Council of the
European Union

Brussels, 14 October 2015
(OR. en)

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COVER NOTE

From:	Secretary-General of the European Commission, signed by Mr Jordi AYET PUIGARNAU, Director
date of receipt:	12 October 2015
To:	Mr Jeppe TRANHOLM-MIKKELSEN, Secretary-General of the Council of the European Union
No. Cion doc.:	SWD(2015) 192 final
Subject:	COMMISSION STAFF WORKING DOCUMENT Accompanying the document Commission Delegated Regulation reviewing harmonised efficiency reference values for separate production of electricity and heat in application of Directive (2012/27/EU) of the European Parliament and of the Council and repealing Commission Implementing Decision 2011/877/EU

Delegations will find attached document SWD(2015) 192 final.

Encl.: SWD(2015) 192 final

EUROPEAN
COMMISSION

Brussels, 12.10.2015
SWD(2015) 192 final

COMMISSION STAFF WORKING DOCUMENT
Accompanying the document

Commission Delegated Regulation

reviewing harmonised efficiency reference values for separate production of electricity and heat in application of Directive (2012/27/EU) of the European Parliament and of the Council and repealing Commission Implementing Decision 2011/877/EU

{C(2015) 6863 final}

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Contents

OBJECTIVES AND APPROACH

According to Directive 2012/27/EU on energy efficiency[1] (EED), CHP plants have to provide primary energy savings (PES) of greater than 10% for schemes 1MWe or greater (greater than 0% for small schemes with capacity less than 1 MWe) to be judged as High Efficiency CHP, when compared with separate generation of electricity and heat.

The calculation of PES requires reference efficiencies for the separate generation of heat and electricity. Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market[2] (Cogeneration Directive) stated that the Commission is responsible for commissioning work to estimate these values based on operational data. The empowerment of the Commission to review these reference values is also emphasised in Article 22.2 of the Energy Efficiency Directive, which replaced the Cogeneration Directive in June 2014.

In 2006 the Commission established the first set of harmonised efficiency reference values for separate production of electricity and heat by publishing Decision 2007/74/EC[3]. The rationale was the need to be able to compare the impacts of Member States' cogeneration policies on a like-for-like basis.

In order to account for technological developments and changes in the distribution of energy sources, these harmonised efficiency reference values for separate production of electricity and heat should be revised every 4 years. This was done for the first time in February 2011 when Decision 2011/877/EU[4] was published.

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 Annex II of 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. 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.

These data should also be normalised (depending on ambient conditions) to ISO conditions (15°C ambient temperature, 1.013 bar, 60% relative humidity), so that a single system is applicable and fair to all Member States.

2. CONSULTATION OF INTERESTED PARTIES

Member State experts and stakeholders were consulted through and ad-hoc Consultation Forum under the Energy Efficiency Directive on 4 May 2015.

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1 OJ L 315, 14.11.2012, p. 1.
2 OJ L 52, 21.2.2004, p. 50.
3 OJ L 32, 6.2.2007, p. 183.
4 OJ L 343, 23.12.2011, p. 91.

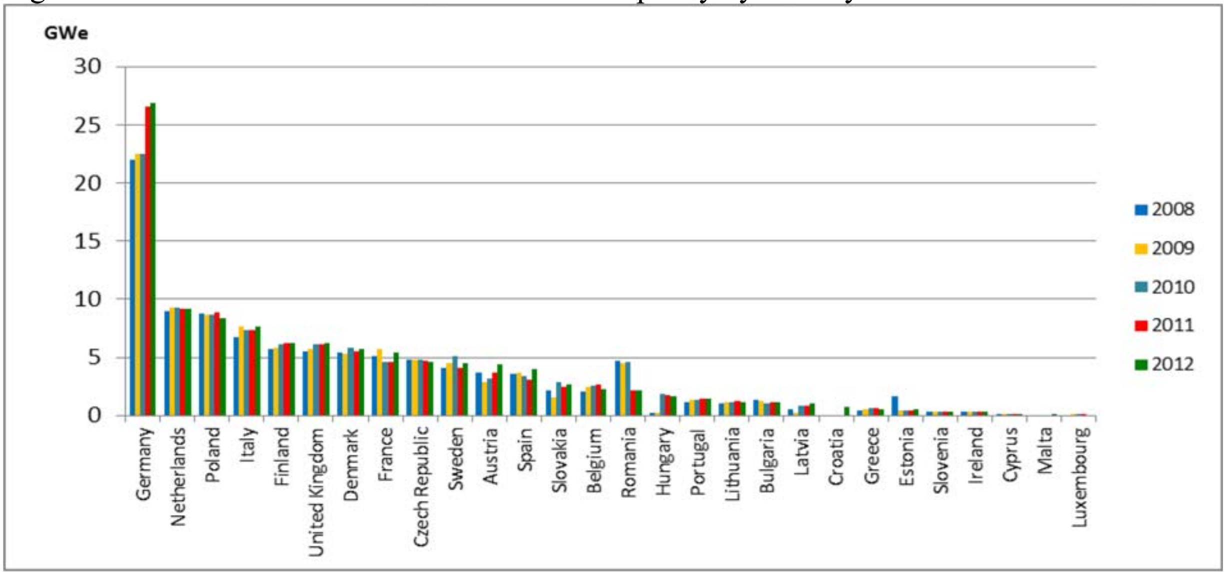
3. CURRENT STATE OF PLAY IN THE EUROPEAN CHP MARKET

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. The CODE[5] project has been analysed and relevant experts have been contacted to allow a more comprehensive review. Additional data sources, such as the Joint Research Centre (JRC), National Energy Institutes and National Statistical Centres, have also been consulted as required.

