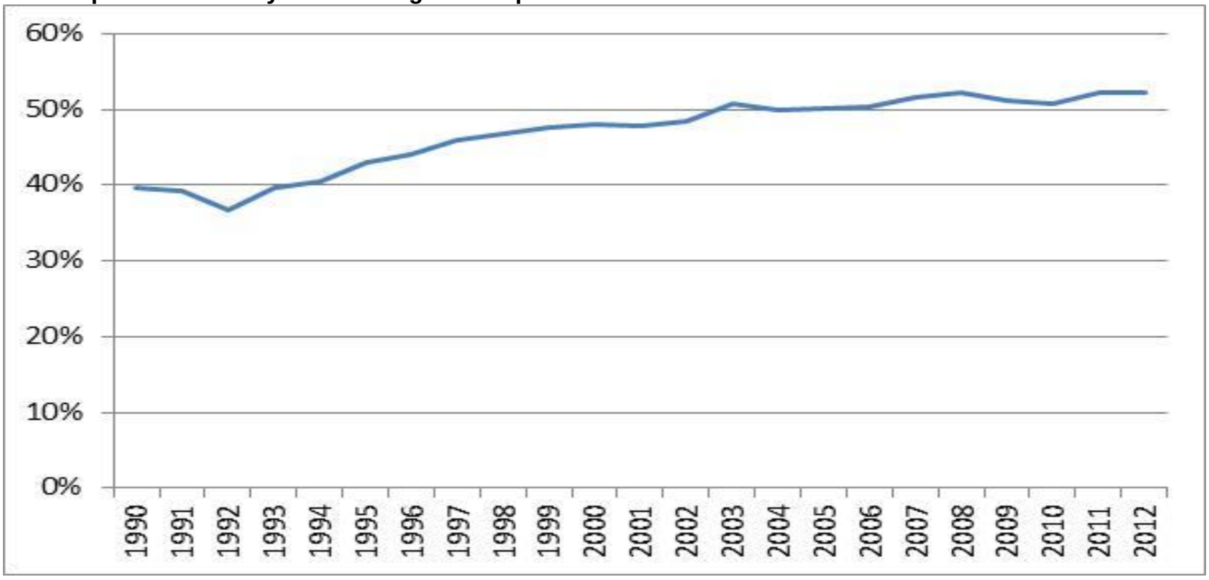
Approach 1: use of operational data

The great majority of operational data submitted under this project was for natural gas plants both CHP and power-only plants. Operational data for larger plants (100 – 400MWe) is not given. For smaller plants (in the range 5 to 67MWe), the efficiency ranges from 33 to 52.8%.

Approach 2: use of IEA statistics

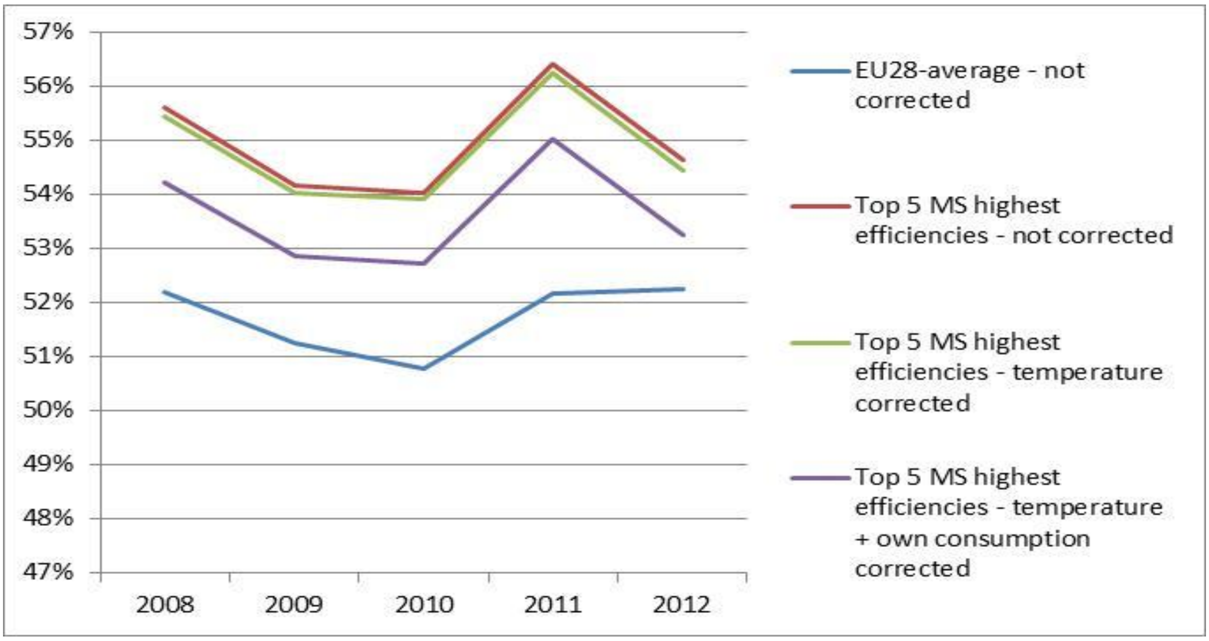
Based on IEA historic data, it is clearly shown that since 1990 the average efficiency of gas-fired power capacity (IEA category: main activity) in the EU-28 has increased from about 40% to more than 52% (LHV).

Annual power efficiency of thermal gas fired power stations



As the data for individual Member States make clear that significant differences exist in efficiency performance, the top-5 Member States are selected based on highest natural gas efficiency achieved. This top-5 includes Austria, Belgium, Netherlands, Portugal and Spain. These 5 countries make up to 31% of total EU28 electricity production (main activity) from natural gas in the given period. The results are given below. The normalised reference efficiency value for natural gas (being the average of the top five MS corrected for temperature and gross/net) is 53.0%. This is in agreement with the current 52.5% reference efficiency.

Annual efficiency of thermal gas fired power stations in top five MS



Approach 3: use of CHP data
Based on CHP design and operational data, average power-only efficiencies for natural gas plants is in the range 45% to 53%.

Category G11
This includes refinery gas/hydrogen gas. In addition, syngas is also added to this category. Syngas (mainly hydrogen and carbon monoxide) results from the gasification and pyrolysis of solid fuels or from the reforming of natural gas. In CHP plants, it should be noted that the boundary should exclude the gasifier or the syngas-producing equipment and so the fuel input to the CHP plant is syngas rather than solid fuel for example.

Approach 1: use of operational data
Data for a 25MWe plant gives an efficiency of 47.3% for refinery gas.

Approach 2: use of IEA statistics
To be included in the final version of the report.

