CEWEP Energy Report III

(Status 2007-2010)

Results of Specific Data for Energy,
R1 Plant Efficiency Factor and NCV of
314 European Waste-to-Energy (WtE) Plants

$$R1 = \frac{Ep - (Ef + Ei)}{0.97 * (Ew + Ef)}$$

December 2012

by Dr.-Ing. Dieter O. Reimann,
Scientific and Technical Advisor to CEWEP
Abt-Wolfram-Ring 11, D-96071 Bamberg, Germany

www.cewep.eu

Content

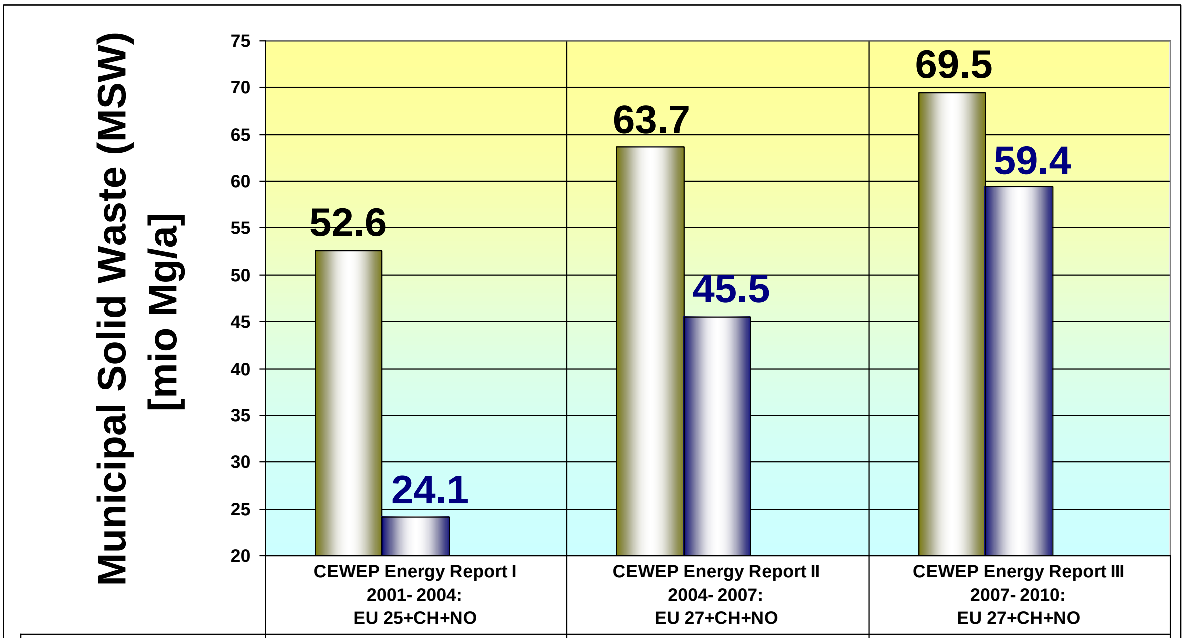
Information about Waste-to-Energy and CEWEP can be found at www.cewep.eu
Layout: CEWEP; Cover photos: www.TWENCE.nl

Executive summary

As a continuation of the work started by CEWEP into the energy efficiency of European Waste-to-Energy (WtE) plants: CEWEP Energy Report I (97 WtE plants (2001-2004)), CEWEP Energy Report II (231 WtE plants (2004-2007)), CEWEP now publishes the CEWEP Energy Report III (314 WtE plants (2007-2010)), abbreviated to Report in the following text.

Energy data from 314 European WtE plants operated by CEWEP members from 17 European countries (15 EU countries +CH+NO) has been collected and used for this Report.

The Municipal Solid Waste (MSW) incinerated by the plants investigated amounts to 59.4 million (mio) Mg/a in 15 Member States of EU 27 +CH+NO = 17 European States and represents a share of 85.5% of the total incinerated MSW of 20 European countries in EU 27 +CH+NO in 2009.



	CEWEP Energy Report I 2001-2004: EU 25+CH+NO	CEWEP Energy Report II 2004-2007: EU 27+CH+NO	CEWEP Energy Report III 2007-2010: EU 27+CH+NO
mio Mg MSW incinerated	52.6	63.7	69.5
mio Mg MSW investigated	24.1	45.5	59.4
number of WtE plants	97	231	314

Figure 1: Growth of total and investigated amount of incinerated MSW in Europe and investigated in the CEWEP Energy Reports I, II and III (Status 2001 - 2010)

The increase in the amount of incinerated MSW from 52.6 to 63.7 mio Mg/a is 21% in about a 4 year period (equivalent to 5.3%/a), is due to the implementation of the EU Landfill Directive (1999/31/EC) [1] and the Council Decision on Waste Acceptance Criteria (2003/33/EC) [2].

In the next 4 year period (2007-2010) the amount of waste incinerated grew to 69.5 mio Mg/a (9.1%), representing a growth of 2.3%/a.

The main objective of this Report was to calculate the key figures ‘Ep’ annual energy produced as heat or electricity, ‘Ew’ annual energy contained in the treated waste, ‘Ef’ annual energy input to the system from fuels contributing to the production of steam and ‘Ei’ annual energy imported excluding Ew and Ef, which forms the R1 efficiency factor according to the formula given in Annex II of the Waste Framework Directive (WFD) (Directive 2008/98/EC) [3] for the 314 installations and to determine if they are Recovery (R1) or Disposal operations (D10).

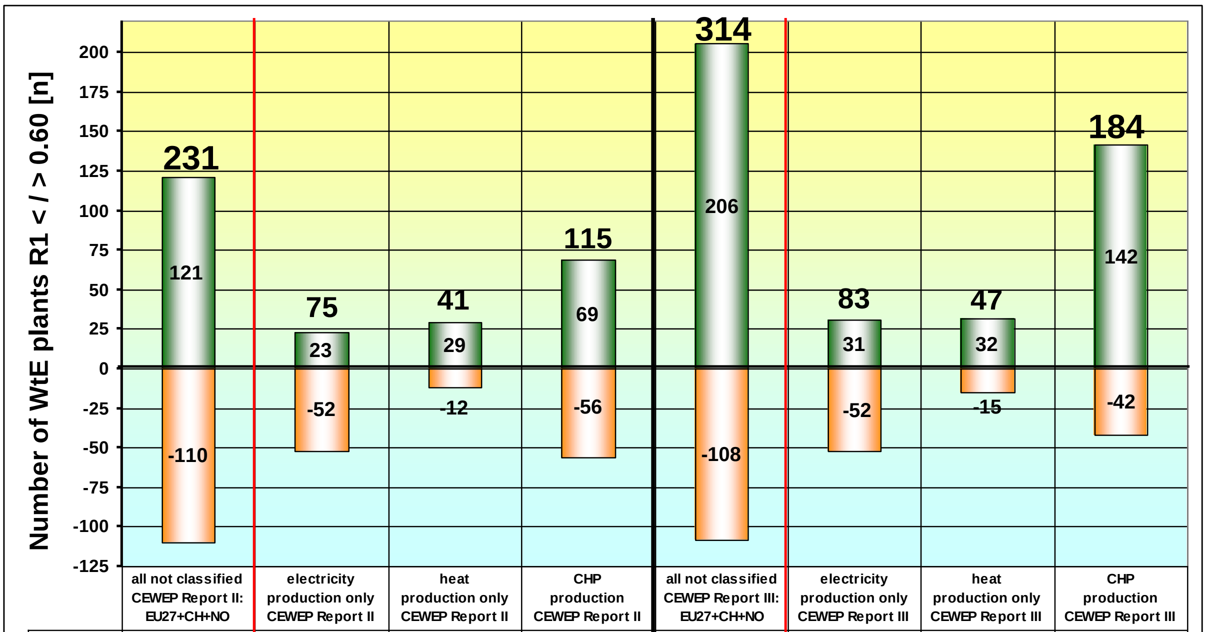
The criterion given in the WFD Directive has to be proven using the R1 energy efficiency factor (R1 factor), which for existing plants has to be $R1 \geq 0.60$ and for plants permitted after 31/12/2008 $R1 \geq 0.65$.

Another objective of this Report was to check the possible effects of the main parameters of energy efficiency performance in the R1 formula, with a view to gathering information for the determination of a possible climate factor, as an additional condition for the R1 criterion, which is currently being discussed by the European Commission.

The calculations in this Report were made assuming the same hypothesis as made in the CEWEP Energy Report I [4], which was used as a reference when the Commission set the thresholds for the R1 formula in the proposal for the WFD.

In the CEWEP Energy Report II [5] the individual and also the mean values for R1 for all 231 investigated WtE plants were higher compared to the current Report, because for the period 2004-2007 the amount of energy for heating up circulated boiler water and combustion air taken into consideration was larger, calculated according to the draft R1 Guidelines document which was available at that time. This Report was made using the stricter interpretation set out in the final version of the R1 Guidelines [6].

Better R1 results have been achieved in comparison with Report II (231 WtE plants), even though more plants from South-Western and Central Europe, often smaller and with less opportunity to export heat, are included in this Report (314 WtE plants). This is due to the optimization efforts made in the plants that participated in Report II.



	all not classified CEWEP Report II: EU27+CH+NO	electricity production only CEWEP Report II	heat production only CEWEP Report II	CHP production CEWEP Report II	all not classified CEWEP Report III: EU27+CH+NO	electricity production only CEWEP Report III	heat production only CEWEP Report III	CHP production CEWEP Report III
WtE plants	231	75	41	115	314	83	47	184
R1 < 0.60	-110	-52	-12	-56	-108	-52	-15	-42
R1 ≥ 0.60	121	23	29	69	206	31	32	142

Reimann, 2012

Figure 2: Comparison of R1 factors of investigated European WtE plants divided into all, electricity only, heat only and Combined Heat and Power (CHP) production in the CEWEP Energy Reports II and III

For all the 314 investigated European WtE plants, the R1 factor is on average R1 = 0.69 (min 0.21 and max 1.37). The R1 factor ≥0.60, which is the criterion established for existing plants in the WFD to obtain recovery status, is met by 206 WtE plants (65.6%) out of the total 314 investigated.

The results of this investigation clearly show strong correlations between the values of R1 and the parameters: type of energy recovery, size of the plant and European geographical location, respectively.

Type of energy recovery:
WtE plants "producing electricity only" have the lowest R1 factor of 0.55, as a non-weighted average, so that only 31 (37.3%) out of 83 plants reach R1 ≥ 0.60.
Although WtE plants "producing heat only" have a higher R1 factor of 0.64, as a non-weighted average, only 32 (68.1%) out of 47 plants reach R1 ≥ 0.60. In this case, the import of the total amount of electricity to treat the waste has a negative influence.
WtE plants "CHP producing" achieve the highest R1 factor of 0.76, as a non-weighted average, so that 142 (77.2%) out of 184 plants reach R1 ≥ 0.60.

Size (throughput) of the plant:
Small sized WtE plants (< 100,000 Mg/a) have the lowest R1 factor of 0.63, as a non-weighted average, so that only 59 (50.0%) out of 118 plants reach R1 ≥ 0.60.

Medium sized WtE plants (100,000 – 250,000 Mg/a) have a higher R1 factor of 0.70, as a non-weighted average, so that 85 (68.5%) out of 124 plants reach R1 ≥ 0.60..

Large sized WtE plants (> 250,000 Mg/a) achieve the highest R1 factor of 0.77 as a non-weighted average so that 62 (86.1%) out of 72 plants reach R1 ≥ 0.60.

Plant location (in European geographical regions):
Plants in South-Western Europe have the lowest R1 factor of 0.58, as a non-weighted average, so that only 27 (49.1%) out of 55 plants reach R1 ≥ 0.60.

Plants in Central Europe have a higher R1 factor of 0.62, as a non-weighted average, so that 110 (58.5%) out of 188 plants reach R1 ≥ 0.60.

Plants in Northern Europe have the highest R1 factor of 0.97, as non-weighted average, so that 69 (97.2%) out of 71 plants reach R1 ≥ 0.60.

The results can be summarized, based on the mean R1 results, as follows:

- **Very low results in general with R1 < 0.60 are found in small sized plants (throughput < 100,000Mg/a), located in South-Western Europe producing electricity only;**

  For plants producing electricity only it is very difficult to meet R1 as only 37.3% meet R1 ≥ 0.60;
- **The highest R1 results are related to large sized plants (throughput >250,000Mg/a), located in Northern Europe with CHP production;**
- **In the Energy Report II, 52% of all investigated WtE plants met R1 ≥ 0.60, whereas in this Report, although the assessment criteria are more stringent according to the final version of the R1 Guidelines, 65.6% of the WtE plants now meet R1 ≥ 0.60 primarily due to the optimization carried out by the plants that participated in the Energy Report II.**

The amount of MSW being recovered in the 206 investigated European WtE plants reaching R1 ≥ 0.60 is 46.39 mio Mg MSW/a equivalent to 78.1% of the corresponding 59.4 mio Mg MSW investigated from this Report.

The R1 factors calculated for individual plants as basis for the weighted averages and mean values in this Report may contain differences due to the NCV calculation and the self used heat of the plants (Ew and Ep). For these data the CEWEP calculations are based on the general formula, but also on assumptions (average approach, ratios) and not on specific measurements in the particular plant. Therefore the results in this Report do not replace individual calculations made by the operators when applying for R1 certification.

The R1 energy efficiency results do not include the R1 "climate factor" (R1cl), which is currently discussed at the EU level. If a R1cl factor would be adopted, it would increase the R1 level for the plants in South-Western Europe and some plants in Central Europe, but its ultimate influence cannot yet be predicted.