3.1. Evolution of CHP installed capacity in the EU

At present, 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. Figure 1 below shows the evolution of installed CHP capacity in the EU-28 since 2008. Eleven 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 EU28.

Figure 1: Evolution of installed CHP electrical capacity by country 2008-2012[6].



3.1.1. 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.

The table below shows the absolute and related growth of CHP electricity production per Member State between 2005 and 2012.

5 http://www.cogeneurope.eu/code_62.html
6 Source: Eurostat Annual Reports

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

MS	Absolute growth of CHP electricity between 2005 and 2012 in GWh	MS	Relative growth factor 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	-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	0.9
France	-3,252	Romania	0.8
United	-4,714	Slovak	0.7
Slovak	-7,480	Hungary	0.7
Denmark	-9,320	Denmark	0.7
Lithuania	-10,209	Lithuania	0.3

3.1.2. CHP output by fuel type in the EU-28

The table below shows the ranking of fuels used in CHP plants in the EU-28. It is noted that natural gas followed by solid fossil fuels dominate the European CHP market (> 85%). While 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 Anaerobic Digestion plants and mainly used in engine-based CHP) and combustible waste (used in steam turbine-based CHP), are becoming increasingly important 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 , Italy, France, the UK, Denmark, the 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.

Table 1: 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%

3.2. Future projections of the Cogeneration Market in Europe

3.2.1. Overview of data sources

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 101 GWe in 2010 to 114 GWe in 2020 and 116 GWe in 2030.
- In the period 2010-2030 80 GW of new CHP capacity will be installed (42 GWe up to 2020).
- This 80 GWe is 41% of total new fossil fuel based thermal power capacity.
- Much of the new investments (GW) 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-waste will be preferable in CHP mode).
- Some countries (Germany, Italy, Poland, UK, France, Spain, and Belgium) show considerable growth whereas other countries (Netherlands, Finland, (Sweden, 2030 only), Denmark, Austria) show a decline of CHP capacity.

4. LIST OF FUELS

4.1. Existing list of fuels

The current Decision 2007/74/EC lists 16 fuel categories.

Table 2: Current list of fuels

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

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 current fuel categories. All the top-ranking CHP fuels, except for 'nuclear' belong to the list above. A comprehensive list of fuels. All fuels currently used in CHP plants in Europe can be matched to one of the existing categories. It is thus recommended to keep the same categories as in Decision 2007/74/EC.

Table 4: 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	G13

Energy crops	S4	Synthesis gas from pyrolysis	G13
Wood pellets, Dry wood chips	S4	Other categories	
Straw	S4	Waste heat	G16
Bagasse, nut shells, husks, olive stones	S4	Nuclear	None
Clean waste wood	S4	Solar thermal	None
		Geolthermal	None

4.2. Recommended changes to the list of fuels

The recommended changes for the current list of fuels are summarised in the table below.

- Anthracite, coking coal, semi coke and petcoke should all be included with coal under one category.
- Shale oil should be included under the same category as lignite.
- The original wood fuel category should include wood pellets and briquettes, dried woodchips, clean waste wood, nut shells and olive and other stones. All other biomass fuels should be included into a separate category (S5) and should be termed 'Other Solid Biomass' rather than agricultural biomass.
- The bio-degradable and non-renewable solid waste categories should be combined into a single category.
- The bio-degradable and non-renewable liquid waste categories should be combined into a single category. This category should include fat and spent grain from beer production.
- Syngas should be included under the same category as refinery gases.
- Waste heat should be separated into a separate category.
- New categories should be added for nuclear, solar thermal and geothermal. These categories should also apply to plants constructed prior to 2016 and not only to new plants.

The final recommended list of fuels (with new numbering system which supersedes the numbering in Table 3) is shown below.

Table 5: Recommended list of fuels

	Category symbol	Description
Solid (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, other peat products
	4	Wood fuels including wood pellets and briquettes, dried woodchips, clean waste wood, nut shells and olive and other stones
	5	Other Solid Biomass including all kinds of solid biomass not included under S4
	6	Municipal and industrial solid waste (non-renewable) and renewable / biodegradable solid waste
Liquid (L)	7	Heavy fuel oil, gas / diesel oil, Naphtha, Kerosene
	8	Bio liquids including bio methanol, bioethanol, bio butanol, biodiesel, other bio-liquids
	9	Waste liquids including biodegradable and non-renewable waste and black and brown liquor
Gas (G)	10	Natural gas,
	11	Refinery gases hydrogen and synthesis gas
	12	Biogas produced from anaerobic digestion, landfills, and sewage
	13	Coke oven gas, blast furnace gas, mining gas, and other recovered gases (excluding refinery gas)
Other (O)	14	Waste heat
	15	Nuclear
	16	Solar thermal
	17	Geothermal
	18	Other fuel not mentioned above

5. DETERMINATION OF COGENERATION REFERENCE EFFICIENCIES

5.1. Method

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.