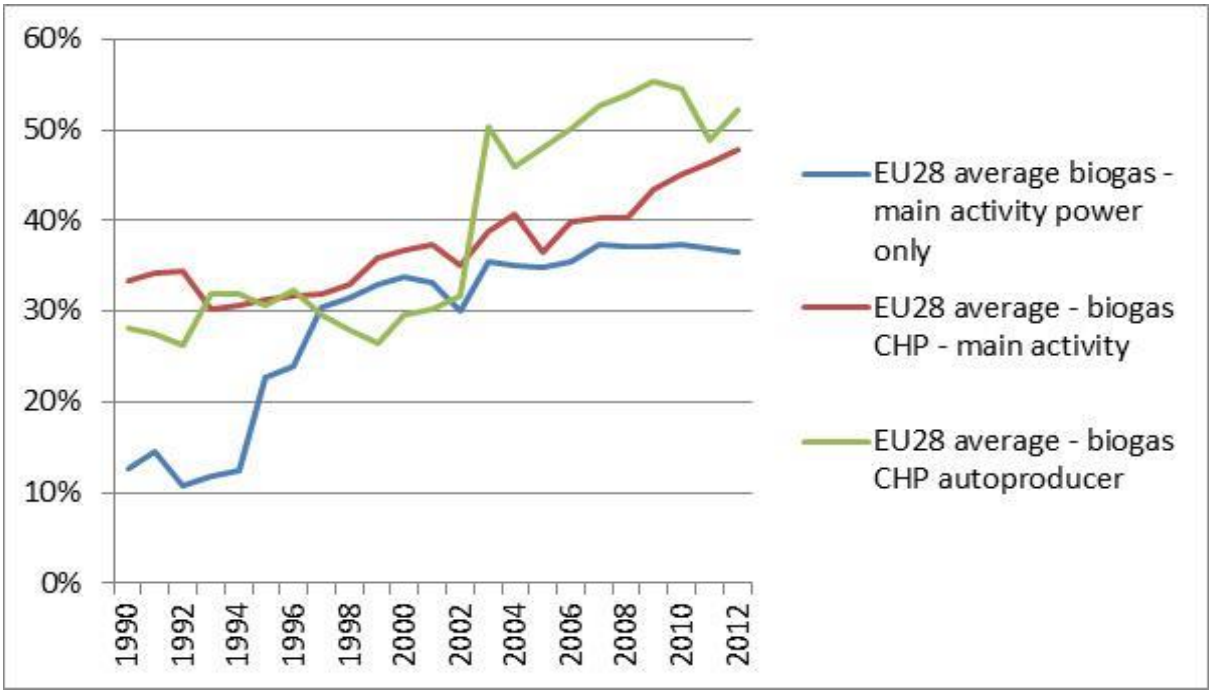
Approach 3: use of CHP data
Based on CHP plant data, power-only efficiencies for refinery gases are in the range 14-32%.

Category G12
This category includes biogas whether from AD plants, landfill gas or from wastewater treatment plants. It should be noted that for biogas-based CHP plants, the boundary should be drawn around the CHP plant with biogas as the fuel rather than the technology producing the biogas (e.g. landfill, AD plant or sewage plant).

Approach 1: use of operational data
None obtained.

Approach 2: use of IEA statistics
The average efficiency for 2008-2012 for biogas for the EU-28 is 37.0% (main activity, power only), 53.0% (main activity CHP) and 44.6% (auto-producer CHP) (Note: main activity CHP is much bigger than auto producer CHP. Data highly dominated by Germany.)

Annual average power efficiency for biogas fired power plant sin EU28



Approach 3: use of CHP data
Based on CHP plant data, power-only efficiencies for plants >1MWe are above 40% (design data). Based on operational data, average efficiencies are 35%.

Category G13

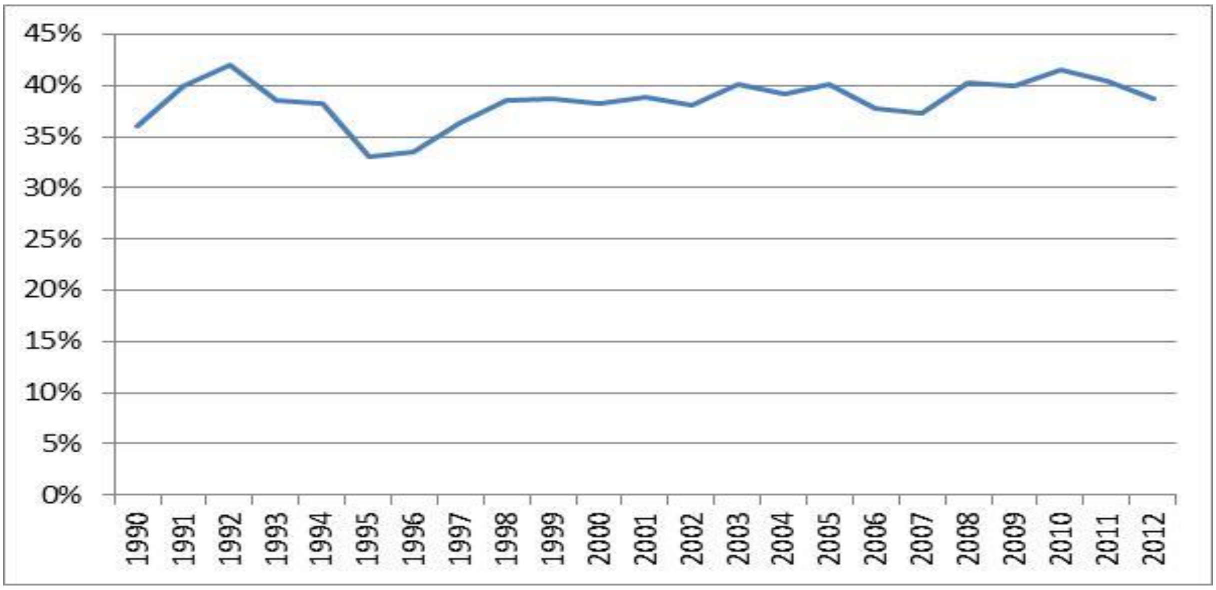
This category covers coke oven gas and blast furnace gas. Both are with similar efficiencies and so are kept in the same category as in previous list of fuels.

Approach 1: use of operational data
None obtained.

Approach 2: use of IEA statistics
The average electrical efficiency for blast furnace gas for the period 2008 - 2012 for the EU28 is 40.2%. The 2008 - 2012 average efficiencies for highest ranking countries: France 42.8%, Austria 40.5%. Coke oven gas is a much smaller fuel for power only production.

Approach 3: Use of CHP data
Based on CHP data, power-only efficiencies for plants operating on coke oven and blast furnace gases is 21-23%.

Annual average power efficiency of thermal power stations using blast furnace gas



Others

Category O14

This category covers waste heat such as the exhaust gas from high temperature processes, or as a product of exothermic chemical reactions.

Approach 1: use of operational data

None was provided and don't expect any power station will be in this category.

Approach 2: use of IEA statistics

No data available.

Approach 3: use of CHP data

Waste heat is usually forms a small part of the energy input it to the CHP plant boundary and we are not aware of any CHP plant operating 100% on waste heat recovery. Therefore no data can be found for this category.

The current reference electrical efficiency for waste heat is 35%. Based on the above, as there is no data to suggest the need for a change, it is recommended to maintain the same power efficiency reference value of 35%.

Category O15

This category covers nuclear CHP. The default power efficiency applied in statistics is 33%. It is strongly recommended to adopt this value as reference value for power production as it provides a transparent base for comparing the statistics of high-efficient CHP with the statistics of power only production. For the reference heat efficiency, we recommend that the reference efficiency for natural gas (92%) is used.

Appendix 2 – Initial recommendations for Heat reference efficiencies – supporting analysis

Solids

Category S1

Fuel category S1 covers hard coal and includes anthracite, sub-bituminous coal, pet coke and semi-coke. Bituminous coal (second place after natural gas) and coking coal (ninth) are top 10 fuels for heat only production (sold heat only). Also heat production from bituminous coal (135PJ in 2012) is much greater than the heat production from coking coal (7PJ).