The results found in this Report are in correlation to the data in the BREF Waste Incineration [7].

1. Introduction

Waste-to-Energy (WtE) plants generate electricity and heat through the thermal treatment of municipal solid waste (MSW). In the past, a decision by the Court of Justice stated that a particular WtE plant was a disposal operation because its main purpose was to treat waste, not taking into account the energy produced and exported by WtE plants, their contribution to the national energy supply, to resources savings (primary fuels savings) and the corresponding reduction of CO_2 emissions (greenhouse gases, climate relevance).

The situation was clarified by the Waste Framework Directive (WFD) 2008/98/EC [3] by including in ANNEX II a calculation formula to determine when a waste incineration installation is a recovery operation (R1) or, when it does not meet the R1 efficiency criteria threshold, a disposal operation (D10). The formula is used to check the recovery of energy from waste and its utilisation by consumers on the basis of the 1st law of thermodynamics (energy output = energy input).

In ANNEX 2 of the R1 Guidelines [6] several diagrams show inter alia the system boundaries of the R1 formula (energy input to energy output), the distinction between R1 and the permit boundary, internal uses excluded from the R1 system boundary as well as the definitions of Ew, Ef, Ei and Ep.

Further details can also be found in the Diagram 1 of the Energy efficiency Report II [6].

2. Methodology

In order to determine the current and future situation concerning energy data for the European WtE plants, a computer program applying the formula laid down in the WFD and R1 Guidelines [6] was developed.

This program is connected to a database, which includes energy data of the WtE plants provided by CEWEP members who completed the plant checklist (**ANNEX E)** and an energy questionnaire (**ANNEX F)**, which were developed and used for this Report (Status 2007-2010).

The **equivalence factors** for energy given in the R1 formula have been used in this Report[1].

All **weighted and non-weighted averages**[2] are based on the specific energy data of each of the 314 individual WtE plants included in this Report.

To avoid any misinterpretation of the results in this Report, the following energy is taken into account:

- The electricity produced as the sum of the exported electricity plus the electricity self used by the plant for the thermal treatment of waste or other internal purposes.

- The heat produced and self used as the sum of heat exported plus heat self used by the plant for the thermal treatment of waste is including e.g. steam demand for soot blowers, flue gas reheating, pipes, silos and building heating and further purposes as mentioned in the R1 Guidelines [6].

- The imported energy as electricity e.g. during planned outages and fuels and heat needed to run the incineration process.

---

[1] Equivalence factors are used for the comparison of different types of energies produced by a WtE plant.
The equivalence factors for energy given in Annex II of the WFD [3] have been used in the formula for the determination of the R1 energy recovery efficiency factor.
The equivalence factors for energy produced (export plus energy self used for the treatment of the waste) are 2.6 for electricity and 1.1 for heat.
Relating to the R1 Guidelines [6] the equivalence factors for Ef and Ei as primary fuels are 1.0 and for Ei as district heat or hot water/steam 1.1 and for electricity 2.6.
In order to differentiate the values, it is specified in the text or the titles if they include the equivalence factor (equ) or not (abs).

[2] Weighted averages are used in this report to enable the comparison of all kinds of energy production, e.g. for NCV:
$(\Sigma_n (\text{MSW throughput}_{\text{individual}} * \text{NCV}_{\text{individual}})) / (\Sigma_n (\text{MSW throughput}_{\text{individual}})) = \text{NCV}_{\text{weighted average}}$.
Non-weighted averages are used for min and max results as well as for the averages of the R1 factor according to WFD.

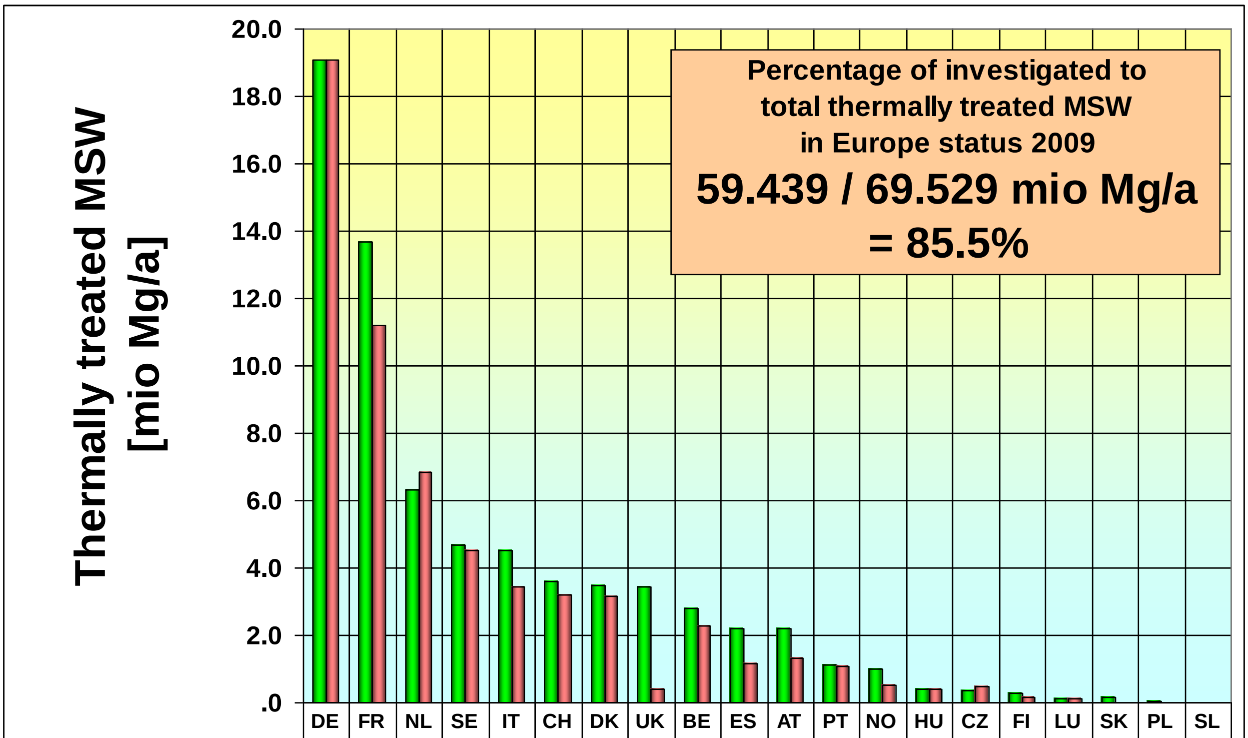
3. Amount of MSW incinerated and number of WtE plants investigated

3.1 Amount of MSW investigated and incinerated

Energy data from 314 European WtE plants operated by CEWEP members from 17 European countries (15 Members States (MS) of EU 27 + CH + NO) is the basis for this Report for the time period 2007-2010[3]. The amount of Municipal Solid Waste (MSW)[4] being incinerated and investigated was summarised from the filled-in checklists accounting for 55.71 mio Mg/a (throughput by 15 MS of EU 27) and 59.44 mio Mg/a (throughput by 15 MS of EU 27 + CH + NO = 17 European States).

These amounts have been compared with the figures for the total waste incinerated in 2009 in the EU 27 respectively in the EU 27+CH+NO based on the data available at that time gathered by CEWEP, listed under "CEWEP: EUROPE - Thermally Treated MSW 2009"[5] including relevant references.

The country specific amount of incinerated MSW in Europe (2009) is shown in Figure 3.



	DE	FR	NL	SE	IT	CH	DK	UK	BE	ES	AT	PT	NO	HU	CZ	FI	LU	SK	PL	SL
total MSW incinerated 2009	19.0	13.7	6.33	4.67	4.52	3.60	3.50	3.44	2.80	2.21	2.20	1.10	1.00	.41	.36	.27	.13	.17	.04	.01
investigated in 2007-2010	19.0	11.2	6.82	4.53	3.43	3.21	3.16	.42	2.30	1.14	1.33	1.09	.52	.41	.49	.15	.14	.00	.00	.00

Figure 3: Thermally treated Municipal Solid Waste (MSW)[6] as total in 2009[27] compared with the throughput of the 314 investigated WtE plants included in this Report (Status 2007-2010)

[3] The information from 13 plants (in addition to the 314 already mentioned) have not been taken into account because of biogas combustion, co-combustion with wood chips, peat or natural gas, gasification by pyrolysis, no energy recovery or under reconstruction because this would have distorted the comparability of the CEWEP Energy Report III (Status 2007-2010).

[4] Municipal Solid Waste (MSW) and similar means waste from households as well as commercial, industrial and institutional waste, which because of its nature and composition is similar to waste from households (although its NCV might be different). In some cases, high calorific waste is added to the MSW incinerated.

[5] http://www.cewep.eu/information/data/studies/m_953

[6] See footnote 1 on page 7

[7] See footnote 2 on page 7

For the determination of the annual amount of MSW incinerated and investigated in this Report for the 4 year period (2007-2010), each plant is only taken into account once, with its most recent data even if several annual energy calculations have been carried out during this period[8]

2007:	36 WtE plants	6.354 mio Mg	10.7%
2008:	0 WtE plants	0 mio Mg	0.0%
2009:	39 WtE plants	5.926 mio Mg	10.0%
2010:	239 WtE plants	47.159 mio Mg	79.3%
total 2007-2010:	**314** WtE plants	**59.439 mio Mg**	**100.0%**

The amounts above represent a share of 85.8% of the total MSW incinerated in the 18 EU Member States in EU 27 and 85.5% of the total MSW incinerated in 18 MS + CH + NO =20 European countries, whereas the percentage have been determined as follows:

	total incinerated 2009	**investigated 2007-2010**	**% investigated**
18 EU Member States (MS):	64.929 mio Mg/a (18 EU MS)	55.705 mio Mg/a (15 EU MS)	85.8%
20 European countries:	69.529 mio Mg/a (18 EU MS+CH+NO)	59.439 mio Mg/a (15 EU MS+CH+NO)	85.5%

In order to evaluate the results in this Report, it should be considered that the specific waste management systems and types of energy recovery differ widely from country to country.

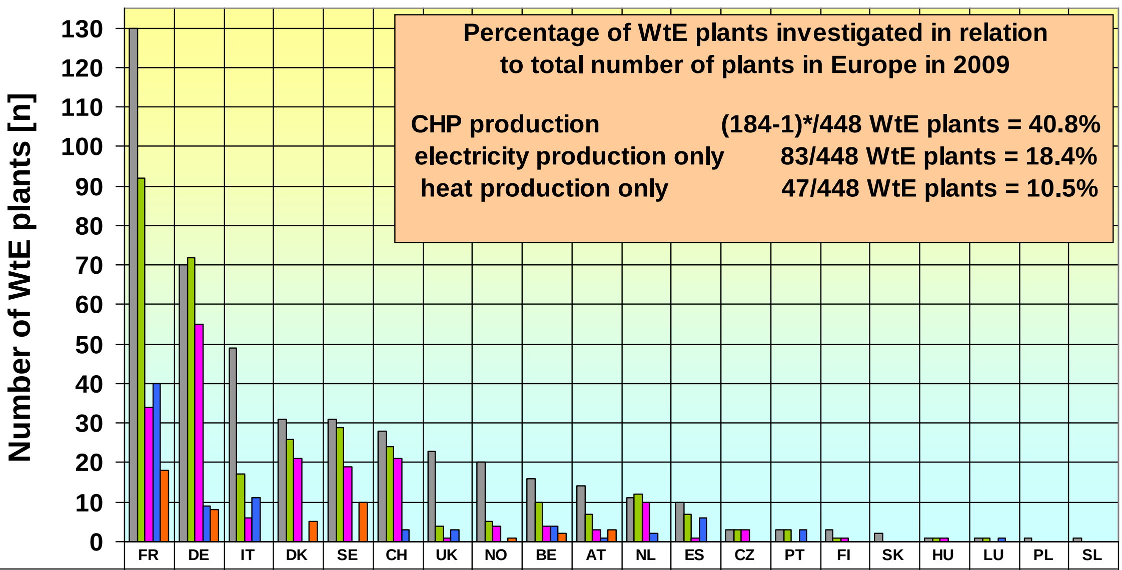
Therefore the degree of participation of each country related to the amount of MSW incinerated in this Report is very important concerning the generalisation of results and can be classified as follows:

~ 100%: DE, NL, SE, PT, HU, CZ, LU;
75-99%: DK, FR, IT, CH, BE;
50-74%: ES, AT, NO, FI;
0- 24%: UK, SK, PL, SL;

Considering the low degree of participation primarily of plants in the UK with < 50%, and the amount of incinerated MSW of about 3.5 mio Mg, the UK is under represented in this Report and therefore may have an impact on the average of the recent results. It also appears that some small plants with low efficiencies in South-Western Europe did not provide data due to their low energy efficiency.

[8] Investigated plants had delivered data for the period 2007 to 2010; some did not update old data to 2010 figures.