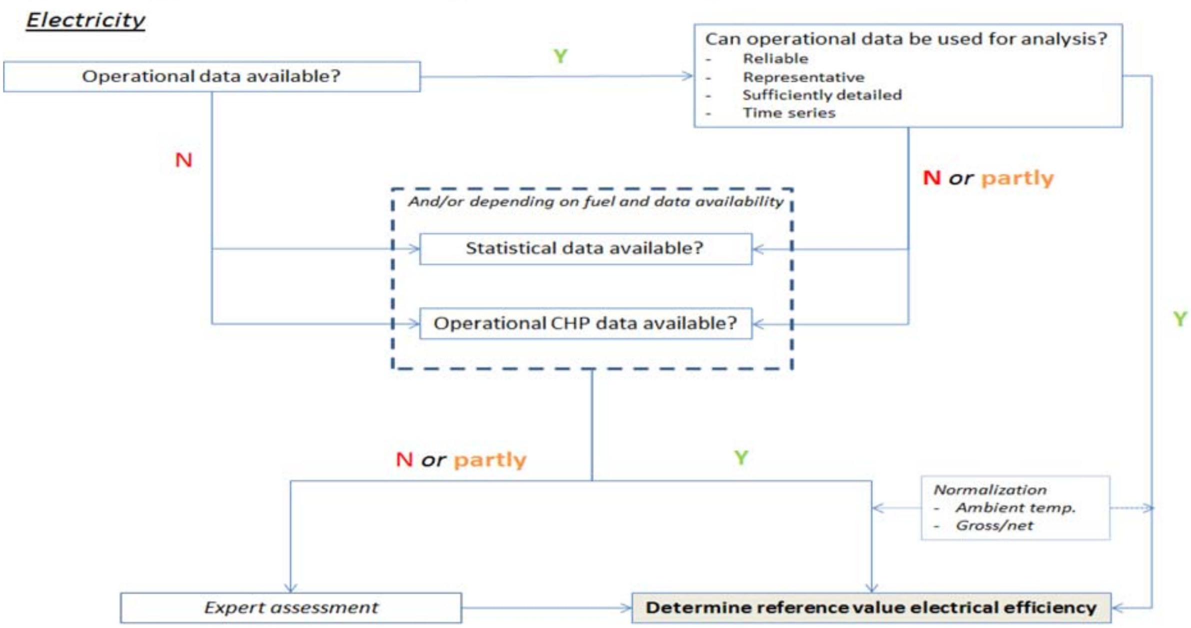
5.1.1. Reference values for electricity

The approach for reviewing and updating the efficiency reference values is visualised in Figure 2. 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.

Figure 2: Approach for determining electrical efficiency reference values



5.1.1.1. Data normalization

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).

5.1.1.2. Alternative approaches

In case the operational data does not or only partly pass the checks, alternative approaches are adopted to determine the electrical efficiency reference value. Depending on fuel type and data availability, either statistical data and/or data from CHP plants are used to determine the reference values:

- **Statistics**: based on the analysis of the statistical trend development of electricity efficiencies of the various fuel types. Focus is on the period 2008 – 2012 (or newer data when available) to 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 source for those fuels that are sufficiently big in size (quality of statistics tend to decrease for smaller quantities) and represent a unique fuel type rather than a set of rather heterogeneous fuel types that have been split in separate fuel categories in the proposed reference value matrix. Natural gas e.g. meets both criteria whereas solid biomass 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**: 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 the so-called power loss coefficient (based on steam conditions and plant size).

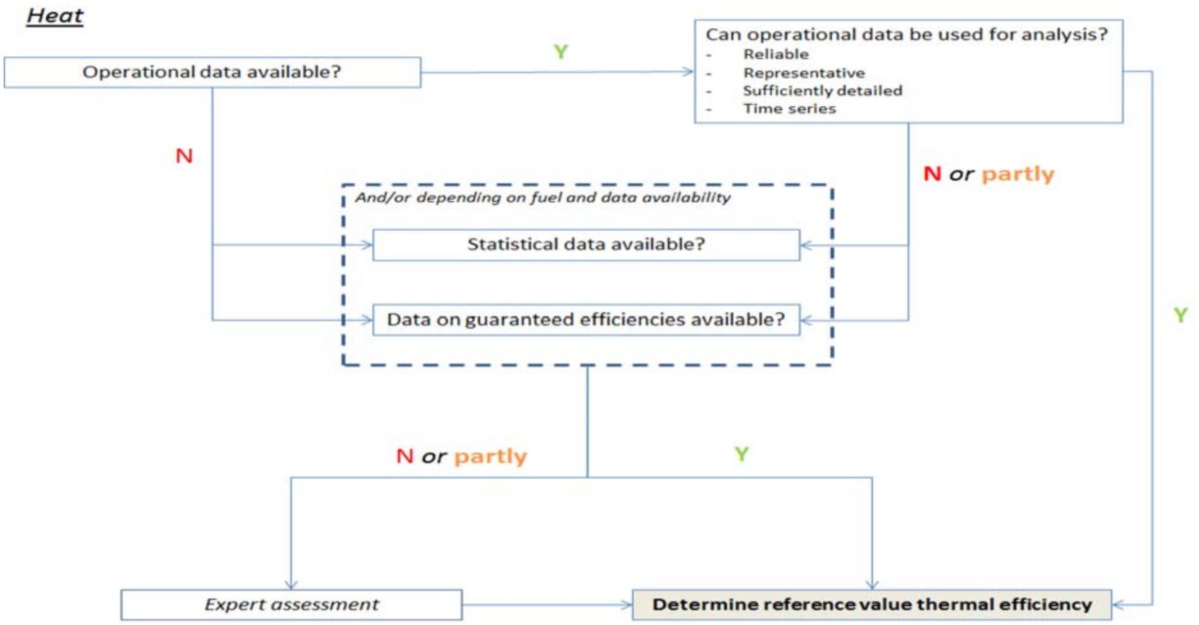
In case statistics and CHP data still provide insufficient proof for determining the reference values (efficiency values often come in ranges: the higher end of the range is not necessarily the most appropriate reference value), expert knowledge used to come to a final decision.