Approach 1 – use of operational data

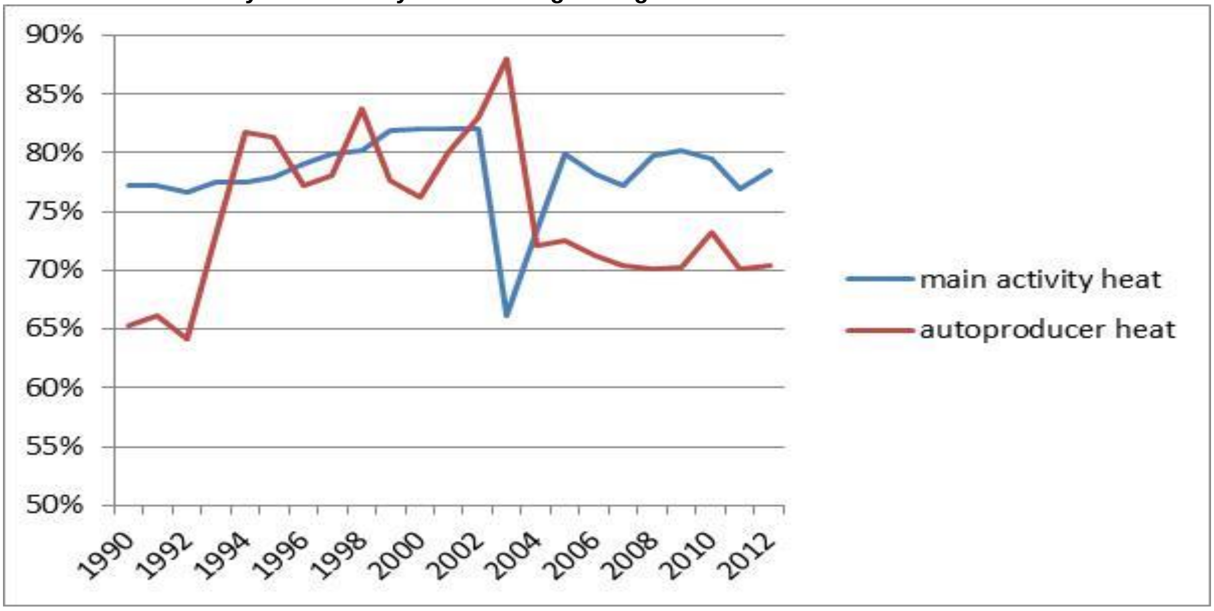
No operational data were received for heat only production based on fuel category S1.

Approach 2 – Use of IEA statistics

The trend development of boiler heat efficiency is shown in the figure below. Efficiencies are shown for main activity heat production and auto-producer heat production. Main activity includes 89% of total sold production heat. The average heat efficiency for main activity heat production from bituminous coal in the period 2008 - 2012 is 79.0%.

For coking coal the trend development of boiler heat efficiency shows an average efficiency in the period 2008 - 2012 of 61.9% for main activity boilers (47% of the sold heat from coking coal) and 95.1% for auto-producer boilers (53%)

Annual heat efficiency for heat only boilers using coking coal



Approach 4 – manufacturer's efficiencies

Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.

None of the indications related to category S1.

Category S2

Fuel category S2 is lignite and lignite briquettes. Shale oil is also included under this category due to lack of data and as it has similar efficiencies. As seen in

Approach 1: Operational data

No data was provided for category S2 fuels.

Approach 2: Use of IEA statistics

Trend development boiler heat efficiency (main activity includes 93% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 85.7%)

Approach 4 – manufacturer's efficiencies

Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
None of the indications related to category S2.

Category S3

This category includes peat and peat briquettes. This category ranks seventh for heat-only production representing in the order of 1% of total heat used.

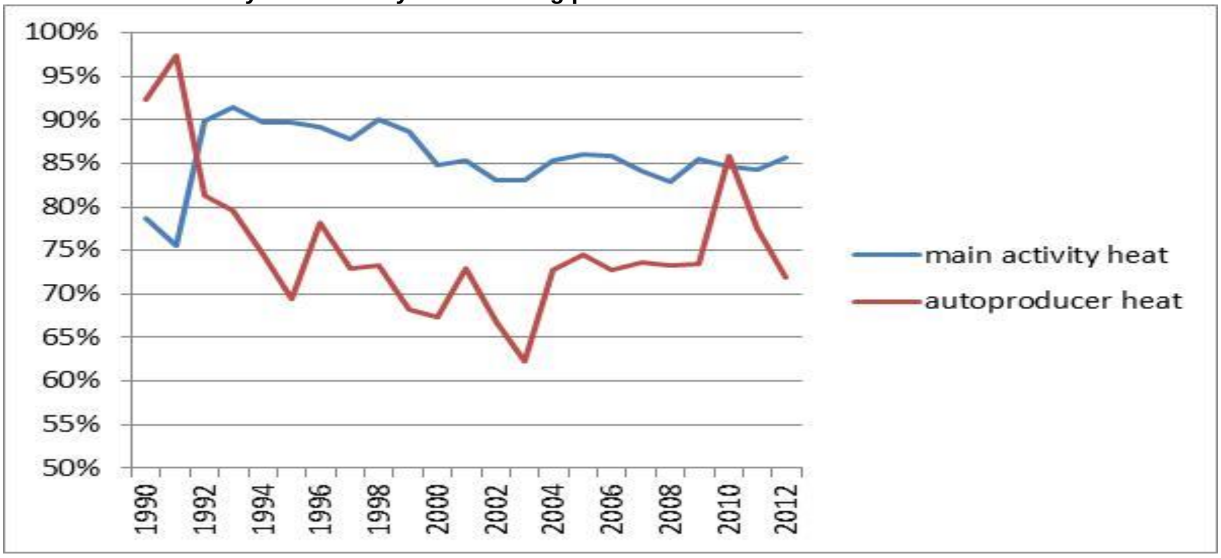
Approach 1: Operational data

No operational data have been received for heat only production based on fuel category S1.

Approach 2: Use of IEA statistics

Trend development boiler heat efficiency (main activity includes 98% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 84.6%).

Annual heat efficiency for heat only boilers using peat



Approach 4 – manufacturer's efficiencies

Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for

each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
None of the indications related to category S3.

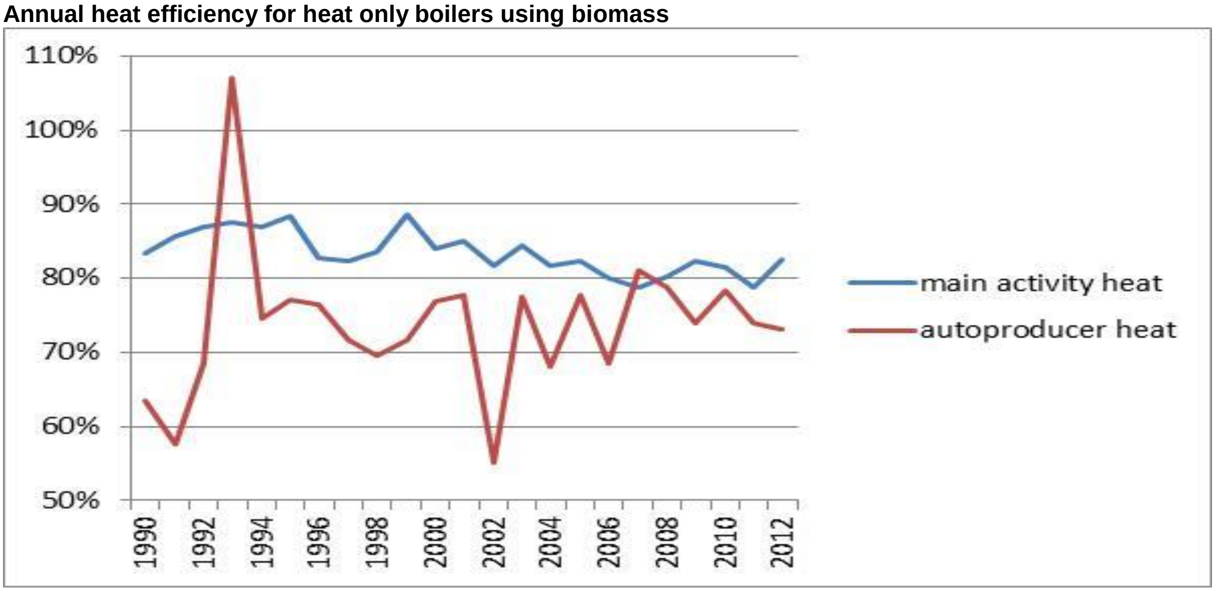
Category S4

This includes wood fuels with relatively high energy content and low moisture content. These include wood pellets, dry woodchips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse. They can all be grouped into the same category as all can produce similar efficiencies. Agricultural biomass, as the case currently in the existing reference values table, is a different category (S5) which includes fuels with higher moisture level and mainly comprise agricultural waste and untreated wood. These two categories (S4 and S5) are usually combined together when it comes to reporting efficiencies as in IEA historic data.