3.2 Number of investigated WtE plants by type of energy recovery



	FR	DE	IT	DK	SE	CH	UK	NO	BE	AT	NL	ES	CZ	PT	FI	SK	HU	LU	PL	SL
total n in 2009	130	70	49	31	31	28	23	20	16	14	11	10	3	3	3	2	1	1	1	1
investigated 07-10	92	72	17	26	29	24	4	5	10	7	12*	7	3	3	1	0	1	1	0	0
CHP production	34	55	6	21	19	21	1	4	4	3	10	1	3	0	1	0	1	0	0	0
electricity prod. only	40	9	11	0	0	3	3	0	4	1	2	6	0	3	0	0	0	1	0	0
heat prod. only	18	8	0	5	10	0	0	1	2	3	0	0	0	0	0	0	0	0	0	0

* 12 investigated plants for NL because in this Report the Amsterdam plant was counted as two plants (plant AEC and plant HRC) whereas NL has only got 11 plants as official number

Country specific number of plants producing CHP, el, heat

(Reimann 2012)

Figure 4: Number of existing European incineration plants as total in 2009 compared with the 314 investigated WtE plants and according to the type of energy recovery included in this Report (Status 2007-2010)

The 314 WtE plants included in this Report represent ~70%[9] of the total 448 European plants (from 18 Member States of EU 27+CH+NO), and ~71%[7] respectively with 285 WtE plants out of the 400 EU plants (from 18 Member States of EU 27) in 2007-2010.

Because no data was provided or available about the WtE plants existing in Poland, Slovakia and Slovenia they are not included in this Report.

The number of WtE plants investigated related to the total number (18 Member States in EU 27+CH+NO) was classified by their percentage in this Report (for all plants ~ 65%):

~ 100%: DE, NL, CZ, PT, HU, LU;
75-99%: SE, DK, CH;
50-74%: FR, BE, AT, ES;
25-49%: IT, NO, FI;
0- 24%: UK, SK, PL, SL

It is possible that the results in this Report will be influenced by the number of plants with a percentage of participation < 50% (e.g. the UK, but also by IT and NO) and their type of energy recovery. If these missing plants were included in this Report then the averages presented could change slightly.

The results from Figure 4 can be summarized as follows:

- In AT, CZ, DK, FI, HU, NO and SE the energy is in general used for “CHP” or “heat production only”.
- In DE, CH, NL “CHP production” or “heat production only” plants are the majority, whereas the minority of plants generate “electricity only”.

[9] For the determination of the percentages the two separately investigated plants of Amsterdam have been counted as one in order to correspond to the official number of plants in the NL.

- In BE and in the central part of FR the number of “CHP production” or “heat production only” plants is nearly equal to the number of “electricity production only” plants.
- In ES, IT, PT, in the north-western part of FR and perhaps also in the UK “electricity production only” plants is by far the majority.

4. Objectives of the Report (Status 2007-2010)

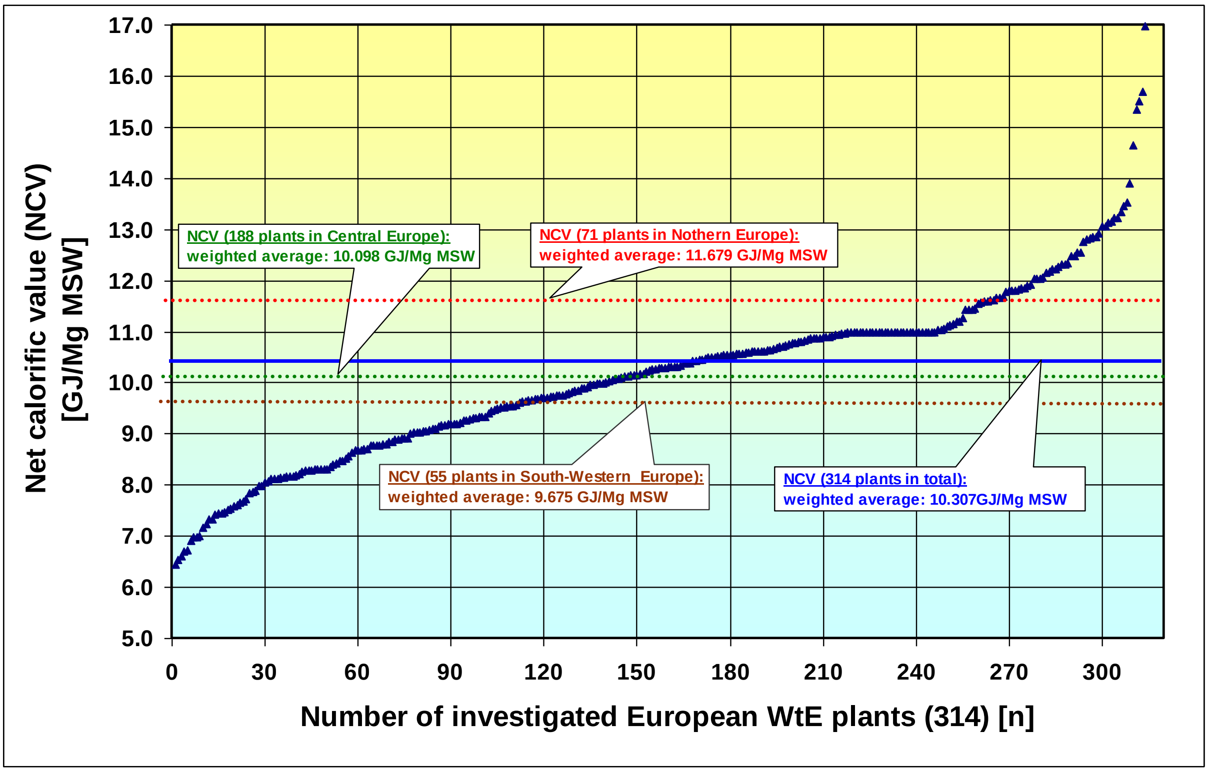
Beside calculating the general energy results (such as Net Calorific Value (NCV), energy production as heat and/or electricity, R1 factor) for the **314 investigated European WtE plants without any classification,** this Report also contains answers to 3 additional decisive questions with a view to identifying correlations between their energy data and the following parameters:

- **type of energy recovery**
  3 categories: electricity production only, heat production only, CHP production**,**
- **size (throughput) of the plant**
  3 categories: <100,000, 100,000-250,000, >250,000 Mg MSW/a,
- **geographical location of the plant in Europe**
  3 categories: Northern Europe (annual HDD [10] > 3350) (DK, FI, NO, SE),
  Central Europe (annual HDD 2150 – 3350) (AT, BE, CH, CZ, DE, part of FR, GB, HU, LU, NL),
  South-Western Europe (annual HDD < 2150) (ES, part of FR (28 plants), IT, PT)

In this Report for all investigated WtE plants with **heat production by exporting steam**, how the steam (heat) is used by the customers is not considered, as mentioned in the R1 Guidelines [6].

5. Net Calorific Value (NCV) of MSW (as basis for Ew in R1 formula) of all WtE plants investigated

Diagram 1: Net Calorific Value (NCV) of the individual WtE plants investigated



The NCVs in Diagram 1 include individual NCV values for 314 European WtE plants with their weighted average and the weighted averages for WtE plants from Northern Europe (71 plants),

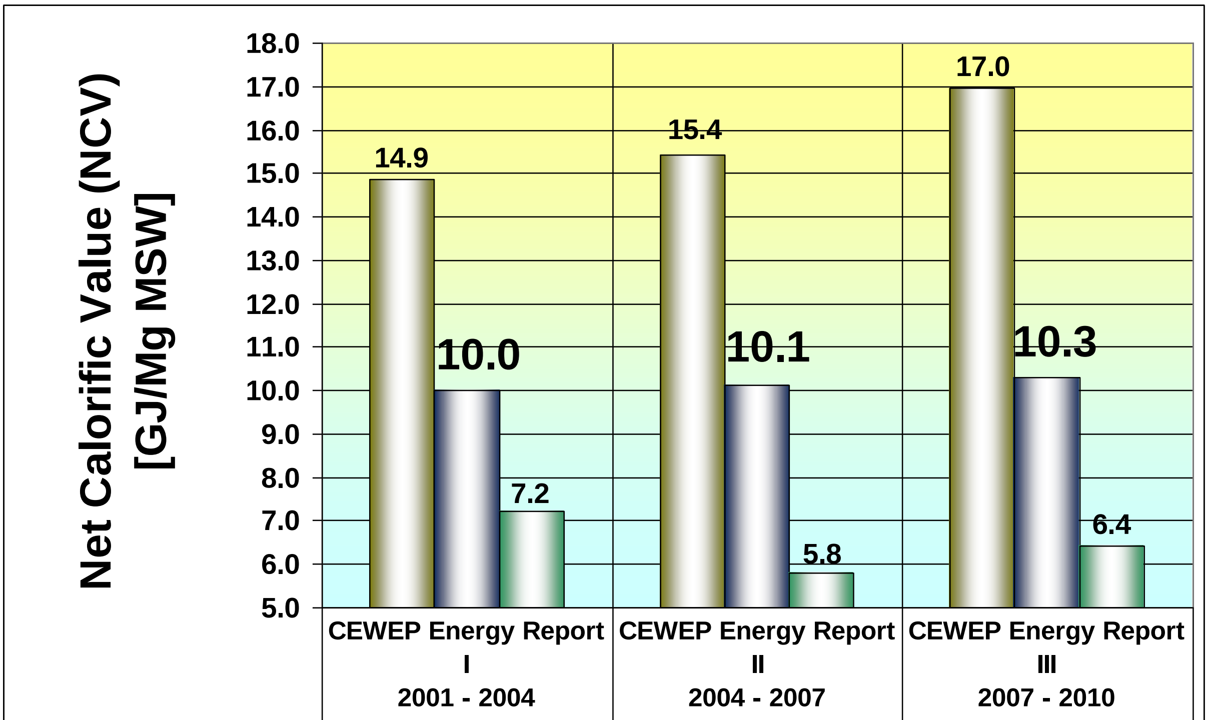
[10] HDD: Heating Degree Days, used for the description of heat demand as climate profile

Central Europe (188 plants) and South-Western Europe (55 plants) (Status 2007-2010).

The weighted mean value of NCV has remained quite stable over the 8 year period (2001-2010) increasing only slightly from 9.987 GJ/Mg MSW [4] to 10.129 GJ/Mg MSW [5] now to 10.307 GJ/Mg MSW as shown in Figure 5.

The weighted average of NCV over the total amount of MSW being incinerated in the 314 WtE plants was determined on initial energy balances as mentioned in the R1 Guidelines [6] in combination with the NCV formula from BREF WI Chapter 2.4.2.1.[8] and the FDBR Guideline [9].

As a result not only measured data (e.g. steam quantity) provided by the operators in the annual CEWEP energy questionnaire (ANNEX F) have been taken into account, after their plausibility has been checked, but also interpretations of the data filled in by the operators in the CEWEP Checklist (ANNEX E).



	CEWEP Energy Report I 2001 - 2004	CEWEP Energy Report II 2004 - 2007	CEWEP Energy Report III 2007 - 2010
max. NCV	14.9	15.4	17.0
weighted mean NCV	10.0	10.1	10.3
min. NCV	7.2	5.8	6.4

Figure 5: Adjustment of NCV of incinerated MSW as weighted averages, min and max values in Europe related to the time periods of CEWEP Energy Reports I-III (2001-2010)

A significant increase can be seen in the range between min and max NCV from 7.2- 14.9 = 7.7 GJ/Mg MSW in CEWEP Energy Report I to 6.4- 17.0 = 10.6 GJ/Mg MSW in this Report.

Possible reasons for this change can be inter alia: pre-treatment of MSW, separate collection, change of collection systems, different political requirements concerning waste management, financial aspects etc. This seems to also confirm that the higher the recycling rate, the higher is the NCV of the residual waste.

5.1 NCV of MSW (basis for Ew) of all WtE plants investigated and divided into three categories (Status 2007-2010)

Table 1: NCV of MSW as weighted averages for the total WtE plants and divided into 3 categories: type of energy recovery, size (throughput) and European geographical region (Status 2007-2010)

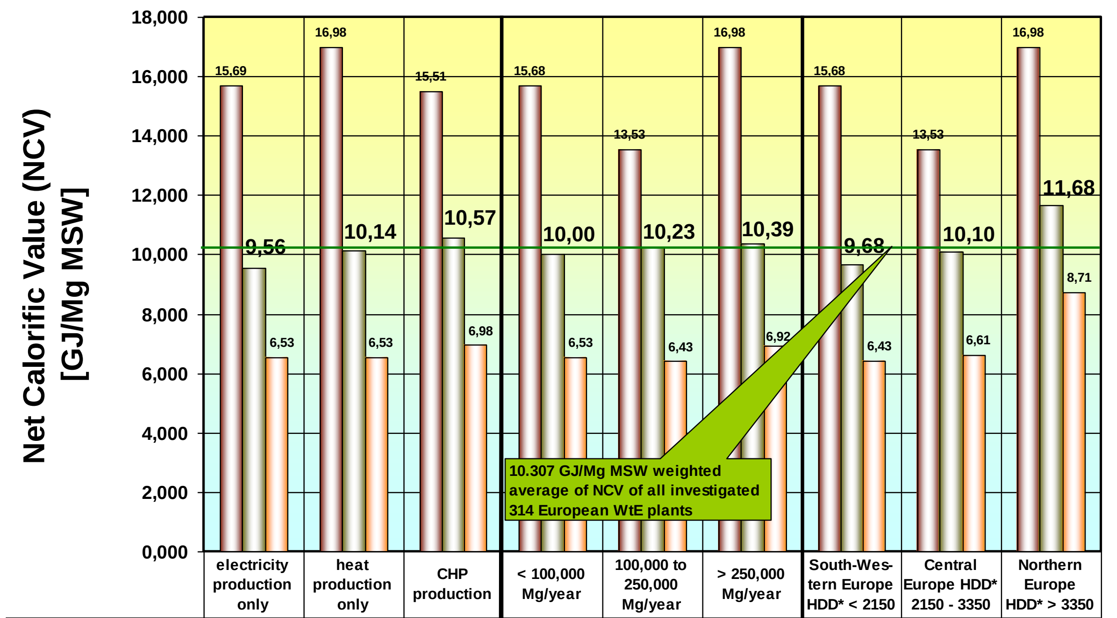
relevant NCV depending on different classifications	unit	all investigated WtE plants	type of energy recovery of a plant			size (throughput) of a plant			geographical European region of a plant		
			electricity production only	heat production only	CHP production	< 100,000 Mg MSW/a	100,000 to 250,000 Mg MSW/a	> 250,000 Mg MSW/a	South-Western Europe	Central Europe	Northern Europe
number of plants included	n	314	83	47	184	118	124	72	55	188	71
total throughput of plants	mio Mg/a	59.44	12.98	5.67	40.78	7.06	19.80	32.57	8.73	40.52	10.19
weighted averages and min/max of NCV of incinerated MSW	GJ/Mg MSW	10.307	9.557	10.141	10.570	9.998	10.233	10.387	9.675	10.098	11.679
	GJ/Mg MSW	6.43 - 16.98	6.53-15.69	6.53-16.98	6.98-15.51	6.53-15.68	6.43-13.53	6.92-16.98	6.43-15.68	6.61-13.53	8.71-16.98
	MWh/Mg MSW	2.863	2.655	2.817	2.936	2.777	2.843	2.885	2.688	2.805	3.244

Table 1 shows the NCV results for all the WtE plants investigated, divided into 3 categories: the type of energy recovery, the size and the geographical region of a plant.