5.1.2. Reference values for heat

The approach for reviewing and updating the efficiency reference values is visualized in Figure 3. As for electricity, the primary approach for each fuel is to collect operational data of – in this case - heat only production. For this, requests have been sent out, on behalf of the Commission, to stakeholders and Member States. If operational data have been received by the consultancy team, these data have been scrutinized by the team in order to assess they could be actually used for determining the heat efficiency reference value. Criteria are similar as for electricity. Different from electricity, heat values should not be normalized for ambient conditions (see chapter 4).

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

Figure 3: Approach for determining heat efficiency reference values



For the development of the heat efficiency reference values acknowledging the difference between hot water and steam production is important.

5.1.2.1. Heat as dealt with in 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.

5.1.2.2. Considerations for 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 it is not recommended to increase the complexity of the 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.

5.2. Proposal to the Commission on electrical and heat reference efficiencies

A summary of the recommendations is given below and in Table 6. Further details on the analysis and the justification behind these recommendations is given in Appendix 1.

5.2.1. Proposal on electrical reference efficiencies

In cases where sufficient operational data, statistical data and CHP data are not available to support changing the current reference value, the efficiency is kept the same. We recommend maintaining the current reference efficiency for

- the coal, lignite and peat categories at the previous levels
- the solid waste category at 25%
- Oil and bio-liquids at 44.2%
- biogas at 42%
- refinery gas (category G11) at 44.2%
- coke over gas, blast furnace gas, etc. at 35%

Due to lack of operational data, IEA statistical data as well as CHP data was used.

Based on available evidence, we recommend increasing the reference efficiency for

- Wood fuels (S4) from 33% to 37%. Operational data submitted as part of the study for wood fuels shows an electrical efficiency of 36%. In addition operational data for a UK biomass plant operating in power-only mode show a 38% efficiency[7]. As a result, while data is limited, evidence exists which show that efficiencies as high as 37% are achievable for high quality biomass. In addition, design data for a number of CHP schemes and power-only plants show electrical efficiencies in full condensing mode as high as 42% (NCV). Taking into account, losses, a 37% seems reasonable.

- Other solid biomass (previously agricultural biomass) from 25% to 30%. Operational data operating on agricultural biomass (lower quality biomass) shows efficiencies (on NCV) of 34%.

- Liquid waste from 25% to 29% (this increase is supported by available CHP data. In addition no power-only operational data was provided to justify keeping the efficiency at 25%).

- Natural gas from 52.5% to 53% (This increase is based on operational data and is justified by increasing efficiencies of CCGT plants. The effect of load factors on efficiencies (lower load factor lead to lower efficiencies) was highlighted by stakeholders. It should be noted that this is applicable to CHP plants where lower load factors could, due to the need for more flexibility, lead to lower efficiencies. However, evidence available to the authors, shows that when average load factor decreased, power-only efficiencies of CCGT plants increased rather than decreased)[8].

- In addition, for nuclear, we recommend a reference efficiency of 33%. No operational data was available and so the estimate for nuclear was based on statistical data.

- For waste heat and solar thermal, we recommend a reference electrical efficiency of 30% (equivalent steam turbine efficiency.) For geothermal a value of 19.5% is recommended in line with the best efficiencies mentioned by stakeholders and coherent with the values proposed in the ETRI 2014[9]. Some stakeholders suggested splitting the geothermal and solar thermal categories into two: one for high temperature (180 – 390 ºC) and another for lower temperature (80 – 180 ºC). Similar suggestions were also made for solar thermal technology. Due to significant lack of data on this, it is recommended to keep the solar thermal and geothermal as a single category each for now and to consider the split in the next review when more data becomes available in the coming years as more plant are constructed.

5.2.2. Proposal on heat reference efficiencies

We therefore propose reference values for steam be lowered by five percentage points (5%) from the hot water reference values for each of the fuels. This reflects a mid-point in the range

7 In addition data shows that a 26 MWe plant operating on 64% 'wood fuels (or high quality fuels) and 36% low quality fuel, has a fully condensing (power-only) efficiency of 33% (based on operational data). It is expected that this will increase further as more high quality biomass is used in the plant.

8 Digest of United Kingdom Energy Statistics (DUKES) 2014. From 2003 to 2013, the load factor to CCFT plants decreased from 64.2% to 27.9% while the efficiency increased from 46.6% to 48.4%.

https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

9 Energy Technology Reference Indicator projectios for 2010 – 2015, ETRI 2014. JRC

of efficiencies for the factors discussed above. In addition, we propose to keep the reference values for the direct use of heat 3-percentage points below those of steam.

In cases where operational data is not available and where statistical data and supplier data on guaranteed efficiencies by suppliers are also not available, the heat reference efficiency for hot water is maintained at its current value.