Approach 1: Operational data
No operational data was received for heat only production based on fuel category S4.

Approach 2: use of IEA statistics
Trend development boiler heat efficiency (main activity includes 94% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 81.1%). When taking the best performing member states in the Statistics (Denmark, Finland, Hungary, Luxembourg, Poland, Lithuania), which represent 33% of total fuel use for main activity sold heat production in the EU-28, the average 2008 - 2012 heat efficiency = 87.9%.

Annual heat efficiency for heat only boilers using biomass



Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
Only one of the indications related to category S4 and this suggested boiler efficiencies of approximately 89%.

Category S5

This category includes biomass with typically high moisture content and lower energy content than wood fuels (category S4). This consists of agricultural biomass (which is used as it is harvested without treatment to increase its energy content), including logs, wound wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains.

Approach 1: Operational data
Data are not available.

Approach 2: use of IEA statistics
IEA data does not differentiate between 'wood fuels' and 'agricultural biomass'.

Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
Only one of the indications related to category S5 and this suggested boiler efficiencies of approximately 87%.

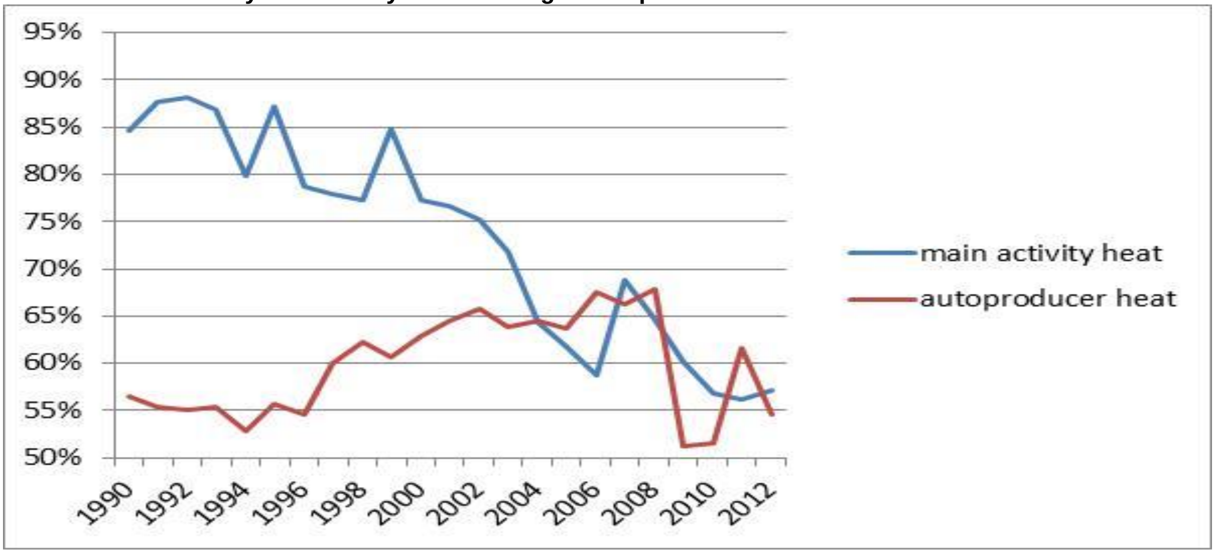
Category S6

This includes solid waste, both bio-degradable and non-renewable including industrial waste, municipal waste and clinical waste. The bio-degradable and renewable waste categories are treated separately under the existing reference values. However, due to similar efficiencies and for simplicity, it is proposed to combine the two in one category.

Approach 1: Operational data
No operational data have been received for heat only production based on fuel category S1.

Approach 2: use of IEA data
Trend development boiler heat efficiency (main activity includes 75% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 59.0% for bio-degradable waste and 63% for industrial waste.

Annual heat efficiency of heat only boilers using municipal waste



Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form

of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
Only one of the indications related to category S6 and this suggested boiler efficiencies of approximately 86%.

Liquids

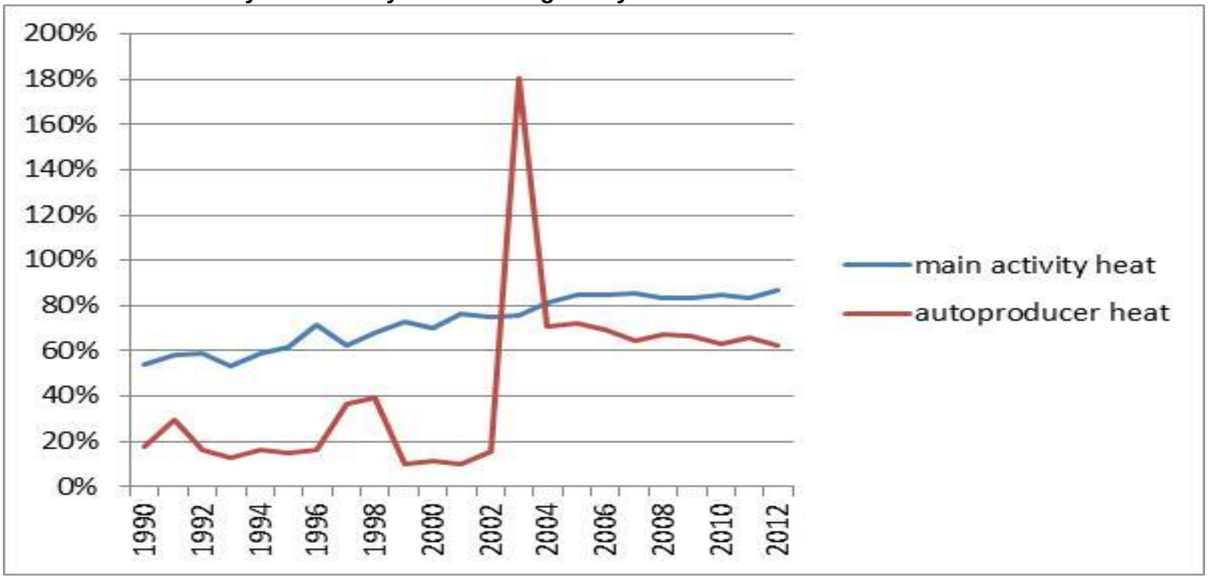
Category L7

This category includes heavy fuel oil, diesel oil and other oils. The current thermal efficiency is 89%. LPG should be removed out of this category and included under natural gas.

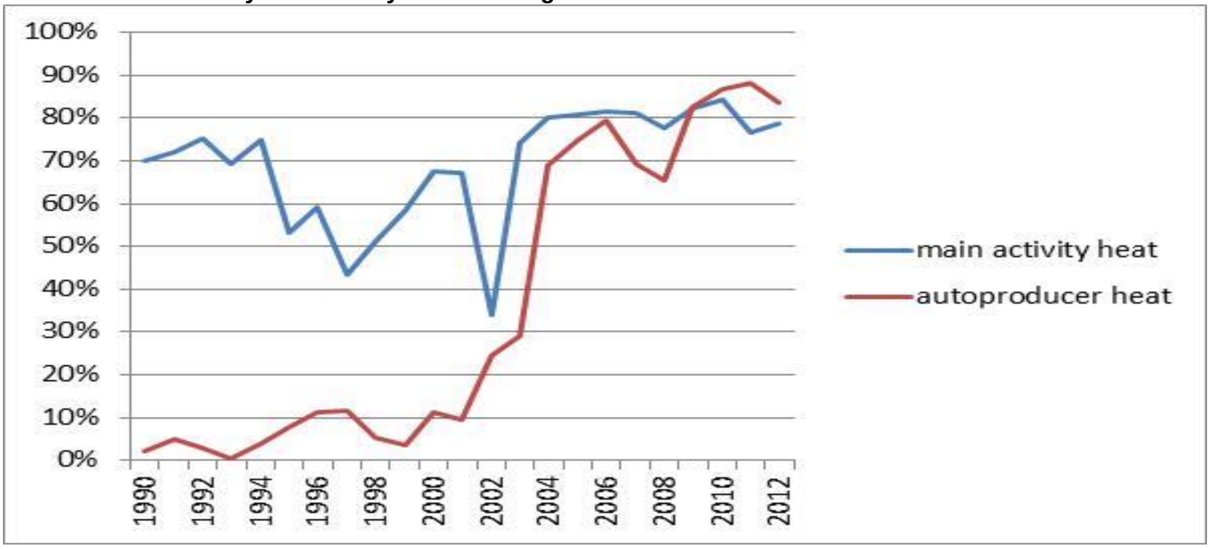
Approach 1: use of operational data
No operational data was submitted.