However the influence of greater amounts of high calorific fractions in the incinerated MSW in plants (e.g. of bulky, trade, industrial and commercial waste, soiled wrapping or waste wood) should not be overlooked.

They are mainly found in large sized plants (> 250,000 Mg MSW/a) in Northern Europe, indicated by max NCVs of up to 17 GJ/Mg MSW.

Min NCV values which are found in all categories are quite stable in the range 6.5-7 GJ /Mg MSW. This could be due to a higher content of green(bio) waste, sewage sludge, waste water, non-combustible fractions or high water content (e.g. in rainy seasons) within the MSW.



	electricity production only	heat production only	CHP production	< 100,000 Mg/year	100,000 to 250,000 Mg/year	> 250,000 Mg/year	South-Western Europe HDD* < 2150	Central Europe HDD* 2150 - 3350	Northern Europe HDD* > 3350
NCV max [-]	15,690	16,980	15,510	15,680	13,530	16,980	15,680	13,530	16,980
NCV weight. average [-]	9,557	10,141	10,570	9,998	10,233	10,387	9,675	10,098	11,679
NCV min [-]	6,530	6,530	6,980	6,530	6,430	6,920	6,430	6,610	8,710

* HDD = Hearing Degree Day

Reimann 2012

Figure 6: NCV calculated of the WtE plants divided into 3 categories according to the type of energy recovery, the size (throughput) and the European geographical region as min and max values and weighted averages (Status 2007-2010)

The weighted NCV averages as shown in Figure 6, depending on the type of energy recovery, size and geographical location of a plant, are in a range between 9.6 and 10.6 GJ/Mg MSW, except in Northern Europe with a weighted average of 11.7 GJ/Mg MSW.

The weighted average NCV of plants producing electricity only is lower than the average of plants generating heat only (-15%) or CHP (-20%). This is primarily related to plants, located in rural areas, incinerating primarily MSW from households with low content of commercial and industrial waste.

The most important difference is due to geographical location, because the lowest weighted average of NCV is found in WtE plants in South-Western Europe, where there are less possibilities to use heat, and which is about 17% lower than in Northern Europe.

This highest weighted mean NCV is related to Northern Europe, where the energy from MSW is mainly used for heating purposes with the aim to substitute primary fuels, which would otherwise have to be imported. Therefore in general an increased NCV of the MSW is required and obtained e.g. by adding waste wood chips or high calorific waste fractions to the MSW.

The accuracy of the NCV results primarily depends on the measuring devices used for steam and should be monitored. This can be checked by comparing the quantity of boiler water with the corresponding steam quantity, whereas the quantity of boiler water should never be lower than the quantity of steam.

6. Energy input, imported, produced as electricity and used as heat in all the investigated WtE plants (Status 2007-2010) (Ep, Ef and Ei in the R1 formula)

The following Table 2 as well as ANNEX A shows the results for the production of electricity and of heat exported plus the self used heat to treat the waste.

Heat self used to treat MSW is for example heat for heating up flue gases (e.g. after wet scrubber before fabric filter or before SCR (Selective Catalytic Reduction)), steam for soot blowing and for injection purposes (e.g. NH_4OH for SNCR (Selective Non-Catalytic Reduction)), for steam driven aggregates (e.g. turbo pumps, compressors, blowers), for internal or external treatment of liquid residues from Air Pollution Control (APC) system, for heating of buildings, silos, pipes etc.

The self used heat to treat the waste is generally not measured, but can be calculated from related operational data and/or based on experience.

Details of what has been taken into account in this Report and the way the specific heat demand was determined are listed in ANNEX D.

Also the imported heat (generally from fuels) and electricity are of importance, because they are relevant for the R1 calculation as Ef and Ei, and furthermore have a financial impact.

The mean data in the Report under these conditions represent not only a trend, but also realistic, process relevant results with a high-level of accuracy.

6.1 Energy produced and used (Ep) as heat and electricity in all WtE plants investigated and divided according to the types of energy recovery (Status 2007-2010)

Differences in the energy recovery rate from MSW depending on the type of energy recovered as heat, electricity or CHP (Ep) are shown in Figure 7.

All results are in absolute values (abs) without equivalence factors. Even if the evaluation method used by adding the recovery rates from heat and electricity is not correct it has been included in this Report due to common practice.

Electricity has a higher value per percentage of recovery rate than heat, because for 1 MWh el produced by MSW about 2.6 MWh of primary fuel are needed by dedicated power plants, whereas for 1 MWh heat produced from MSW about 1.1 MWh of primary fuel is needed by dedicated heating plants, and these primary fuels can be substituted by waste incineration with energy recovery. These ratios are taken into account by the equivalence factors included in the R1 formula.

Table 2: Specific energy recovery rates for MSW in absolute and percentages as weighted-averages for the total WtE plants and divided into the categories type of energy recovery, size (throughput) and European geographical region (Status 2007-2010)

type of energy recovery depending on different classifications	unit	all investigated WtE plants	type of energy recovery of a plant			size (throughput) of a plant			geographical European region of a plant		
			electricity production only	heat production only	CHP production	< 100,000 Mg MSW/a	100,000 to 250,000 Mg MSW/a	> 250,000 Mg MSW/a	South-Western Europe	Central Europe	Northern Europe
number of plants included	n	314	83	47	184	118	124	72	55	188	71
total throughput of plants	mio Mg/a	59.44	12.98	5.67	40.78	7.06	19.80	32.57	8.73	40.52	10.19
Total specific energy input (incl. import) as weighted averages	MWh abs. / Mg total (Ew+Ef+Ei)	2.894	2.690	2.980	2.965	2.810	2.874	2.907	2.718	2.830	3.281
Specific electricity produced (Ep) as weighted averages	MWh el abs. /Mg total	0.431	0.581	0.000	0.444	0.341	0.426	0.454	0.570	0.419	0.362
	% of Mg total	*14.89*	*21.6*	*0.0*	*15.0*	*12.1*	*14.8*	*15.6*	*21.0*	*14.8*	*11.0*
Specific heat produced (Ep) as weighted averages	MWh th abs. /Mg total	1.001	0.122	2.301	1.101	0.951	0.921	1.061	0.328	0.800	2.381
	% of Mg total	*34.59*	*4.5*	*77.2*	*37.1*	*33.8*	*32.1*	*36.5*	*12.1*	*28.3*	*72.6*
total specific thermal recovery rate as heat + electricity (Ep) as weighted averages	MWh th+el abs. /Mg total	1.432	0.703	2.301	1.545	1.292	1.347	1.515	0.898	1.219	2.743
	% of Mg total	*49.48*	*26.1*	*77.2*	*52.1*	*46.0*	*46.9*	*52.1*	*33.0*	*43.1*	*83.6*

The results of the total 314 plants investigated without classification reach a rate of electricity production of 14.9% (in Report II 14.4%) and of heat production of 34.59% as weighted averages.

This reflects a total used energy recovery rate of 49.5%, whereas the total recovery rate for all investigated plants can only be used as general information.

In order to have precise results an additional evaluation of the WtE plants according to the type of energy recovery as electricity, heat or CHP is necessary. This is listed in Table 2 and ANNEX A.

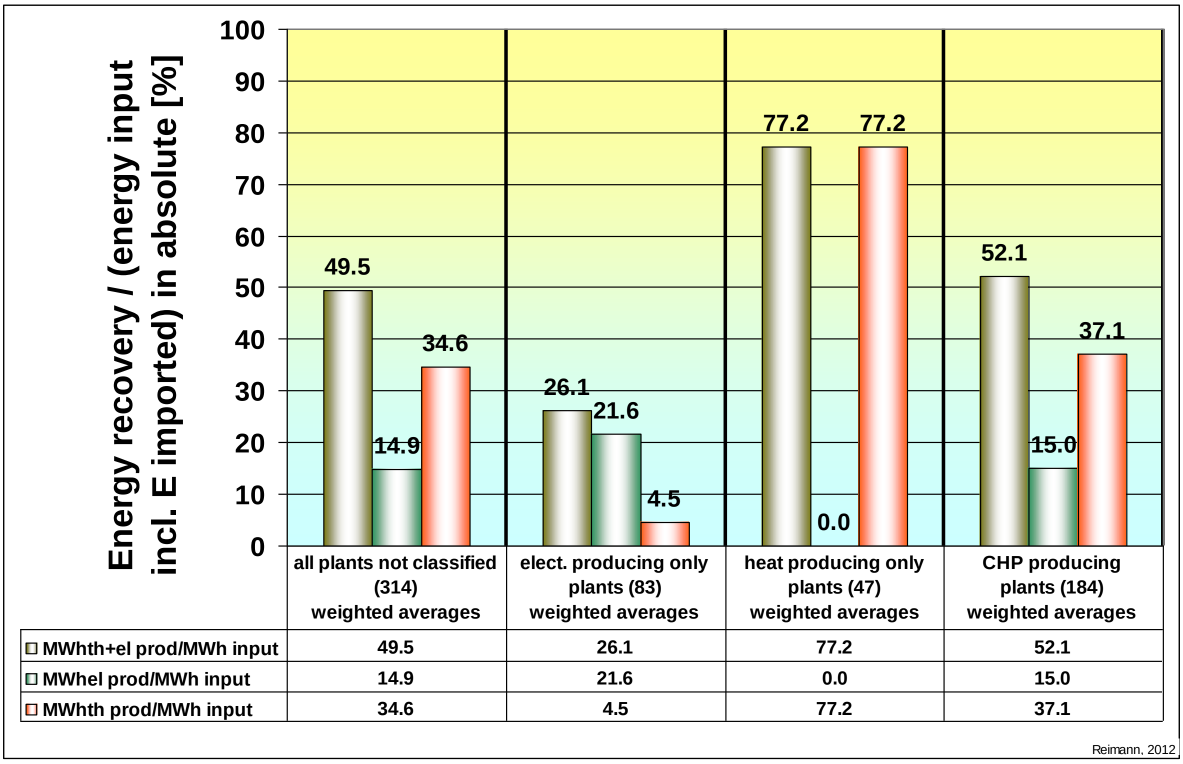


Figure 7: Energy recovery rates in percentages of total energy input for all plants, divided into electricity, heat and CHP production as weighted averages (Status 2007-2010)

The energy recovery rates given in Figure 7 for all plants and classified by their type of energy recovery as producing electricity only, heat only and CHP are indicated as percentages of the total energy input from MSW, including imported energy and based on the results listed in Table 2.

In Table 2 the resulting recovery rates are shown as percentages, which reflect the possibility of general use, but also as specific figures in absolute, which are related to the data presented in this Report.

The energy produced in percentages of the total energy input from MSW including imported energy can be specified for the different types of energy recovery with weighted averages as follows:

Type of energy recovery
WtE plants "producing electricity only" achieve the highest rate of electricity production, 21.6% (Energy Report II: 20.7%), but have the lowest rate of heat recovery, 4.5%, which is the heat self used to treat the MSW.
The total used energy recovery rate is 26.1% abs.

WtE plants "producing heat only" have the highest rate of heat production, 77.2%, but no electricity production and therefore must import the total demand of electricity to treat the MSW.

The very high efficiency of WtE plants producing only heat is plausible, because most often roughly all the steam produced in these plants is used and therefore the used energy efficiency can increase up to the boiler efficiency of a WtE plant. Furthermore these high results are mostly reached by WtE plants in Northern Europe using condensing energy from steam mostly all year long.
The total used energy recovery rate is very high and reached 77.2% abs.

WtE plants "CHP producing" have an energy recovery rate of electricity of 15.0% and of heat of 37.1%.
The total used energy recovery rate is 52.1% abs.

Size (throughput) of a plant
Small sized WtE plants < 100,000 Mg/a have the lowest rate of electricity production, 12.1%, and a rate of heat recovery of 33.8%.
The total used energy recovery rate is 46.0% abs.

Medium sized WtE plants 100,000-250,000 Mg/a have a higher rate of electricity production, 14.8%, but a slightly lower rate of heat recovery than small sized plants, 32.1%.
The total used energy recovery rate is 46.9% abs.