For waste heat, nuclear, solar thermal and geothermal, we recommend a heat efficiency of a standard boiler. One option is to use a thermal efficiency depending on the fuel used in the boiler being replaced. Alternatively, a fixed reference value can be used based on the fuel replaced being natural gas. It is recommended to use the latter option and so a thermal reference efficiency of 92% is recommended for waste heat, nuclear, solar thermal and geothermal.

Table 3: Proposed final electricity and heat reference values

Category symbol		Description	Electrical efficiency	Thermal efficiency		
				Hot water	Steam	Direct use of exhaust gases
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 and other solid biomass including wood pellets and briquettes, dried woodchips, clean and dry waste wood, nut shells and olive and other stones	37.0	86	81	78
	5	Other solid biomass including all wood fuel not included under S4	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 bio-liquids	44.2	85	80	77
	9	Waste liquids including biodegradable and non-renewable waste	29.0	75	70	67
Gas (G)	10	Natural gas, , LPG and LNG > 100 MWe	53.0	92	87	84
	11	Refinery gases hydrogen and synthesis gas	44.2%	90	85	82
	12	Biogas produced from anaerobic digestion, landfills, and sewage treatment	42.0	80	75	72
	13	Coke oven gas, blast furnace gas, mining gas, and other recovered gases (excluding refinery gas)	35.0	80	75	72
Other (O)	14	Waste heat	30.0	92	87	-
	15	Nuclear	33.0	92	87	-
	16	Solar thermal	30.0	92	87	-
	17	Geothermal	19.5	92	87	-
	18	Other fuel not mentioned above		92	87	-

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[10]. As the rated efficiency of a certain power or heat generation technology reported by the manufacturer is usually tested under ISO standard reference (ambient) conditions, it is necessary to correct the efficiency reference value for the same technology that operates under different ambient conditions. To revise and update correction factors (CF) for ambient conditions in Annex III of Decision 2011/877/EU (EC, 2011), a literature has been conducted.

This section present the results 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. The 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 solid, 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 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.

Currently the guidance shows that ambient temperature correction should be applied to all fules (solid, liquid and gaseous). As the evidence shows, the effect of ambient temperature on cooling water temperature is negligible. For simplicity, the ambient temperature correction is

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only to be applied to correct the harmonised reference efficiency values when calculating the primary energy savings of specific CHP units operating on gaseous fuels (G10, G11, G12, G13).

6.1.2. Correction for ambient conditions - heat

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

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 natural gas, propane, fuel oil, coal and biomass can be combusted. The produced flue gases then passes 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. Correction for grid losses

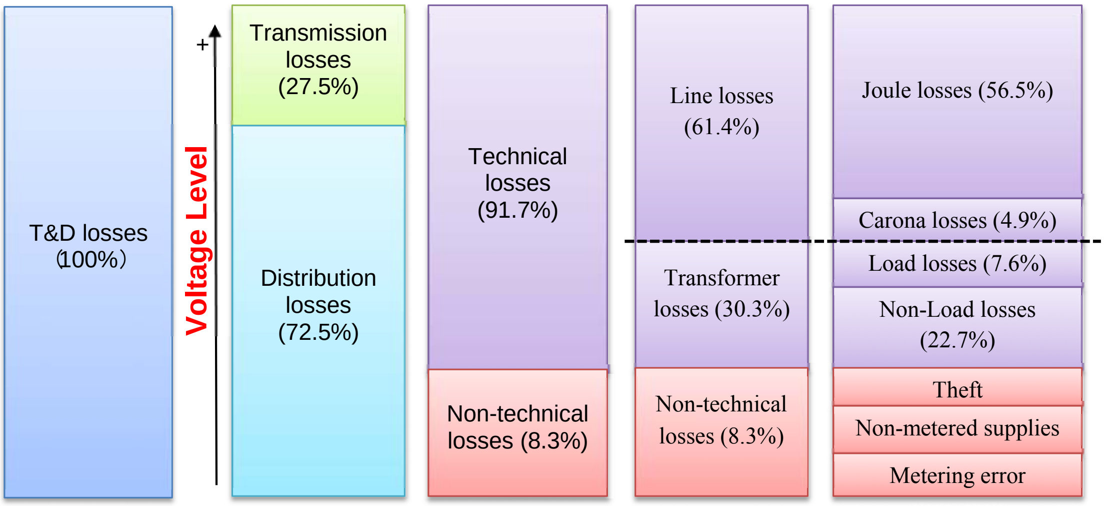
Transmission and distribution (T&D) losses refer to the amount of electric power consumed within the transmission and distribution network from electricity suppliers to end-users. They can be expressed as the percentage of losses out of the electricity output of power plants. The average T&D losses for EU-28 are ~6.5% in 2013[11], but they vary significantly from different Member States, depending on the specific national characteristics of network design, operation and management[12]. T&D losses are highest in Lithuania (19.5%) but lowest in Greece (2.7%) across Europe.

T&D can be mainly categorized 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, which cause the dissipation of electric energy into heat and noise. In contrast, 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 with technical losses, non-technical losses are relatively less significant.