Approach 2: use of IEA statistics
For heavy oil, trend development boiler heat efficiency (main activity includes 92% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 84.3%)
For diesel, trend development boiler heat efficiency (main activity includes 94% of total sold heat production; average heat efficiency main activity 2008 - 2012 = 79.8%).

Annual heat efficiency of heat only boilers using heavy fuel oil



Annual heat efficiency of heat only boilers using diesel



Approach 4 – manufacturer's efficiencies

Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.

Only one of the indications related to category L7 and this suggested boiler efficiencies similar to natural gas, of approximately 93%.

Category L8

This category include Bio liquids including bio methanol, bioethanol, bio butanol, biodiesel, and other liquid biofuels.

Approach 1: use of operational data

No operational data was provided.

Approach 2: use of IEA statistics

Trend development boiler heat efficiency (main activity includes 100% of total sold heat production; average main activity 2008 - 2012 = 82.0%).

Approach 4 – manufacturer's efficiencies

Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.

None of the indications related to category L8.

Category L9

This category includes liquid waste from bio- biodegradable and non-renewable sources

Approach 1: use of operational data

Not available

Approach 2: use of IEA statistics
Not available

Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
None of the indications related to category L9.

Gases

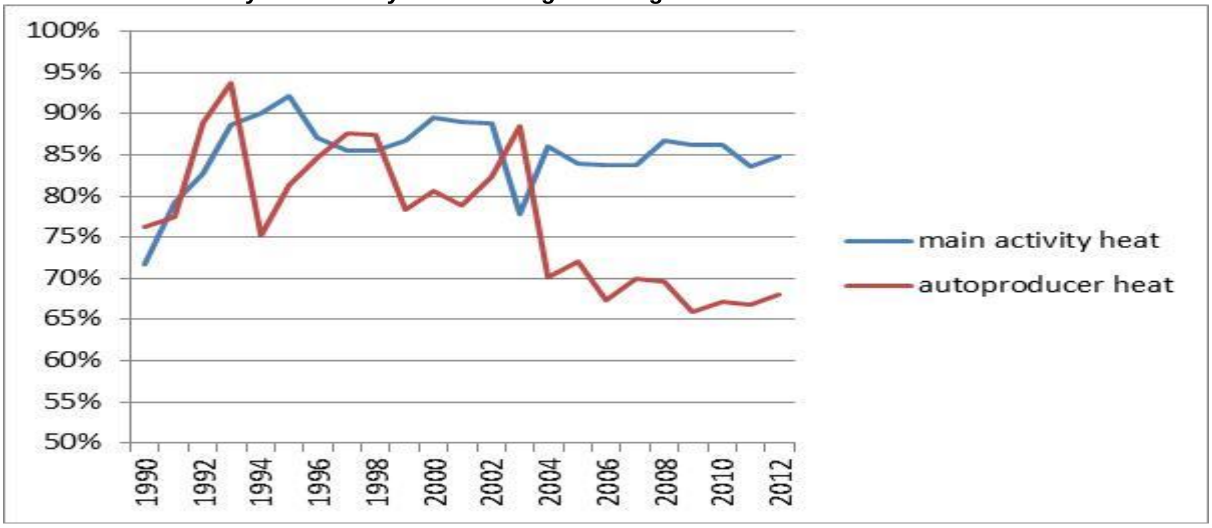
Fuels in Category G10

This category includes natural gas, LPG and LNG.

Approach 1: use of operational data
See the discussion in Section 4.1 for further information.

Approach 2: use of IEA statistics
The trend development boiler heat efficiency (main activity includes 77% of total sold heat production; average main activity 2008 - 2012 = 85.5%). When taking the best performing member states in the Statistics (Czech, Denmark, Finland, Netherlands, Slovenia, Sweden, Bulgaria and Latvia), which represent 28% of total fuel use for main activity sold heat production in EU28, the average 2008 - 2012 efficiency = 92.4%.

Annual heat efficiency of heat only boilers using natural gas



Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
Most of the indications related to category G10, and indicated boiler efficiencies in the range 91% to 95%.

Category G11

This includes refinery gas/hydrogen gas. In addition, syngas is also added to this category. Syngas (mainly hydrogen and carbon monoxide) results from the gasification and pyrolysis of solid fuels or from the reforming of natural gas. In CHP plants, it should be noted that the boundary should exclude the gasifier or the syngas-producing equipment and so the fuel input to the CHP plant is syngas rather than solid fuel for example.

Approach 1: use of operational data
No data received

Approach 2: use of IEA statistics
No data for fuels in this category

Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
None of the indications related to category G11.

Category G12

This category includes biogas whether from AD plants, landfill gas or from wastewater treatment plants. It should be noted that for biogas-based CHP plants, the boundary should be drawn around the CHP plant with biogas as the fuel rather than the technology producing the biogas (e.g. landfill, AD plant or sewage plant).

Approach 1: use of operational data
None

Approach 2: use of IEA statistics
None

Approach 4 – manufacturer's efficiencies
Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
None of the indications related to category G12.

Category G13

This category covers coke oven gas and blast furnace gas. Both are with similar efficiencies and so are kept in the same category as in previous list of fuels.

Approach 1: use of operational data
None

Approach 2: use of IEA statistics
None

Approach 4 – manufacturer's efficiencies

Eleven manufacturers of heat-only boiler systems, across the European market, were approached to provide latest, best available, boiler efficiency (i.e. fuel to fluid efficiency, at NCV) that are currently being offered across all the identified fuel types. Only four of these manufacturers provided any form of indication of efficiencies and these indications were very simple estimations. It is important to note that for many fuels, particularly solid fuels, heat only boiler installations are designed specifically for each installation on a case by case basis, and the differing needs of heat consumers will have an impact on the boiler efficiency that is achieved at each installation.
None of the indications related to category G13.

Others

Category O14

This category covers waste heat such as the exhaust gas from high temperature processes, or as a product of exothermic chemical reactions.

Category O15

This category covers nuclear CHP. For the reference heat efficiency, we recommend that the reference efficiency for natural gas (92%) is used.

Category O16 and O17

Solar thermal and geothermal were not considered initially and so were not discussed at the stakeholder meeting. However, stakeholder feedback suggested that geothermal should be included. Further research and analysis by the consulting team revealed that these two categories will be common in the near future and so should be included in the reference values table.

These two categories are discussed in Sections 2.1.4.5 and 5.3.2.3 of the report.