Large sized WtE plants > 250,000 Mg/a have the highest rate of electricity production, 15.6%, but also the highest rate of heat recovery, 36.5%.
The total used energy recovery rate is 52.1% abs.

Location of a plant in an European geographical region
Plants in South-Western Europe achieve the highest rate of electricity production, 21.0%, but the lowest rate of heat recovery with 12.1%.
The total used energy recovery rate is 33.0% abs.

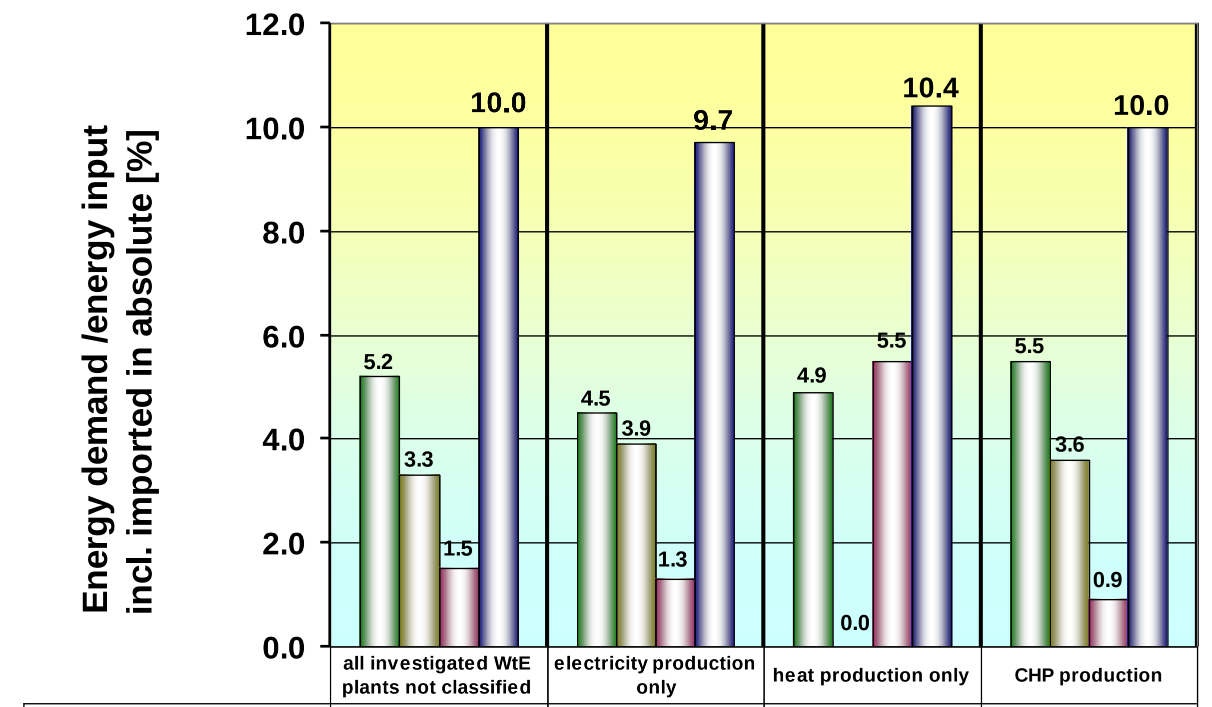
WtE plants in Central Europe have a lower rate of electricity production, 14.8%, but a better rate of heat recovery, 28.3%.
The total used energy recovery rate is 43.1% abs.

Plants in Northern Europe have an electricity production rate of 11.0%, which is similar to the rate of small sized plants, but the best result for heat recovery with 72.6 %. This is due to optimal climate conditions (>> 3350 HDDs (Heating Degree Days)).
The total used energy recovery rate is 83.6% abs.

A comparison between the results of produced and self used heat in this Report with the results from Energy Report II is not possible for heat. The reason is that in the Energy Report II self used heat was counted more generously according to the R1 Guidelines draft available at that time, e.g. for the internal heating-up of boiler water and combustion air (also see remarks in the "Executive Summary").

Further details about exported and self used electricity and heat as weighted averages, min and max values in absolute and in percentages can be found in ANNEX A.

6.2 Energy self used and imported as heat and electricity (Ep, Ef + Ei) for all WtE plants investigated according to the types of energy recovery (Status 2007-2010)



	all investigated WtE plants not classified	electricity production only	heat production only	CHP production
MWh th Ep/MWh input	5.2	4.5	4.9	5.5
MWh el Ep/MWh input	3.3	3.9	0.0	3.6
MWh (Ef+Ei(th+el)/MWh input	1.5	1.3	5.5	0.9
MWh (Ep+Ef+Eiall)/MWh input	10.0	9.7	10.4	10.0

Reimann 2012

Figure 8: Comparison of energy demand as self used and imported energy in percentages of total energy input of all investigated and classified types of WtE plants

The total energy demand, including imported energy, in order to run an appropriate incineration process in a WtE plant, is in the range of 9.7-10.4% and specified for plants with “electricity production only” 9.7%, 10.4% for plants with “heat production only”and 10.0% for plants with “CHP production” as well as for “all plants” related to the total energy input by MSW including imported energy as weighted averages.

Most of the total energy demand is covered by self used heat in the range of 4.5-5.5% and by self used electricity of 3.6-3.9% as weighted averages.

In ANNEX B, besides the total energy demand in percentage the results are also listed in detail as absolute (abs) figures based on the data used in this Report.

Furthermore ANNEX B includes as a second version besides the general basic demand for imported energy also the additional demand of imported energy needed in case of “heat production only”.

The specific mean self used heat demand of the investigated WtE plants, related to the type of energy recovery (ANNEX A) is in the range of 0.122 - 0.163 and a mean value of 0.152 MWh th/Mg MSW as weighted averages.

The individual specific self demand for heat shows a wide range between min *0.014 (not plausible)* and max 0.389 MWh th/Mg MSW depending on the type of equipment used, as well as the temperature flow in the flue gas cleaning system (ANNEX A).

The calculations in particular for the self used heat of the plants are based on the general formula, but also on assumptions (average approach, ratios) and not on specific measurements in the particular plants. Therefore the results in this Report do not replace individual calculations made by the operators when applying for R1 certification.

A specific mean self demand for electricity, range between 0 and 0.105-0.106 MWh el/Mg MSW with a mean value of up to 0.095 MWh el/Mg MSW, as weighted averages. For WtE plants "heat producing only" the total electricity demand has to be imported (ANNEX B) so in this case self used electricity is zero. This is the reason why the weighted average of all plants is lower than the results of the range mentioned above.

The individual specific self demand for electricity shows a very wide range between min 0 (plants "heat producing only") and max 0.286 MWh el/Mg MSW depending on the use of electricity for different purposes, e.g. for electrical driven aggregates, heating or cooling of installations, buildings, silos, heating of combustion air etc. (ANNEX A).

These results, in absolute or as percentages, can be used as approaches to evaluate and optimize the individual heat and electricity self demand of a WtE plant.

Details concerning imported energy are explained in the following chapter.

6.3 Energy imported as heat (by fuels) and electricity for all WtE plants investigated and the types of energy recovery (Ef and Ei), (Status 2007-2010)

The total energy input into a WtE plant includes the energy from the waste (Ew), and generally the small amount of additional energy such as electricity and/or (primary) fuels (Ef and Ei(th+el)), which are imported in order to run an appropriate incineration process in accordance with the regulations and sometimes to increase the energy input or the calorific value by mixing MSW with a fuel to make it more combustible.

Because the R1 formula [3] takes the imported energy into consideration, it is necessary to make a distinction between Ef and Ei (further details in ANNEX C of the Report).

The imported energy with steam production (or hot water) is Ef, whereas the imported energy without steam production is Ei.

Examples of imported energy with steam production (Ef) are the fuel used for start-up after connection with the steam grid, fuel for keeping the incineration temperature > 850 °C by using auxiliary burners or fuels for increasing the energy input (by addition of coal, unpolluted wood etc.).

Examples of imported energy without steam production (Ei) are imported electricity, fuel for re-heating flue gases after wet scrubber or before a SCR process or fuel for start-up situations during the first phase before steam is produced and connected to the grid.

The imported energy (Ef, Ei(th) and Ei(el)) is mostly based on measured data, and if data was not available, on theoretical and practical assessments of consumption e.g. from delivery invoices.

The weighted average of the imported energy demand is presented in ANNEX C.

A distinction is necessary between WtE plants "heat producing only", "electricity producing only" and "CHP producing". If only heat is produced the total electricity demand has to be imported, which is as weighted average 0.094 MWh el/Mg MSW, and thus about 15 times higher than for plants "electricity producing only" or "CHP producing".

The total additional imported energy demand of all investigated plants is as weighted average 0.031 MWh th+el/Mg MSW as (Ef + Ei th+el) absolute and is listed in detail in ANNEX C. This represents about 1.1% of the total energy input from MSW plus imported (2.894 MWh/Mg MSW), whereas 0.9% are related to heat (Ef + Ei th) and 0.2% to electricity (Ei el).

The demand for imported energy Ei(th) is significantly reduced in WtE plants that use self produced heat (e.g. steam) instead of primary fuel e.g. for re-heating flue gases before the SCR process.

Specific data concerning the energy demand for imported energy as Ef and Ei depending on type of energy recovery, size and European geographical region are summarized in ANNEX C.
The results are mentioned as percentages and in absolute figures.

The specific basic demand for imported energy **as heat** (Ef plus Ei th) is in all categories at a similarly low level between 0.7-1.1% and is as mean value 0.9% of the energy input from MSW plus the imported energy, or in absolute figures 0.020-0.029 and is as mean value 0.025 MWh th/Mg MSW. In case of "heat producing only" the imported heat demand is higher because the basic demand is increased from 0.029 to 0.040 MWh th/Mg MSW as average related e.g. to guarentees by heat delivery contracts.

Ef is in the range of 36-48% and as weighted average of all investigated plants 44% from this total imported basic heat of all investigated plants or 0.011 MWh th/Mg MSW in absolute. The remainig part is **Ei** with 56% of the total imported basic heat or 0.014 MWh th/Mg MSW in absolute.

This result corresponds to the general approach as mentioned in the R1 Guidelines [6], using 50% of the imported basic heat demand as Ef and 50% as Ei.

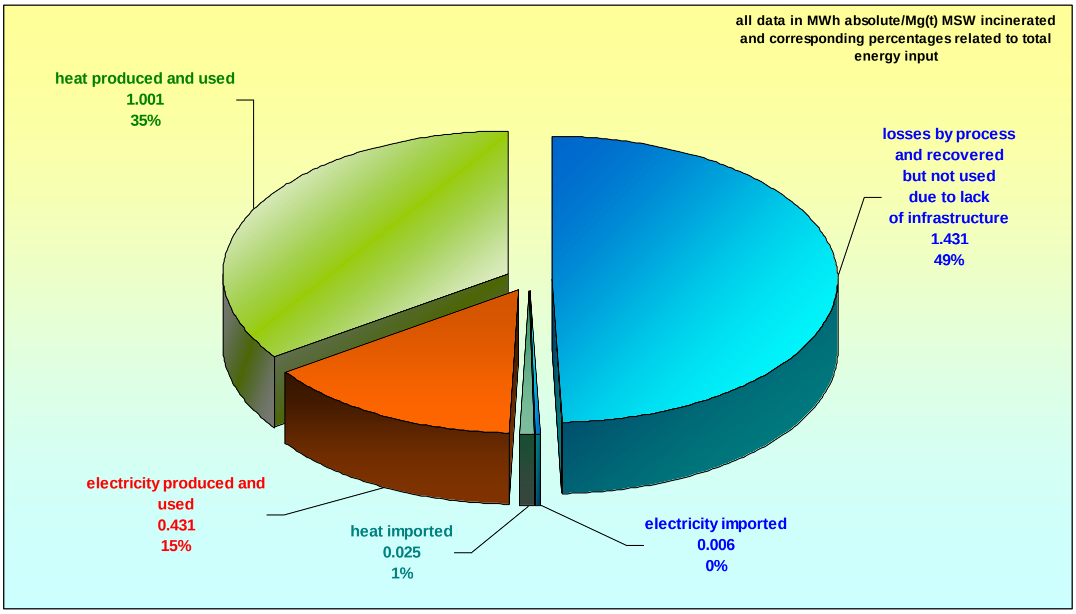
The specific basic demand for imported energy **as electricity** (Ei) is in all categories, except in the case of WtE plants "producing heat only", at a level between 0.17-0.27% and as mean value 0.25% of the energy input from MSW plus imported energy, or in absolute figures 0.001-0.009 and as mean value 0.006 MWh el/Mg MSW.

In the case of WtE plants "producing heat only" the import of heat and electricity to treat the MSW is 5.5% with about 3.2% for electricity and 2.3% for heat.

All results are listed in detail in ANNEX B and C.

6.4 Summary of energy produced and used, imported as heat (by fuels) and as electricity (Ef and Ei) for all WtE plants investigated (Status 2007-2010)

In Figure 9 the results of Chapter 6 have been summarized to present an overview of the energy recovery rates in percentage of the energy input from MSW plus the imported energy, and in absolute figures.