[11] IEA 2014

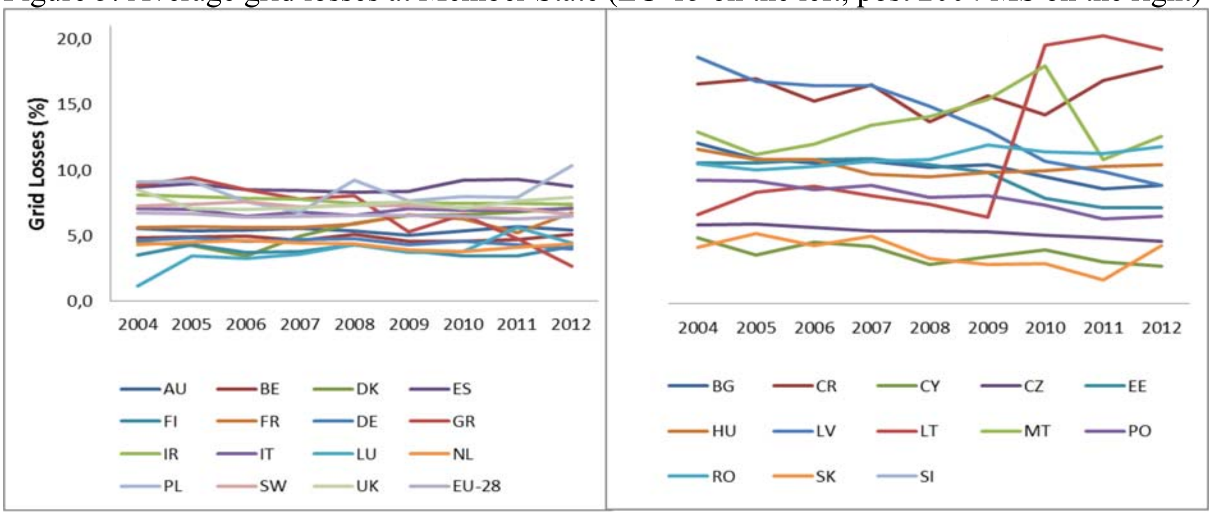
[12] Papafthymiou et al. 2013

Figure 4: Components of T&D losses and their percentage contributions to total losses



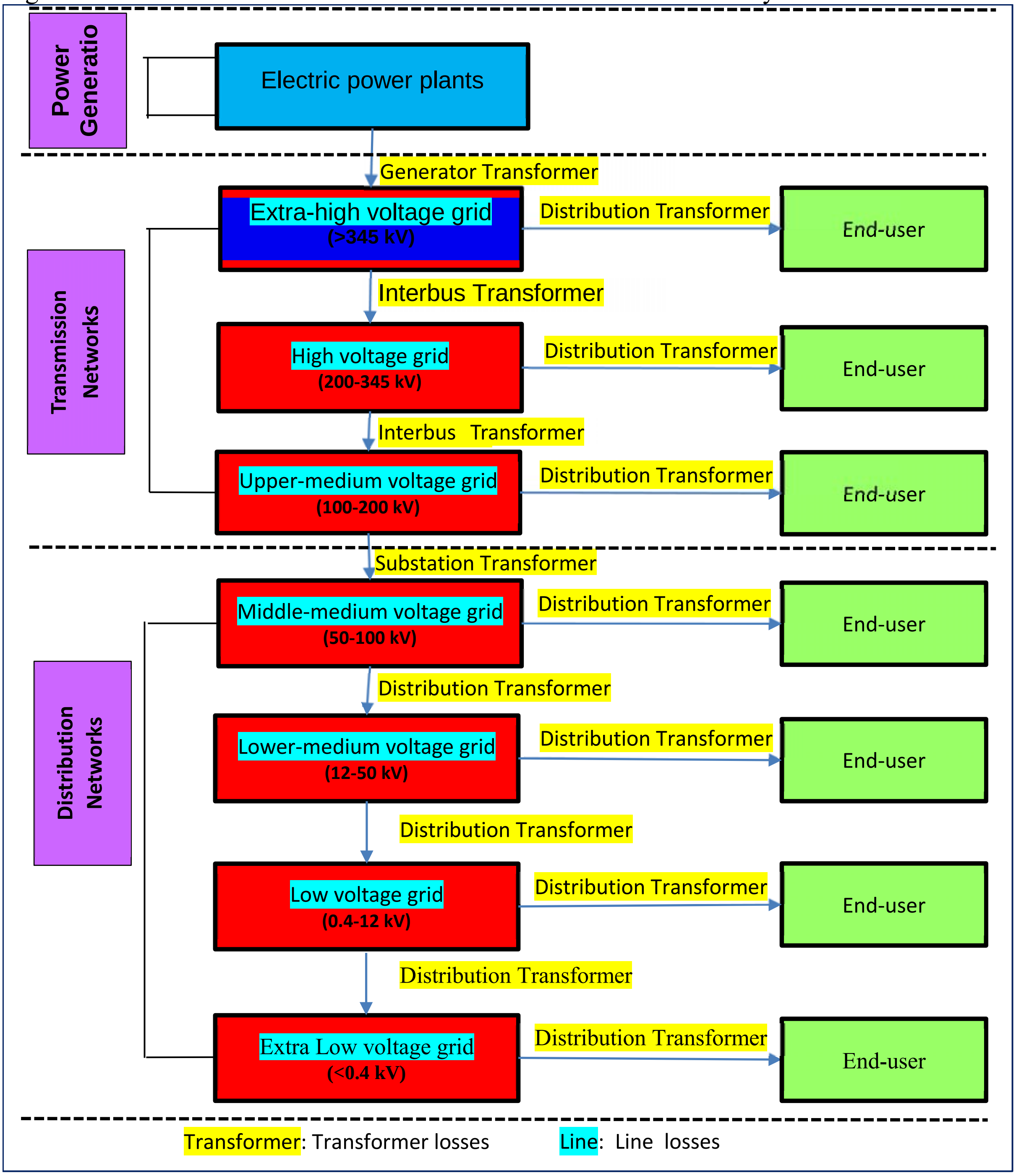
There exists a heterogeneity in system configurations and the corresponding grid losses of the electric power T&D system across different EU Member States. The average grid losses at both Member State and EU-aggregate levels are presented below. It can be observed that average grid losses in West European Member States (EU-15) are generally lower than 10%, and they tend to be stable from 2004 onwards. Although grid losses in new Member States are still more significant, they have experienced large improvement during 2004-2012. At EU-aggregate level, the average grid losses are ~6.5% in 2013.