Appendix 3 - Stakeholder comments and responses

Contributor	Comment	Response
Italcogen	The references values should be referred as average values of the existing plants (and not to BAT values).	According to the Directive, each cogeneration unit shall be compared with the best available and economically justifiable technology for separate production of heat and electricity on the market in the year of construction of the cogeneration unit.
	***Solid fuel S4 (below 25 MW)** electrical output.* The 33% value is high, in particular for small plants. Plants below 25 MW should be divided in at least three tiers, to account of size effects and thermodynamics : • <1MWe electrical efficiency ~ 16% • 1-5MWe electrical efficiency: 17-20% • 5 – 25MWe: efficiency ~ 30%	We initially considered splitting the wood fuel category (S4) into two capacity thresholds. This is viewed as necessary due to the difference in efficiency observed between smaller and larger plants. Smaller plants show that efficiencies as high as 33% can be achieved. Further splitting as suggested here will add to complexity and is not recommended. In any case, we have now, following the stakeholder consultation, abandoned this approach and are recommending a single reference electrical efficiency of 37% for all plants operating on wood fuel. This is based on evidence from CHP data and IEA statistics. It should be noted that, even at this high reference value, CHP plants operating on wood fuels, will still achieve, as shown in Section 7 of this report, significant PES.
	Waste Heat The proposed values is probably assessed considering also big plants all over the world. For Europe, typical size should be smaller, below 5MWe with Rankine or ORC cycle. For waste heat recovery should be highlighted that maximum efficiency is not always the only value to be considered studying a plant feasibility, e.g. is more interesting a lower efficiency cycle recovering 2MWe from low temperature gases (e.g. 200 to 100°C) rather than an high efficiency 100kWe plant that cools gases from 400 to 300°C. In other words, efficiency, is not always the main parameter to be considered as it is not a merit value when recovering heat from low temperatures gases (as thermodynamic efficiency is intrinsically low for low temperatures sources)	A waste heat electrical efficiency of 30% is considered
	Natural gas heat reference efficiency It is proper considering the decreased Fuel Energy efficiency reference level (G10A) from the current 52.5% to the new one at 50%. It is not clear the significant gap between G10A fuel efficiency value and G10B. The electrical efficiency reference level doesn't change compared to the current base value at 46**%. In our opinion this condition is adequate.**	Refer to Sections 5.3.1 and 5.5 for additional information. The proposal of splitting the natural gas category is now abandoned.

Contributor	Comment	Response
	Hot water efficiency level: from 90% to 92%, the value increased generates a reduction of the primary energy saving but it is compensated by the Steam efficiency level decreased from 90% to 87%. The coming condition is almost similar than the current state. **It is adequate.**	No comment
	The proposed Grid loss correction factors are adequate.	No comment
Contributor	**Comment**	Response
Czech DH	It is appropriate to rename the categories 'wood fuel (S4)' and 'agricultural biomass (S5)' and replace them with a more relevant and more meaningful ones such as "high quality biomass" and "low quality biomass". The reason is that origin of the biomass (wood/agriculture) is not decisive from its heating value and hence efficiency of combustion process point of view. Different biomass types should then be divided into these two categories according to heating value and other criteria impacting efficiency of combustion process and plant efficiency. These criteria should be made public so that they can be used also for other types of biomass because any list cannot be exhaustive.	The categorisation is based on the fact that fuels in the same category have similar efficiencies. This simplifies the calculation procedures for Member States and plant operators. Splitting fuels based on additional criteria (e.g. moisture content) will complicate the procedure and is thus not recommended.
	We believe that capacity thresholds in reference values for electricity should not be introduced.	We initially considered splitting the wood fuel category (S4) into two capacity thresholds. This is viewed as necessary due to the difference in efficiency observed between smaller and larger plants. Smaller plants show that efficiencies as high as 33% can be achieved. Further splitting as suggested here will add to complexity and is not recommended. In any case, we have now, following the stakeholder consultation, abandoned this approach and are recommending a single reference electrical efficiency of 37% for all plants operating on wood fuel. This is based on evidence from CHP data and IEA statistics. It should be noted that, even at this high reference value, CHP plants operating on wood fuels, will still achieve, as shown in Section 7 of this report, significant PES.
	We cannot agree to increase the electrical efficiency of wood fuels (S4) from previous 33 % to 37 %. In our opinion 25 % for low quality biomass (e.g. moisture content above 20%) and 33 % for high quality biomass (e.g. moisture content below 20%) would be more appropriate and realistic.	Evidence shows that electrical efficiencies for wood fuels can reach up to 35-37% while for 'low quality fuels', efficiencies can be as high as 30-33%.
	Thermal efficiency should be then adjusted to 86 % for low moisture content biomass and 80 % for high moisture content biomass.	See Section 5.5
	For natural gas (G10) and other fuels we propose to stay on the previous values according to Commission Implementing Decision 2011/877/EU. There is no major evidence for sufficient technological progress since last	The proposed reference heat efficiencies for hot water are 86% for category S4 and 80% for category S5.

Contributor	Comment	Response
	revision in 2011 and there is also lack of real operational data to confirm the improvement in efficiency.	
	According to general remarks biomass categories should be reconsidered based on moisture content and other criteria influencing combustion and plant efficiency. If the current approach stands than items "Logs" and "Round wood" should be in S4 category. Items "Agriculture residues" to "Distillers grain" should be in S5 category. Items "Energy crops" and "Straw" should be in S5 category.	Adding another dimension to the current reference values (i.e. differentiation based on moisture content) will significantly add to the complexity. Categorisation is based on similarities in terms of efficiencies.
	Shows inconsistency in used data – fluctuation in heat efficiency from 60% to more than 105% and back. Statistical data needs to be reconsidered / adjusted before they are used.	Data is indeed corrected and adjusted before conclusions are made on the reference efficiencies.
Bio-Energie platform, Belgium	Biomass is not an easy fuel • It might not be familiar to you but know that if there is one 'constant' in biomass – well it's not 'constant'! • Several fuels are mentioned in the table 6 – under S there are categories and for instance if we take S6 Biodegradable Municipal Solid waste it groups MSW – Industrial Waste – RDF – Sewage slugde – and paper sludge. These fuels have a wide variation in NCV (1 to 18MJ/kg) and in constituents regarding ashes and components such as P-S-Cl –F and heavy metals!! • Table 8 gives the maximum efficiencies for these systems for which a range of 25-27% for MSW etc. which is acceptable and reflecting actual practice. Logs and Roundwood also seems ok. • The last group has 31-37% would be acceptable - large systems should have 37%!? The lower range in many cases is already challenging and only for large systems like 100MWe+ you could get up to 37%... but even this is not a simple task!! We are ok with the lower range and it should also remain a range! (see above)	This comment supports the recommended reference values for waste and biomass so no comment. reference values are acceptable
	Reference values in table 12 • Group 4A: electrical eff. Of 32% would be a realistic figure • Group 4B ; intermediate stage to say 10 MWe of 33-35 would be acceptable • Remark: group 10B for large systems today 60%+ is achievable according their sector brochures.. ! so take in this group	No comment

Contributor	Comment	Response
	than also the maximum the sector promises to do 60% !! and not a poor 53%	
	Section 5.1.1.4 Cat S4 : remarks see above + we ask to be careful regarding too high values concerning efficiencies! – as mentioned above. • We agree on approach 3 - that proves our case. The recommendation is 25 to 30% - which is a big step for a developing technology!! 27 % would be much more realistic. • Heat references are ok.	The split in the biomass category is abandoned. A single reference electrical efficiency for category S4 is recommended. This might be slightly high for smaller plants but in any case, our analysis in Section 7 shows that plants can easily achieve PES of 10% (in fact reaching PES above 30%).
	Section 5.1.3.3.1 category G12 : we agree the reference value is kept on 42% - this is still a value ahead of the market (check Germany > 7.000 plants in operation)	No comment
IFIEC	IFIEC Europe welcomes the proposal to create two categories for the electrical reference values for natural gas fired cogeneration (below and above 100MW) which reflects the technological reality.	The threshold does recommend technological reality and we think the market is moving in that direction. However, as looked at the evidence
	IFIEC Europe suggests specifying the electrical reference values on hard coal, waste and waste liquids by introducing subcategories in analogy to gases (10A and 10B) due to their importance to CHP (slide 39 and 46 of the presentation from Ricardo-AEA):	We believe that sub-categories based on capacity threshold are required and should be considered in future reviews. The case for splitting the cola and waste categories has not been explored for this study and should be considered in the next review. The recommendation for the splitting of the biomass and natural gas categories according to size, as was initially suggested during the stakeholder meeting, has now been abandoned.
	On slide 44 a consideration of the condensate return is questioned. IFIEC Europe welcomes the measure coming back into place (compare Commission Decision of 21 December 2006, C (2006) 6817). Returning condensate is a measure to reduce fuel consumptions which should be rewarded. No return of condensate improves efficiency because the feed water enters at ambient temperature in the boiler and leads to a lower flue gas temperature- but more fuel will be burned. Another suggestion would be to provide the reference value of direct heat usage with the words "if the steam temperature amounts to 250°C or more this reference value has to be taken into account".	See Section 5.3.4.
German Chemical Industry (VCI)	The draft report suggests splitting up natural gas reference values in two power categories (<100 MWe, >100 MWe). It has been pointed out during the workshop that this categorisation reflects the conditions of the current generation market (increased investment in gas-fired generation units <100 MWe). VCI supports this twofold categorisation of reference values for	See Section 5.3.1