WtE plants	314 CEWEP plants	period of energy balance	2007-2010
total amount of waste incinerated	59.44 mio Mg MSW	total recovery efficiency in absolute in % of total energy input	49.5
NCV by BREF formula for the total waste	2.863 MWh/Mg	total recovery efficiency in equivalent in % of total energy input	76.8
Total energy input (including imported energy)	2.894 MWh abs/Mg	R1 factor in accordance to WFD and EU R1 Guideline [-]	0.69
		heat produced (exported and self used) equ = 1.1	

Figure 9: Pie chart of the total energy input from MSW and imported energy in MWh abs/Mg MSW in absolute and in percentages subdivided into the production and import of heat and electricity as well as remaining energy from the WtE plants investigated (Status 2007-2010)

The pie chart shows that the segment "losses by process and recovered but not used due to lack of infrastructure" is important. By decreasing this value higher recovery rates can be achieved. However, this can generally not be influenced by the operator of a plant.

7. Total annual energy production and demand

The total annual energy production and demand for imported energy in absolute figures for the 314 investigated plants, as shown in Table 3, is based on the specific weighted averages mentioned in Table 2 of this Report. The total amount of MSW incinerated in Europe (Chapter 3) is taken into account.

Table 3: Total energy recovery potential from MSW related to the investigated (Status 2007-2010) and total amounts of incinerated MSW (Status 2009) in EU 27 and EU 27 + CH + NO in absolute figures

type of energy	investigated amount of MSW incinerated in 285 plants, related to EU 27	investigated amount of MSW incinerated in 314 plants, related to EU 27+CH+NO	total amount of MSW incinerated in 2009 related to EU 27 (extrapolated)	total amount of MSW incinerated in 2009 related to EU 27+CH+NO (extrapolated)
	55.71 mio Mg MSW/(2007-10)	*59.44 mio Mg MSW/(2007-10)*	*64.93 mio Mg MSW / 2009*	*69.53 mio Mg MSW / 2009*
	MWh abs/a	MWh abs/a	MWh abs/a	MWh abs/a
heat produced gross	55,783,760	59,518,699	65,015,967	69,622,058
electricity produced gross	24,022,486	25,630,885	27,998,206	29,981,753
heat imported	1,371,680	1,463,520	1,598,693	1,711,954
electricity imported	334,945	357,371	390,379	418,035
heat produced net	54,412,080	58,055,179	63,417,274	67,910,104
electricity produced net	23,687,541	25,273,514	27,607,827	29,563,718

Assuming that the specific energy efficiencies of the plants which did not provide data is similar to the average values of the investigated plants, the energy results of the 285 WtE plants investigated (Status 2007-2010) in EU 27 in this Report have been extrapolated by adding the amount of waste processed by all WtE plants in the EU 27 (Status 2009).

The result is that:

- about 63 TWh th net/a are produced and used as heat

and at the same time

- about 27.5 TWh el net/a are produced as electricity

The results of the 314 WtE plants investigated (Status 2007-2010) in this Report have similarly been extrapolated, but related to the total waste incinerated in the European WtE plants from EU 27 + CH + NO (Status 2009). It shows that

- about 68 TWh th net/a is produced and used as heat

and at the same time

- about 29.5 TWh el net/a is produced as electricity

The ratio between produced (used) heat net to produced electricity net is 2.3 to 1. This correlation depends on many factors e.g. technology used in the WtE plant, market, region, political requirements, number of plants participating in this Report etc.

8. R1 recovery efficiency factor according to the Waste Frame Directive (WFD)

The R1 efficiency factor is a non-dimensional figure, based on the 1st law of thermodynamics (energy input = energy output) combined with political objectives (minimizing demand for primary fuels).

To avoid any ambiguity in the interpretation of the efficiencies in this Report, only the formula indicated in the WFD to determine the R1 Status (recovery operation) is used. The R1 recovery efficiency formula is always calculated with the equivalence factors included in Annex II of the WFD.The energy data result from Chapter 6 and 7, ANNEX A , B (not including data for "all investigated WtE plants") and C.

In the WFD the R1 threshold value for a WtE plant to be classified as a recovery operation is:

- **0.60** for installations in operation and permitted before 1 January 2009,
- **0.65** for installations permitted after 31 December 2008

The R1 formula to calculate the 'efficiency'factor is:

- **(Ep-(Ef+Ei))/(0,97*(Ew+Ef))**

where Ep is the energy produced (produced and used electricity and heat including electricity and heat self used to treat the MSW) with an equivalence factor of 2.6 for electricity and of 1.1 for heat.

According to WFD [3] and EU R1 Guidelines [6] the equivalence factors for Ef and Ei as primary fuels are 1.0, for Ei as heat or hot water/steam 1.1 and as electricity 2.6.

Unlike the R1 results in the Energy Report II, based on the parameter "self used heat", the results between the Reports I and this Report are comparable.

In the Energy Report II the individual, and also the mean values of R1 for the WtE plants investigated were higher compared to the current Report, because for the period 2004-2007 (Report II) the self used heat included more generously the energy for heating up circulated boiler water and for combustion air as indicated in the version of the R1 Guidelines [6] available at that time.

In this Report (Status 2007-2010) the number of investigated plants compared to the CEWEP Energy Report II has increased from 231 to 314 WtE plants.

The R1 factors in Diagram 2 include individual R1 values for 314 European WtE plants with their non-weighted average: 71 plants from Northern Europe, 188 plants from Central Europe and 55 plants from South-Western Europe (Status 2007-2010).

The R1 factors have been determined using the NCV results from Chapter 5.

8.1 R1 results of all plants as individual and non-weighted averages

Diagram 2: R1 factor calculated as individual R1 values as non-weighted average for 314 European WtE plants: 71 from Northern Europe, 188 from Central Europe and 55 from South-Western Europe (Status 2007-2010)

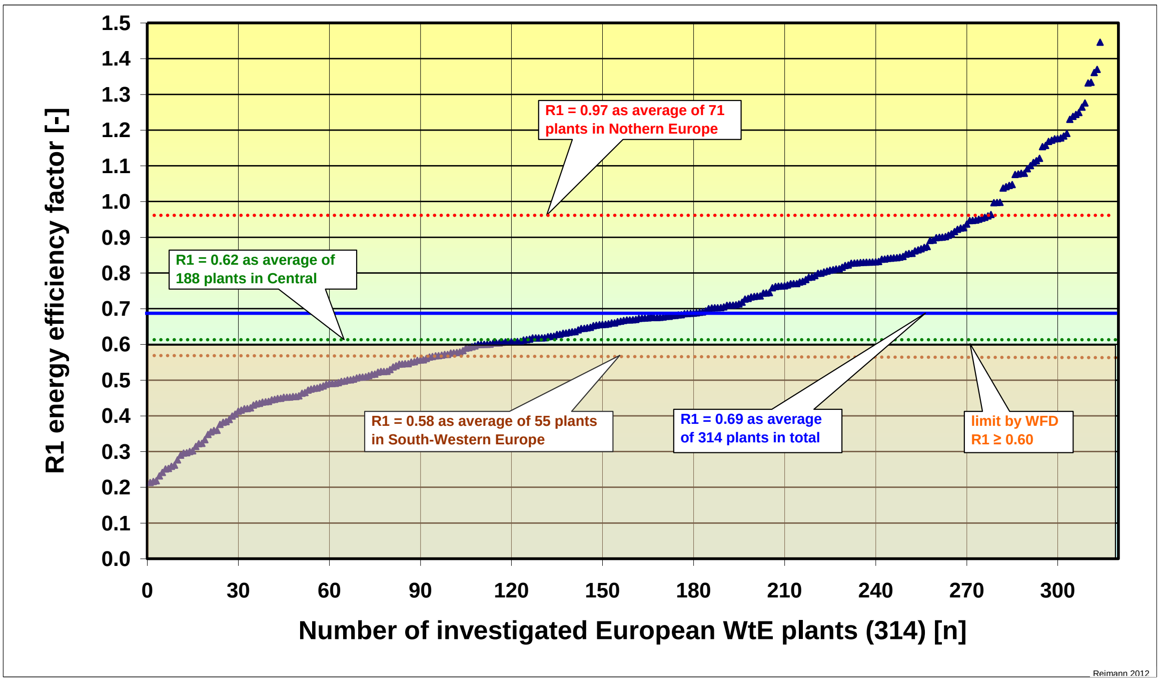


Table 4: R1 factors for all 314 WtE plants and classified as min, max values and non-weighted averages as well as number of plants reaching/not reaching R1 ≥ 0.60 (Status 2007-2010)

R1 depending on different classifications	unit	all investi-gated WtE plants	type of energy recovery of a plant (weighted averages)			size (throughput) of a plant (weighted averages)			geographical European region of a plant (weighted averages)		
			electricity production only	heat production only	CHP production	< 100,000 Mg MSW/a	100,000 to 250,000 Mg MSW/a	> 250,000 Mg MSW/a	South-Western Europe	Central Europe	Northern Europe
number of plants included	n	314	83	47	184	118	124	72	55	188	71
total throughput of plants	mio Mg/a	59.44	12.98	5.67	40.78	7.06	19.80	32.57	8.73	40.52	10.19
R1 result (averages)	[-]	0.69	0.55	0.64	0.76	0.63	0.70	0.77	0.58	0.62	0.97
R1 result (min-max)	[-]	0.21-1.45	0.22-0.85	0.21-1.08	0.23-1.45	0.21-1.45	0.22-1.37	0.36-1.33	0.21-1.04	0.22-1.17	0.50-1.45
number of plants: R1 at least 0.60	n *(%)*	206 *(65.6)*	31 *(37.3)*	32 *(68.1)*	142 *(77.2)*	59 *(50.0)*	85 *(68.5)*	62 *(86.1)*	27 *(49.1)*	110 *(58.5)*	69 *(97.2)*
number of plants: R1 under 0.60	n *(%)*	108 *(34.4)*	52 *(62.7)*	15 *(31.9)*	42 *(22.8)*	59 *(50.0)*	39 *(31.5)*	10 *(13.9)*	28 *(50.9)*	78 *(41.5)*	2 *(2.8)*

8.2 R1 factor as non-weighted averages for the 314 WtE plants and divided into the categories: type of energy recovery, sizes (throughput) and European geographical region (Status 2007-2010)

Max R1 results >1, which are found in this Report, are generally connected to NCV >13 GJ/Mg MSW combined with the possibility of very high recovery rates by use of condensing energy as heat during the whole year. These results are therefore neither representative nor comparable with the R1 results of typical WtE plants treating MSW with a weighted mean NCV of about 10.3 GJ/Mg MSW. R1 results > 1 are therefore only for information and should not be used for qualification purposes.

For the total of 314 investigated European WtE plants without classification (Table 4 and Figure 10) the R1 factor (calculated with the equivalence factors as mentioned above) is:

0.69 (min 0.21 - max 1.45) as non-weighted average and therefore ≥ 0.60.
206 plants (65.6%) out of the total 314 investigated European WtE plants reach ≥ 0.60.

The tendency of the results in Diagram 2 for R1 is similar to the results of Diagram 1 because plants reaching high R1 factors may prioritise waste with higher NCV in order to require less fuel.

In respect to the influencing parameters, the results of the investigation clearly show strong correlations between the values of R1 and the type of energy recovery, the size of the plant and the European geographical region.

The R1 results for the 3 investigated categories as non-weighted averages can be summarized as follows:

Type of energy recovery:
WtE plants “producing electricity only” have the lowest R1 factor of 0.55, as a non-weighted average, so that only 31 (37.3%) out of 83 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.22-0.85.

Although WtE plants “producing heat only” have a higher R1 factor of 0.64, as a non-weighted average, only 32 (68.1%) out of 47 plants reach R1 ≥ 0.60. In this case, the import of the total amount of electricity to treat the waste has a negative influence. The range of R1 between min and max is 0.21-1.08.
WtE plants “CHP producing” achieve the highest R1 factor of 0.76, as a non-weighted average, so that 142 (77.2%) out of 184 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.23-1.45.

Size (throughput) of the plant:
Small sized WtE plants (< 100,000 Mg/a) have the lowest R1 factor of 0.63, as a non-weighted average, so that only 59 (50.0%) out of 118 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.21-1.45.

Medium sized WtE plants (100,000 – 250,000 Mg/a) have a higher R1 factor of 0.70, as a non-weighted average, so that 85 (68.5%) out of 124 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.22-1.37.

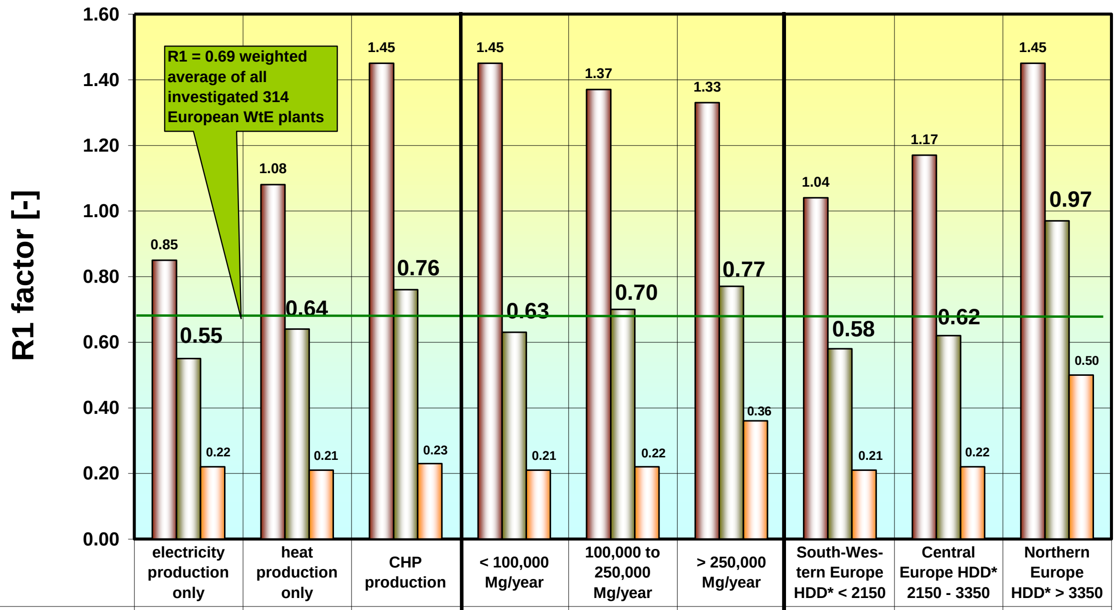
Large sized WtE plants (> 250,000 Mg/a) achieve the highest R1 factor of 0.77 as a non-weighted average so that 62 (86.1%) out of 72 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.36-1.33.