Figure 5: Average grid losses at Member State (EU-15 on the left, post 2004 MS on the right)



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, where voltage levels for the T&D network are divided into seven main bands. They are extra-high (> 345 kV), high (200-345 kV) and upper-medium (100-200 kV) voltages for the transmission network; middle-medium (50-100 kV), lower-medium (12-50 kV), low (0.45-12 kV) and extra-low voltages (<0.45 kV) for the distribution network. 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 6: One-size-fits-all model of EU transmission and distribution system



Following the developed model, the cumulative grid losses for each connection voltage level in principle can be determined once the marginal losses for each voltage line and transformer are known. Although transformer losses can be derived from the efficiency values for different types of transformers, marginal losses for each voltage line are not given in existing literature.

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

Table 7: 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 presents avoided cumulative losses for on/off site electricity production of CHP plants at different connection voltage levels.

Table 8: 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)
>345kV	0.024	0
200 - 345kV	0.037	0.028
100 - 200kV	0.049	0.037
50 - 100kV	0.064	0.048
12 - 50kV	0.086	0.065
0.45 - 12kV	0.109	0.082
<0.45kV	0.149	0.112

Corresponding to avoided cumulative grid losses, the proposed correction factors for grid loss correction are presented in Table 8. 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.

A concern was raised regarding the relaxation of CHP standards for EU-15 Member States. A suggestion is to maintain the older grid loss coefficients table for EU-15. It is to be noted that the new grid loss coefficients are comparable to the old ones. The additional of two more voltage levels makes it more beneficial for CHP plants connected to medium voltage and low voltage levels. In addition, as the impact of grid loss coefficients is relatively small. Allowing different Member States to use different tables of grid loss coefficients is not recommended as it will make this unnecessarily more complex.

Table 9: Correction factors for on/off site electricity production from CHP plant

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

Appendix I

Recommendations for Electrical and Heat Reference Efficiencies – Supporting Analysis

This Appendix provides the evidence and reasoning for reference values shown in Table 6. Each of the fuel textboxes 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.

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	Hot Water: 88%

for Heat Reference Efficiency	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 wood pellets and briquettes, dried woodchips, clean and dry waste wood, nut shells and olive and other stones
Introduction	This category mainly refers to high quality biomass fuels. This includes wood fuels with relatively high purity and 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, as observed from available operational data, could reach 37% (NCV). This wide range of efficiencies is not observed for other types of fuels (lower quality biomass under category S5). As a result, this argument supports assigning two efficiency values to plants operating on high quality biomass, a lower value for smaller plants and another for larger plants. Evidence shows that the most reasonable capacity threshold is 25 MWe. However, as discussed later under category G10, splitting the natural gas category into two sub-categories is expected to complicate the analysis as efficiencies need to be assigned for the ≤100 MWe sub-category (for natural gas) for the period prior to 2016. As a result, and due to lack of historic operational data, it is recommended to keep the natural gas category as a single category and not to split it into two sub-categories based on capacity threshold. For consistency purposes, it is proposed to keep the biomass category (S4) as a single category. Limited operational data was provided for plants operating on wood fuels and fuels of high quality (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 operational data, shows that, depending on capacity and the quality of the fuel, power-only efficiency range from 21% to 39%. Operational data submitted as part of this project for wood fules show an electrical efficiency of 36%. In addition operational data for a UK biomass plant operating in power-only mode shows efficiencies of 38%. As a result, while data is very limited, evidence exists which show that efficiencies as high as 37% are achievable for high quality biomass. It is noted that power plants with large capacities (>250MW) are now in planning in Europe and, based on design data, these plants, using dried fuel, normally have efficiencies in excess of 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	Other solid biomass, including wood not included under S4
Introduction	This category mainly refers to low quality biomass fuels. This consists of wood (round wood, forest residues and wood chips that are not dried), agricultural biomass (which is used as it is harvested without treatment to increase its energy content), agricultural residues, pruning, milling residues and distillers

	grains. These fuels tend to have a higher moisture content or otherwise inferior characteristics 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 different types of biomass (based on quality). 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 high quality biomass vs other types of biomass ('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 be in the range 30%-34%. Data for plants reaching 34% efficiencies does exist but while the main fuel for these plants is agricultural or low quality biomass, they also use a smaller percentage of high quality biomass. Therefore, it is proposed to increase the reference efficiency value from the current level of 25% to 30%. Again, while operational data is limited, evidence shows that such efficiencies are achievable. 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 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 as well as paper waste for example. 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 Efficiency	Hot Water: 80% Steam: 75% Direct Use: 72%