Contributor	Comment	Response
	gas-fired cogeneration as this provides a fair approach to enable investments also in smaller generation units, suiting the requirements for heat and electricity supply of chemical parks and flexible decentralised back-up capacities.	
	The current Commission Implementing Decision on harmonised efficiency values (2011/877/EU) allocates utilisation of steam >250°C to the category of "direct use of exhaust gases". Such an approach is not recognised in the draft report. As high temperature steam utilisation implies usage of a high exergy level, such application should be allocated to the *direct use* category with the underlying reference values. VCI requests for a continuing application of this existing rule with respect to the revised reference values. Alternatively, a fourth category for high temperature steam utilisation >250°C could be introduced.	See Section 5.3.1. Recommendation is to keep the same.
	The reference value for hard coal based electricity generation has been kept at 44.2%. Assuming continuing application of past practices, this reference values would be applied for new and existing CHP facilities. In this context, older existing facilities could hardly qualify to be suggests reducing the reference value for hard coal based electricity generation by 1.5% to 42.7%. Such a value would prevent decommissioning older units still contributing to resource saving operations. Alternatively, different reference values for hard coal above and below 100 MW could be established with an electricity reference value of 40% for Pel<100 MW in order to consider smaller units operating for the purpose of e.g. industrial supply, while keeping the existing reference value for larger units.	The approach to split categories according to capacity or size has been abandoned but is recommended for further review in 2019 / 2020.
	There has been little investment in CHP based on solid waste in recent years. For the same reasons mentioned in the context of coal fired CHP, VCI suggests reducing the electricity reference value to 23.1% or, alternatively, distinguish between facilities above and below 100MWe and defining a reference value of 22% for solid waste based CHP units with Pel<100MW. The suggested significant increase of the electricity reference values for non-renewable liquid waste from 25% to 29% is baseless. The report reveals no substantial supportive reasoning for such an increase. Furthermore, according to the report, 43% of cogeneration units utilising this fuel are installed in Germany. These facilities would be selectively discriminated by	Evidence for the 29% for category L9 is based on CHP data available to the consulting team. See Section 5.5. Our PES analysis in Section 7 shows that even with the higher reference efficiency of 29%, plants operating on liquid waste are still achieving very high PES (> 30%) and so this new reference value is unlikely to affect HE CHP for plants operating on liquid waste. We believe it is simpler to keep this category as a single category at this stage due to lack of data. Splitting can be considered in the next review.

Contributor	Comment	Response
	enhancing the electricity reference value significantly. VCI suggests keeping non-renewable liquid waste as a separate fuel category with an electricity reference value defined at 23.1%. Alternatively, a reference value of 22% could be defined for units with Pel<100 MW, to take account of smaller units.	
	In the draft report it is not outlined whether re-condensation is already reflected in the suggested reference values. VCI requests for according clarification.	See Section 5.3.4
	Chapter 5 – Determination of Cogeneration Reference Efficiencies Table 12 , page 23 : for Gases G12 – Biogas produced from anaerobic digestion, landfills and sewage treatment : we recommend to consider 40% instead of 42 % for Electricity efficiency	The recommendation to stick with the current 42% is due to lack of data.
	Recommendations for power efficiency – G12 , page 40 : same comment , we recommend to consider 40% instead of 42 % for Electricity efficiency " Due to lack of operational data …" : a member of ARPEE is operating such kind of Biogas CHP feed with biogas produced from AD on Waste Water Treatment Plant with following data : 5 gas engines (out of 5) have an average power efficiency , 42% from these 5 engines 3 gas engines have an electrical efficiency around 41.5% 2 gas engines have an electrical efficiency around 40.5%	Evidence available to us shows efficiency (on NCV) can reach 42%.
Cogen Flanders	We understand the division between the thermal reference values of hot water and steam. Before the last update (where the difference was dropped) however, the lower reference value could only be applied when return condensate was subtracted from the useful heat. In the draft report, there is no conditionality suggested for applying different reference values. Do you suggest that all member states are obligated to subtract the return condensate from the useful heat, or that the 85% is applied regardless of how return condensate is treated?	See Section 5.3.4
	You are suggesting a separation in the natural gas category (as well as for biomass). The report itself doesn't go into great detail on the reason for this. We feel there is a difference between the size of the CHP installation on the one hand, and the size of the reference installation on the other hand (right now even a 1 kW decentralised CHP installation is compared with a CCGT for	Refer to Sections 5.3.1 and 5.3.2.

Contributor	Comment	Response
	central electricity production). Could you supply us with some additional background information on the reasoning behind the split at 100 MW, and the reference values that were chosen accordingly?	
	Secondly, we understand the division between the thermal reference values of hot water and steam. Before the last update (where the difference was dropped) however, the lower reference value could only be applied when return condensate was subtracted from the useful heat. In the draft report, there is no conditionality suggested for applying different reference values. Do you suggest that all member states are obligated to subtract the return condensate from the useful heat, or that the 85% is applied regardless of how return condensate is treated?	The return of condensate as well as the utilisation of all the steam on site should both be encouraged. If a site utilises all the heat without returning any condensate return, then it will have high thermal efficiencies and so in this situation, it is reasonable to allow the site to have the advantage of using the lower steam reference efficiencies. Sites which return and account for condensate return in their calculation of thermal efficiencies should use the steam reference values as will be shown in the 'steam' column of the thermal reference values table. If condensate return is not accounted for then MS should increase their reference efficiencies by 5% (or multiply the efficiencies by a factor of 1.05).
	Thirdly, you are suggesting a separation in the natural gas category (as well as for biomass). The report itself doesn't go into great detail on the reason for this. We feel there is a difference between the size of the CHP installation on the one hand, and the size of the reference installation on the other hand (right now even a 1 kW decentralised CHP installation is compared with a CCGT for central electricity production). Could you supply us with some additional background information on the reasoning behind the split at 100 MW, and the reference values that were chosen accordingly?	Background to the need for splitting the gas category into two (>100 MWe and < 100 MWe) is provided in the report in Section 5. This is based on Platts database which supports the argument that the market is moving (and has been moving for several years) in a direction in which most smaller gas CHP plants (< 100 MWe, with lower electrical efficiencies) are OCGT plants which are mainly used for power production
	Fourthly, in the questionnaire for boiler operational data (in spreadsheet-format) which I downloaded from the website, I couldn't find biogas in the list of fuels. Can you check this?	Biogas should be in the fuel list for both the power-only and heat-only questionnaires.
Flemish Energy Agency	Originally (EU Commission Decision 2007/74/EC), the reference value for the separate production of steam had to be deducted with 5 percentage points when retour condensate was taken into account in the calculations of the efficiency of the cogeneration unit. This net steam production-approach (deduction of retour condensate, feed water and thermal auxiliary services) was also used in the calculation method in the Flemish support system for high efficiency cogeneration systems. In the Commission Implementing Decision of 2011 (2011/877/EU) however, this deduction with 5 percentage points was deleted. This has led to a change in the calculation method in the Flemish support system, since the reference values for separate production of steam were now based on the gross steam production, instead of the net steam	Under real operational conditions heat efficiencies for steam systems are lower than those for hot water system. This was recognised in the original Commission Decision (2007/74/EC) which is not applicable anymore. The current reference values for heat do not make that important distinction. The right approach would be to recommend two different heat efficiencies for steam system: one for systems which return condensate return and another for system which do not return condensate return. Operational data for both cases is required to determine reference efficiencies. As this data is not available, our approach is to allow systems which account for condensate return to use the steam value while systems which do not account for condensate return are not allowed to use value which provide a clear advantage. To simplify things, we recommend that systems which do not return the condensate use the hot water reference value. We think that adopting an approach which encourages