Plant location (in European geographical regions):
Plants in South-Western Europe have the lowest R1 factor of 0.58, as a non-weighted average, so that only 27 (49.1%) out of 55 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.21-1.04.

Plants in Central Europe have a higher R1 factor of 0.62, as a non-weighted average, so that 110 (58.5%) out of 188 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.22-1.17.

Plants in Northern Europe have the highest R1 factor of 0.97, as non-weighted average, so that 69 (97.2%) out of 71 plants reach R1 ≥ 0.60. The range of R1 between min and max is 0.50-1.47.

The results found in this Report are in correlation to the data in the BREF Waste Incineration [7].



	electricity production only	heat production only	CHP production	< 100,000 Mg/year	100,000 to 250,000 Mg/year	> 250,000 Mg/year	South-Wes-tern Europe HDD* < 2150	Central Europe HDD* 2150 - 3350	Northern Europe HDD* > 3350
R1 max [-]	0.85	1.08	1.45	1.45	1.37	1.33	1.04	1.17	1.45
R1 weight. average [-]	0.55	0.64	0.76	0.63	0.70	0.77	0.58	0.62	0.97
R1 min [-]	0.22	0.21	0.23	0.21	0.22	0.36	0.21	0.22	0.50

* HDD = Hearing Degree Day

Figure 10: Comparison of R1 results of 314 WtE plants investigated divided into type of energy recovery, size (throughput) and the European region as min and max values and non-weighted averages (mean values) (Status 2007-2010)

As shown in Figure 10 and Table 4, for small sized plants (R1 = 0.63 on average), producing electricity only (R1 = 0.55 on average) and located in South-Western Europe (R1 = 0.58 on average) it is difficult to reach R1 ≥ 0.60.

Medium sized plants (R1 = 0.70 on average) in Central Europe (R1 = 0.62), which are producing heat only (R1 = 0.64 on average) or CHP (R1 = 0.76 on average), have a better basis to reach R1 ≥ 0.60..

The highest R1 factors >> 0.60 are achievable in large sized plants (R1 = 0.77 on average) in Northern Europe (R1 = 0.97 on average) producing CHP with R1 averages of R1 = 0.76, whereas many of these Northern plants are using condensing energy over the whole year.

The results can be summarized, based on the mean R1 results, as follows:

- **Very low results in general with R1 < 0.60 are found in small sized plants (throughput < 100,000Mg/a), located in South-Western Europe producing electricity only;**

  For plants producing electricity only it is very difficult to meet R1 as only 37.3% meet R1 ≥ 0.60;
- **The highest R1 results are related to large sized plants (throughput >250,000Mg/a), located in Northern Europe with CHP production;**
- **In the Energy Report II, 52% of all investigated WtE plants met R1 ≥ 0.60, whereas in this Report, although the assessment criteria are more stringent according to the final version of the R1 Guidelines, 65.6% of the WtE plants now meet R1 ≥ 0.60 primarily due to the optimization carried out by the plants that participated in the Energy Report II.**

The amount of MSW being recovered in the 206 investigated European WtE plants reaching R1 ≥ 0.60 is 46.39 mio Mg MSW/a equivalent to 78.1% of the corresponding 59.4 mio Mg MSW investigated from this Report.

In conclusion, the results of this investigation clearly show strong correlations between the R1values and the type of energy recovery, the size of the plant and the geographical region, respectively.

9. CO_2-reduction potential of waste incineration with energy recovery

Greenhouse gases are responsible for the global temperature increase with all its negative consequences.

Because today MSW incineration plants are generally recovering by generating high amounts of energy as electricity or heat, these energy resources no longer need to be provided by dedicated plants using primary fuels for energy production of electricity or heat. By using energy recovered by WtE plants the consumption of these primary fuels with a release of 100 % fossil CO_2 eq emissions can be substituted.

The renewable carbon content in MSW expressed by biogenic CO_2 emissions is in this Report in the range of 50-70%, on average 63% related to references [10, 11].

The CO_2 production by the combustion of biogenic carbon is considered by the IPCC (Intergouvernmental Panel on Climate Change) as CO_2 neutral, and therefore without any negative influence on the climate.

As a consequence, only 37% of the total CO_2 emission of about 0.9 Mg CO_2 /Mg MSW, equivalent to 0.334 Mg CO_2 /Mg MSW (≈ 0.033 Mg CO_2 /GJ in MSW), is of fossil origin.

Also the use of imported fuels such as light oil (0.266 Mg CO_2 /MWh th) and natural gas (0.202 Mg CO_2 /MWh th) have a negative influence on the CO_2 balance.

On the other hand the substitution, and in case of imported electricity pollution potential for electricity based on the EU 27 energy mix including nuclear power (published by IEA for 2009 [12]) is about 0.540 Mg CO_2 /MWh el and for heat about 0.232 Mg CO_2 /MWh th.

If the European energy mix for electricity and/or heat does not match with the data from the IEA for EU 27, the energy mix of the individual European country has to be taken into account as well as the type of primary fuel that might be replaced (e.g. nuclear power or coal).

Furthermore by material recovery from incinerated MSW 0.053 Mg CO_2 /Mg MSW can be substituted [10].

Further details are shown in Table 5.

Table 5: CO_2 substitution potential through energy recovery from WtE plants related to the investigated (Status 2007-2010) and total amounts of incinerated MSW in EU 27 and EU 27 + CH + NO (Status 2009)

CO_2 balance related to recovered energy as electricity, heat and material and incinerated MSW and imported energy	pollution/savings based on Europian energy mix	investigated amount of MSW incinerated in 285 plants, related to EU 27	investigated amount of MSW incinerated in 314 plants, related to EU 27+CH+NO	total amount of MSW incinerated in 2009 related to EU 27 (extrapolated)	total amount of MSW incinerated in 2009 related to EU 27+CH+NO (extrapolated)
		55.71 mio Mg MSW/(2007- 10)	*59.44 mio Mg MSW/(2007- 10)*	*64.93 mio Mg MSW / 2009*	*69.53 mio Mg MSW / 2009*
		Mg CO_2 /a	Mg CO_2 /a	Mg CO_2 /a	Mg CO_2 /a
heat produced	savings: 0.232 Mg CO_2 /MWh th	12,941,832	13,808,338	15,083,704	16,152,317
electricity produced	savings: 0.540 Mg CO_2 /MWh el	12,972,143	13,840,678	15,119,031	16,190,147
material recovery	savings: 0.053 Mg CO_2 /Mg MSW	2,952,630	3,150,320	3,441,290	3,685,090
MSW incinerated	pollution: 0.334 Mg CO_2 /Mg MSW (36% fossil fraction)	18,607,140	19,852,960	21,686,620	23,223,020
heat imported	pollution: 0.232 Mg CO_2 /MWh th (0.266 oil; 0.202 nat.gas)	318,230	339,537	370,897	397,173
electricity imported	pollution: 0.540 Mg CO_2 /MWh el	180,870	192,980	210,804	225,739
Σ net for total Europe	savings of Mg CO_2 /a	9,760,365	10,413,859	11,375,704	12,181,622

On the basis of the assumptions mentioned above and taking into account the corresponding total amounts of waste incinerated in 2009, the European wide net CO_2 substitution potential by MSW WtE plants for EU 27 is about 11 mio Mg CO_2/a, for the EU 27 + CH + NO about 12 mio Mg CO_2/a.

As said above, this CO_2 balance only includes the benefits for producing energy through incineration of MSW and recycling of materials from combustion residues.

The CO_2 eq savings related to CO_2 eq emissions avoided by diverting MSW from landfill are not included in this balance. Indeed, the methane gas (CH_4), which is released by MSW in landfills, has, in mass, a Global Warming Potential (GWP) of 25 times that of CO_2.

These CO_2 emission savings make WtE plants net reducers of CO_2. The amount of avoided CO_2 depends on the kind and quantity of energy produced from MSW by the plant and of the type and landfill avoided.

10. Optimisation possibilities to increase energy utilisation and efficiency

The first condition for optimisation is to have reliable measurements, in particular on steam and other energy relevant flows, and to have a thorough evaluation of the uncertainty of the data.

10.1 Optimisation according to the type of energy recovery

For existing and new plants the following 4 issues have been identified as having an influence on energy production and its utilisation. Additional investment or operation costs must be taken into account. Optimization of existing installations, when possible, usually requires extremely high expenditure.

- Increasing heat utilisation: steam, district heating or district cooling (medium to very high investment); by far the most effective means. However this is not possible everywhere as it depends on the presence of customers for heat in area the surrounding the plant, and the length of the heat (cooling) demand period (climate zone) and the local energy market conditions (prices).
- Increasing electricity production (medium to high investment; possible increase in maintenance costs). This is not possible for every plant (e.g. often no optimal equipment available for small plants/units).
- Optimisation of the thermal process (low to medium investment); low to medium effect.
- Optimisation of the plant consumption in recovered and primary energy (low to medium investment); low to medium effect as many existing plants have already been refurbished in this respect when brought intocompliance with the Waste Incineration Directive.

From the outset of new installations or rebuilding, the energy demand for maximum operational efficiency and high efficient flue gas cleaning systems, with low energy demand, should be taken into account. In this case later optimisation measures and extra costs can be minimised.

The type of the energy recovery of an existing and new or rebuilt plant is an important parameter for R1, and may sometimes be influenced by the operator of a plant.

10.2 Optimisation according to the size of a plant

An optimisation of the size of a plant is in general only an option for new installations or rebuilding, because this depends e.g. on the density and concentration of the population in a region, distances and type of transport, amount and quality (type and NCV) of waste, which will be delivered to the plant, separate collection and pre-treatment systems, the capacity of existing plants located nearby and their available (free) capacities, market prices for waste to be treated and for recovered energies, the acceptance by the people, the permit of the local authorities, etc.

The size of an existing plant, an important parameter for R1, cannot be influenced by the operator. This is only an option for the planning of new installations or rebuilding of plants. It is usually more difficult for small size plants than for medium and large sized plants to reach R1 ≥ 0.60 or for new ones ≥ 0.65.

10.3 Optimisation according to the location of a plant in a European geographical region

The location of a plant in a European geographical region (climate zone), the most important parameter for R1, can neither be influenced by the operator nor by the designer of new installations or rebuilding of plants.

Therefore WtE plants in South-Western Europe are at a disadvantage in comparison to WtE plants in Northern Europe and even, but to a lesser extent, to WtE plants in Central Europe in order to reach R1 ≥ 0.60 or, even worse, for new ones ≥ 0.65.

Final remarks

I would like to thank all members of the CEWEP Energy Working Group and especially the CEWEP team in Brussels for their constructive assistance, and primarily the national WtE associations and all individual operators of WtE plants for the data delivered. Only with their constructive help it was possible that this CEWEP Energy Report (Status 2007 – 2010) could be realised.