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 bio-liquids
Introduction	This category include bio methanol, bioethanol, bio butanol, biodiesel, and other bio-liquids. Alcohols produced from biomass and residues from the production of ethyl alcohol are also included under this category. This is a very broad set of fuels and with the increasing use of renewable sources is likely to increase in scope.
Current	The existing reference efficiency for category L8 is 44.2% for

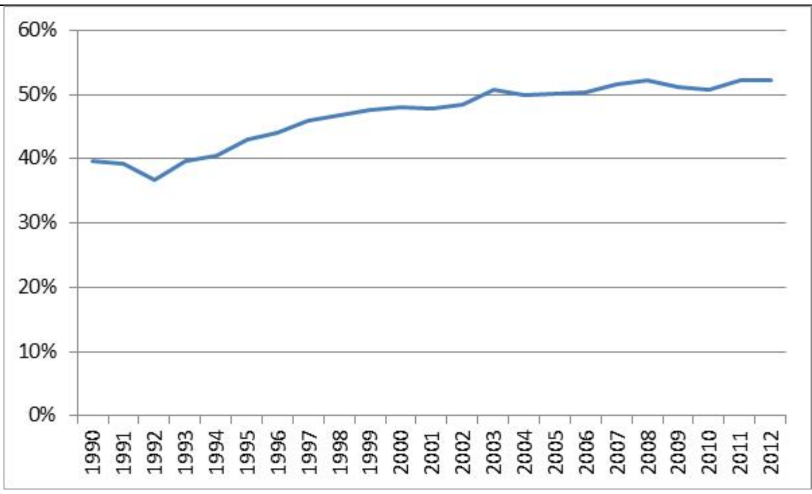
reference efficiency	electricity and 89% for hot water / steam.
Commentary on Approach Adopted	Submissions were made for two plants (4 MW and 24 MW) operating on bio-liquids (both CHP plants). Data was available for one of the plants with power-only efficiency of 44.7%. This compares well with the current value of 44.2%. Statistical IEA data was not available for bio-liquids. 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, tallow, fat and spent grain from beer production processes) and black and brown liquor.
Introduction	This category includes liquid waste from bio- biodegradable and non-renewable sources. It also includes black and brown liquor.
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%. Existing CHP data supports this argument. In addition, in light of this CHP operational data, no power-only operational data was provided to justify maintaining the reference efficiency at the same level. 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	29%

for Electricity Efficiency	
Recommendation for Heat Reference Efficiency	Hot Water: 75% Steam: 70% Direct Use: 67%

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.



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, the split of the natural gas category into two sub-categories based on a capacity threshold of 100 MWe will complicate the table of reference values. The addition of a sub-category for capacities ≤ 100 MWe means that reference values will need to be assigned to this sub-category for the period prior to 2016. This, as it was not done for the initial review in 2006, needs to initially be based on data prior

	to 2006. These efficiencies are expected to be lower than those for larger capacity of > 100 MWe (52.5% for the period 2006 – 2015) but, nevertheless, should be based on historic operational data. One option would be to scale down the prior-to-2016 values for larger capacity but this is a rough estimate and not based on evidence (note that the recommended value for natural gas plants ≤ 100 MWe is 3 percentage points lower than that for plants with >100 MWe.) It is recommended not to split the natural gas 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%.
Recommendation for Electricity Efficiency	53%
Recommendation for Heat Reference Efficiency	Hot Water: 92% 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 44.2% for electricity and 89% for hot water / steam.
Commentary on Approach Adopted	No sufficient operational data was received. Based on a single operational data point, an efficiency of 47% is obtained. Based on analysis of CHP data, efficiencies much lower than the current 44.2% are achieved. IEA data are also not available. Due to lack of data, we recommend that this value is kept at 44.2%. 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	44.2%
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%. It is believed that the operational of boilers, whether on natural gas or biogas should be similar and both fuels will have close efficiencies. The different of 20% between natural gas and biogas in terms of heat efficiencies in boilers seems unreasonable. 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, mining 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	The existing reference efficiency for category G13 is 35% for electricity and 80% for hot water / steam.

efficiency	
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%

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: 92% Steam: 87%

Category	Other Fuel, O15
Description	Nuclear
Introduction	This category covers nuclear CHP. There is little CHP using nuclear, but there is a small amount. This category also applies to plants constructed prior to 2016 and not only to new plants, as this kind of installations are already in operation.
Commentary on Approach Adopted	Due to lack of operational data, the default power efficiency applied in statistics (33%) is used. 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%

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. This category also applies to plants constructed prior to 2016 and not only to new plants.

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	**We recommend a heat efficiency of a standard boiler (based on natural gas as the fuel)** Hot Water: 92% Steam: 87%

Category	**Other Fuel, O17**
Description	Geothermal
Introduction	This category covers geothermal used in CHP mode. This is a new category and is included as it is to be recognised that there is a potential for this technology in the near future. This category also applies to plants constructed prior to 2016 and not only to new plants, as this kind of installations are already in operation.
Commentary on Approach Adopted	The value is based in comments from stakeholders and its coherent with the values proposed in the Energy Technology Reference Indicator projections 2010 – 2050, ETRI 2014, published by the JRC.
Recommendation for Electricity Efficiency	19.5%
Recommendation for Heat Reference Efficiency	**The use of the heat efficiency of a standard boiler (based on natural gas as the fuel) is recommended.** Hot Water: 92% Steam: 87%