Contributor	Comment	Response
	production. The Flemish energy legislation was adjusted accordingly. In the current proposition, the reference values for separate production of steam are once again deducted with 5 percentage points compared to the reference values for separate production of hot water. This implies that the reference values for separate production of steam are again based on the net steam production, instead of the gross steam production. If this calculation method will come into force, the Flemish energy regulation has to be changed all over again. The communication on the consecutive changes in European and Flemish regulation will be very difficult. Next to this, the measurement setup in the gross steam production-approach is much less complex than in the net steam production approach, since less flows have to be measured. The proposed change will lead to a more complex measurement setup, and for significant extra measuring costs for investors and calculation costs for operators and administration. The Flemish government would prefer to stay with the gross steam production approach, where the less complex measurement setup can be used to calculate the steam production and which doesn't imply another change in the Flemish Energy legislation. hope that these arguments will be taken into consideration, Thanks in advance and sincerely yours,	condensate return should be applied. CHP schemes in MS which account for condensate return in their calculations (i.e. resulting lower thermal efficiencies) should be allowed to use the lower steam reference values. Refer to Section 5.3.4.
	Solid fuel 4 below 25 MW electrical output (S4A=wood fuels including wood pellets, dry woodchips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse) o **electrical efficiency** (for power only installations) proposed at **33%**; o Is it in line with latest commercial development? Too high?	See Section 5.5
	Solid fuel 5 (S5=agricultural biomass including logs, wound wood, agricultural residues, pruning, milling residues forestry residues and distillers grains) o **Electrical efficiency** proposed at **30%** from the current 25% o Is it in line with latest commercial development? Too high?	See Section 5.5
	Liquid fuels 9 (L9=waste liquids including biodegradable and non-renewable waste)	See Section 5.5

Contributor	Comment	Response
	o **electrical efficiency** proposed at **29%** instead of 25%; o Is it in line with latest commercial development? Too high?	
	Gases 10 (G10=natural gas, LPG and LNG) o **hot water efficiency** (for thermal only installations) proposed at **92%** instead of 90%; o Is it in line with latest commercial development? Too high?	See Section 5.5
	Gases 12 (G12=biogas produced from anaerobic digestion, landfills, and sewage treatment) o **hot water efficiency** proposed at **80%** instead of 70%; o Is it in line with latest commercial development? Too high?	See Section 5.5
	Waste Heat (brand new category called O14) o **Electrical efficiency** proposed at **33%** and **100%** for thermal efficiency o Do you have material, studies supporting those values or others?	See Section 5.5
	New electrical capacity thresholds for solid fuel 4 and gaseous fuel 10: o The rationale for setting the **thresholds at 25MWe and 100MWe** respectively is not clear o What are your views on those thresholds? Should they be set at a different level?	See Section 5.3.
Ineos	If the proposal for ambient T correction is only applicable to new installations	Our recommendation is that the temperature correction is only applied to gaseous fuels and not to solid or liquid fuels. Older plants operating on solid and liquid fuels should have not been applying a temperature correction factor in the first place. To avoid this confusion, the text in the new Commission Decision will be updated to emphasise that temperature correction is only applicable to gaseous fuels whether the plant is old or new.
	Whether the new heat values only apply to new installations (as the values are independent from year). In that case two sets of heat values will appear in the new commission decision.	Two tables of heat reference values will be included in the new Commission Decision. The first will apply to older plants up to 2015. The second table with new heat reference efficiencies (for some of the fuels) will apply to new plants (for the period 2016 – 2019)

Appendix 4: Draft reference electrical and heat efficiencies presented to stakeholders

Fuel Category		Description	Electrical efficiency %	Boiler efficiency, % Hot Water	Steam	Direct Use
Solids (S)	1	Hard coal including anthracite, bituminous coal, sub-bituminous coal, coke, semi-coke, pet coke	44.2	88	84	80
	2	Lignite, lignite briquettes, shale oil	41.8	86	82	78
	3	Peat, peat briquettes	39.0	86	82	78
	4A	Wood fuels <25MWe including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse	33.0	86	82	78
	4B	Wood fuels >25MWe including processed wood pellets and chips, straw, nut shells, husks and cobs, olive stones, clean waste wood and bagasse	37.0	86	82	78
	5	Agricultural biomass including logs, round wood, agricultural residues, pruning, milling residues, forestry residues and distillers grains, contaminated waste wood	30.0	80	76	72
	6	Municipal and industrial waste (non-renewable) and renewable/ bio-degradable waste	25.0	80	76	72
Liquids (L)	7	Heavy fuel oil, gas/diesel oil, other oil products	42.0	85	81	81
	8	Bio-liquids including bio-methanol, bioethanol, bio-butanol, biodiesel, other liquid biofuels	44.2	85	81	81
	9	Waste liquids including biodegradable and non-renewable waste (including pyrolysis oils, black and brown liquor, tallow)	29.0	75	71	65
Gases (G)	10A	Natural gas, LPG and LNG <100MWe	50.0	92	87	82
	10B	Natural gas, LPG and LNG >100MWe	53.0	92	87	82
	11	Refinery gases hydrogen and synthesis gas	42.0	90	86	81
	12	Biogas produced from anaerobic digestion, landfill, and sewage treatment	42.0	80	76	72
	13	Coke oven gas, blast furnace gas and other recovered gases (excluding refinery gas)	35.0	80	75	72
Others (O)	14	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)	30.0	100	100	100
	15	Nuclear	33.0	92	87	82

Appendix 5 - Stakeholder questionnaires

Cells in yellow below are 'dropdown list' questions

1	**Contact Details**	
	Name	
	Telephone number	
	E-mail address	

2	**Plant Details**	
	Operator	
	Location	
	Electrical Capacity, MW	
	Select power station cooling system type	
	Enter the number of fuels used on site	
	Please select the **main** type of fuel used on site	
	Please select second type of fuel used (if applicable)	
	Please select third type of fuel used (if applicable)	
	Select grid connection level	
	Is all electricity generated exported to the grid	
	If not, what percentage of the electricity generated is exported to the grid?	
	Does the plant also operate in CHP mode?	
	If the plant operates in CHP mode, select the grade of heat supplied	

3 Operational Data (in MWh) for plant named above for all years of operation (2006 - 2013 as applicable)

Are the fuel input figures given below (MWh) based on LHV or HHV?

Year	Total fuel input (MWh)	% of Main fuel	% of second fuel	% of third fuel	Total Generated Power (MWh)	Total Heat Output (MWh), if applicable
2006						
2007						
2008						
2009						
2010						
2011						
2012						
2013						

Cells in yellow below are 'dropdown list' questions

1 Contact Details

Name	
Telephone number	
E-mail address	

2 Plant Details

Operator	
Location	
Thermal Capacity, MW_{th}	

3 Fuel used on site

Enter the number of fuels used on site		
Please select the **main** type of fuel used on site		Please select fuel from dropdown list to the left
Please select second main type of fuel used (if applicable)		
Please select third main type of fuel used (if applicable)		
Type of heat application		Select from dropdown list to the left

4 Operational Data (in MWh) for plant named above for all years of operation (2006 - 2013 as applicable)

Are the fuel input figures given below (MWh) based on LHV or HHV? (select from dropdown list)

Year	Total fuel input (MWh)	% of fuel			Total Heat Output (MWh)	% of heat used in **district heating** systems	% of heat used in **industry**
		Main fuel	Second fuel	Third fuel			
2006							
2007							
2008							
2009							
2010							
2011							
2012							
2013							

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