References

[1] EU Landfill Directive (1999/31/EC)

[2] Council Decision on Waste Acceptance Criteria (2003/33/EC)

[3] Directive 2008/98/EC of the European Parliament and of the Council "on waste and repealing certain Directives" Annex II, 19 November (2008)

[4] Confederation of European Waste to Energy Plants (CEWEP) "CEWEP Energy Report I (Status 2001-2004)" see http://www.cewep.eu/studies/climate-protection/art230,223.html, by D. O. Reimann, Bamberg, Germany, October 2005/ updated July (2006)

[5] Confederation of European Waste to Energy Plants (CEWEP) "CEWEP Energy Report II (Status 2004-2007)" see http://www.cewep.eu/studies/climate-protection/art230,223.html, by D. O. Reimann, Bamberg, Germany, October 2005/ updated July (2006)

[6] "Guidelines on the Interpretation of the R1 Energy Efficiency Formula for Incineration Facilities dedicated to the Processing of Directives" Annex II, 19 November (2008) Municipal Solid Waste according to Annex II of Directive 2008/98/EC on Waste by the EUROPEAN COMMISSION, June (2011)

[7] BREF/BAT Waste Incineration (WI) for Integrated Pollution Prevention and Control (IPPC), "Reference Document on the Best Available Techniques for Waste Incineration", EUROPEAN COMMISSION, EIPPC Bureau Sevilla, August (2006), http://eippcb.jrc.es/pages/FActivities.htm

[8] of [7] BREF WI (above) - formula for NCV determination : Chapter 2, article 2.4.2, pg. 83-84

[9] FDBR "Acceptance Testing of Waste Incineration Plants with Grate Firing System" Guidelines Edition 04 (2000)

[10] Manders, J. "Life cycle Assessment of the treatment of MSW in 'average' European Waste-to-Energy plants", presentation in Malmö (SE), November (2009)

[11] Reimann, D.O. "Positive impact on climate relevant green house gases by energy recovery from MSW incineration" presentation in Brno (CZ), December (2011)

[12] International Energy Agency (IEA) "Electricity/heat in European Union in 2009", www.iea/stats/electricity (heat) data.asp (2009)

ANNEX A

Specific production of electricity and heat as sum out of exported plus self used recovered energy as min and max values as well as weighted averages in absolute MWh abs /Mg MSW and as percentages (%) of the total energy input from MSW plus imported energy for all 314 WtE plants and divided according to the type of energy recovery in this Report (Status 2007-2010)

specific heat and electricity produced and used depending on different classifications	unit	all investigated WtE plants	type of energy recovery of a plant		
			electricity production only	heat production only	CHP production
number of plants included	n	314	83	47	184
total throughput of plants	mio Mg/a	59.44	12.98	5.67	40.78
Total specific energy input (incl. import) as weighted averages	MWh input total abs. / Mg MSW	2.894	2.690	2.980	2.965
Specific electricity exported (Ep) as weighted averages	MWhel abs. /Mg MSW	0.336	0.476	0.000	0.338
	min / max MWhel abs. /Mg MSW	*0.0 - 0.899*	*0.075 - 0.873*	*0.0*	*0.007 - 0.899*
	% of MWhth input	*11.61*	*17.70*	*0.00*	*11.40*
Specific electricity self used (Ep)[1)] as weighted averages	MWhel abs. /Mg MSW	0.095	0.105	0.000	0.106
	min / max MWhel abs. /Mg MSW	*0.0 - 0.286*	*0.0 - 0.251*	*0.0*	*0.0 - 0.286*
	% of MWhth input	*3.28*	*3.90*	*0.00*	*3.58*
Specific electricity produced (Ep) as weighted averages	MWhel abs. /Mg MSW	0.431	0.581	0.000	0.444
	% of MWhth input	*14.90*	*21.6*	*0.0*	*15.0*
Specific heat exported (Ep) as weighted averages	MWhth abs. /Mg MSW	0.849	0.000	2.154	0.938
	min / max MWhth abs. /Mg MSW	*0.0 - 3.333*	*0.0*	*0.520 - 3.333*	*0.004 - 3.267*
	% of MWhth input	*29.34*	*0.00*	*72.28*	*31.64*
Specific heat self used (Ep)[1)] as weighted averages	MWhth abs. /Mg MSW	0.152	0.122	0.146	0.163
	min / max MWhth abs. /Mg MSW	*0.014 - 0.389*	*0.014 - 0.389*	*0.014 - 0.350*	*0.020 - 0.387*
	% of MWhth input	*5.25*	*4.54*	*4.90*	*5.50*
Specific heat produced (Ep) as weighted averages	MWhth abs. /Mg MSW	1.001	0.122	2.300	1.101
	% of MWhth input	*34.59*	*4.54*	*77.18*	*37.13*
Σ Specific heat and el produced (Ep) as weighted averages	MWhth+el abs. /Mg MSW	1.432	0.703	2.300	1.545
	% of MWhth input	*49.5*	*26.1*	*77.2*	*52.1*

[1)] amount of self used electricity and heat based on the EU Guidelines on the R1 energy efficiency formula in Annex II of Directive 2008/98/EC (June 2011) - not legally binding

ANNEX B

Specific self used as well as imported electricity and heat as weighted averages in absolute MWh abs /Mg MSW and as percentages (%) of the total energy input by MSW plus imported energy for all 314 WtE plants and divided according to the type of energy recovery in the Report (Status 2007-2010)

specific total energy demand depending on different classifications	unit	all investigated WtE plants	type of energy recovery of a plant		
			electricity production only	heat production only	CHP production
number of plants included	n	314	83	47	184
total throughput of plants	mio Mg/a	59.44	12.98	5.67	40.78
Total specific energy input (incl. import) as weighted averages	MWh input total abs. / Mg MSW	2.906	2.690	2.980	2.965
Σ Specific el imported (Ei) as weighted averages	MWhel abs. /Mg MSW	0.006[1)]+0.008[2)]	0.006	0.005[1)]+0.089[2)]	0.006
	% of MWhth input	*0.48*	*0.22*	*3.15*	*0.20*
Specific energy (heat) imported (Ef) as weighted averages	MWhth abs. /Mg MSW	0.011[1)]+0.001[2)]	0.013	0.013[1)]+0.013[2)]	0.010
	% of MWhth input	*0.41*	*0.48*	*0.87*	*0.34*
Specific energy (heat) imported (Ei) as weighted averages	MWhth abs. /Mg MSW	0.014[1)]+0.003[2)]	0.016	0.016[1)]+0.027[2)]	0.013
	% of MWhth input	*0.58*	*0.59*	*1.44*	*0.44*
Σ Specific el self used (Ep) as weighted averages	MWhel abs. /Mg MSW	0.095	0.105	0.000	0.106
	% of MWhth input	*3.27*	*3.90*	*0.00*	*3.58*
Specific heat self used (Ep) as weighted averages	MWhth abs. /Mg MSW	0.152	0.122	0.146	0.163
	% of MWhth input	*5.23*	*4.54*	*4.90*	*5.50*
Σ Total specific el demand (Ei+Ep) (self used plus imported) as weighted averages	MWhth abs. /Mg MSW	0.101[1)]; 0.109[2)]	0.111	0.094	0.112
	% of MWhth input	*3.48 [1)] ; 3.75 [2)]*	*4.13*	*3.15*	*3.78*
Σ Total specific heat demand (Ef+Ei+Ep) (self used plus imported) as weighted averages	MWhel abs. /Mg MSW	0.177[1)]; 0.181[2)]	0.151	0.215	0.186
	% of MWhth input	*6.12 [1)] ; 6.23 [2)]*	*5.61*	*7.21*	*6.27*
Σ Total specific heat plus el demand (Ef+Ei+Ep) (self used plus imported) as weighted averages	MWhel abs. /Mg MSW	0.278[1)]; 0.290[2)]	0.262	0.309	0.298
	% of MWhth input	*9.57 [1)] ; 9.98 [2)]*	*9.74*	*10.37*	*10.05*

[1)] basic demand of imported energy as in ANNEX C; [2)] additional demand of imported energy in case of "heat production only"

ANNEX C

Specific imported energy by fuels and heat as well as imported electricity classified into Ef and Ei as weighted averages in absolute (MWh abs /Mg MSW) and as percentages (%) of the total energy input by MSW plus imported energy for all 314 WtE plants and classified according to the type of energy recovery, size and geographical European region (Status 2007-2010)

specific imported energy demand depending on different classifications	unit	all investigated WtE plants	kind of energy recovery of a plant			size (throughput) of a plant			geographical European region of a plant		
			electricity production only	heat production only	CHP production	< 100,000 Mg MSW/a	100,000 to 250,000 Mg MSW/a	> 250,000 Mg MSW/a	South-Western Europe	Central Europe	Northern Europe
number of plants included	n	314	83	47	184	118	124	72	55	188	71
total throughput of plants	mio Mg/a	59.44	12.98	5.67	40.78	7.06	19.80	32.57	8.73	40.52	10.19
Total specific energy input (incl. import) as weighted averages	MWh input total abs. / Mg MSW	2.894	2.690	2.980	2.965	2.810	2.872	2.916	2.718	2.835	3.279
Specific electricity imported (Ei) as weighted averages	MWhel abs. /Mg MSW	0.006	0.006	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.009
	% of MWhth input	*0.21*	*0.22*	*0.17*	*0.19*	*0.18*	*0.21*	*0.21*	*0.22*	*0.18*	*0.27*
Specific energy (heat) imported (Ef) as weighted averages	MWhth abs. /Mg MSW	0.011	0.013	0.013	0.010	0.012	0.010	0.011	0.011	0.011	0.010
	% of MWhth input	*0.38*	*0.48*	*0.44*	*0.32*	*0.43*	*0.35*	*0.38*	*0.40*	*0.39*	*0.30*
Specific energy (heat) imported (Ei) as weighted averages	MWhth abs. /Mg MSW	0.014	0.016	0.016	0.013	0.016	0.013	0.014	0.013	0.014	0.016
	% of MWhth input	*0.48*	*0.59*	*0.54*	*0.42*	*0.57*	*0.45*	*0.48*	*0.48*	*0.49*	*0.49*
Σ Specific imported heat and el (Ef+Ei) as weighted averages	MWhth+el abs. /Mg MSW	0.031	0.035	0.034	0.029	0.033	0.029	0.031	0.030	0.030	0.035
	% of MWhth input	*1.07*	*1.30*	*1.14*	*0.94*	*1.17*	*1.01*	*1.06*	*1.10*	*1.06*	*1.07*

note: in this ANNEX C the basic (general) results of imported energy are listed; imported electricity > 0.030 MWhel /Mg MSW and/or imported heat > 0.060 MWhth /Mg MSW have not been taken into account

ANNEX D, part 1

Overview of application and method to determine the self used heat for the thermal waste treatment related to the different kind of processes - basic formula, necessary measured data, approaches for the calculation of self used heat with examples, necessary correction by double or not counted energy flows on the NCV results of MSW based on the NCV formula according to BREF Waste Incineration for the CEWEP Energy Efficiency Report (Status 2007-2010)

purpose of energy self use	type of self used heat	heat taken before or after steam Measuring Device (MD)	determination method of heat self used (Ep) [GJ/Mg MSW] or (GJ/Mg)/3.6 [MWh/Mg MSW]		double or not counted energy flows included in the NCV determination according to BREF WI in the CEWEP Energy Report III	remarks
			general formula with data necessary measured	approaches with mean practical data in the CEWEP Energy Report III		
heating up of primary combustion air	use of energy by heat exchanger with condensate effluent	before and after MD	(1.25 kJ/m3*°C * (xTout-xTin)°C *xm3/Mg MSW) * (1- xboiler eff./100)/1000000	**((1.25*(110 - 15)*3000)) *(1- 80/100)/1000000 = 0.071 GJ/Mg MSW = 0.020 MWh/Mg MSW**	NCV relevant: extraction **before steam MD** = included in T°C fluegas ; **after MD** = -(E*boiler eff./100) (double counted)	classified as Ep; about 3 m3/kg MSW
heating up of secondary/tertiare combustion air	use of energy by heat exchanger with condensate effluent	before and after MD	(1.25 kJ/m3*°C * (xTout-xTin)°C *xm3/Mg MSW) * (1- xboiler eff./100)/1000000	**((1.25*(110 - 15)*1500)) *(1- 80/100)/1000000 = 0.036 GJ/Mg MSW = 0.010 MWh/Mg MSW**	NCV relevant: extraction **before steam MD** = included in T°C flue gas ; **after MD** = -(E*boiler eff./100) (double counted)	classified as Ep; about 1.5 m3/kg MSW; with recigas about 1.5-0.8 (Recigas)=0.7 m3/kg MSW
recirculation of flue gas; Tin fluegas < Tout fluegas	use of energy straight out of the combustion chamber	before MD (energy extraction from boiler)	(1.40 kJ/m3*°C * (xTout flue gas-xTin flue gas)°C *x m3 recigas/Mg MSW)/1000000	**((1.4*(200 - 160)*800))/1000000 = 0.048 GJ/Mg MSW = 0.012 MWh/Mg MSW**	NCV relevant: - Δ (T out -T in)°C in flue gas if Tin flue gas < T out flue gas (double counted)	classified as Ep; (in general < 30% additional secondary air), about 0.8 m3/kg MSW
cooling of combustion grade with energy recovery	use of energy straight out of the combustion chamber; cooling by additional air condens.	before MD (energy extraction from boiler)	(4.1868 kJ/kg * (xT out H2O -xT in H2O)°C *xMg H2O/Mg MSW *(E used)/E total)/1000	**(4.1868*(79 - 40)*0.350/1000)*(0.9/1) = 0.051 GJ/Mg MSW = 0.014 MWh/Mg MSW generally not used = 0**	if no use: 100% NCV relevant; if partially used, only the remainig part is increasing NCV	only classified as Ep, if externally used e.g.for heating up condensate from district heat or combustion air
H2O addition for cleaning or cooling the boiler, if necessary for processing	use of energy straight out of the combustion chamber (with normal water/waste water)	before MD	((xE out steam in flue gas -4.1868 kJ/(kg*°C) * xT°C in H2O) kJ/kg *xMg H2O (in situ cleaning, cooling))/Mg MSW/1000	**(2895 (1 bar/210°C)-4.1868*8)/1000*(0.005+0.0125) = 0.050 GJ/Mg MSW = 0.014 MWh/Mg MSW**	NCV relevant, because injected in the combustion chamber, generally measured by increased humidity (%) in flue gas under operational conditions	classified as Ep; only if necessary for the process and representing BAT
NH4OH addition for SNCR or SCR	use of energy staight out of the combustion chamber	before MD	((xE out steam in flue gas - 4.1868 kJ/(kg*°C) * xT°C in H2O) kJ/kg *xMg H2O (NH4OH))/Mg MSW/1000	**(2895 (1 bar/210°C)-4.1868*8)/1000*0.0025 = 0.007 GJ/Mg MSW = 0.002 MWh/Mg MSW**	NCV relevant, because injected in the combustion chamber, generally measured by increased humidity (%) in flue gas under operational conditions	classified as Ep;
steam for the injection of NH4OH in case of SNCR	use of energy straight out of the combustion chamber; no condensate	before and after MD	((xE out steam in flue gas) *xMg steam/Mg MSW)/1000	**(2895 (1 bar/210°C)-4.1868*8)/1000*0.013 = 0.037 GJ/Mg MSW = 0.010 MWh/Mg MSW**	NCV relevant **before or after** steam MD to be added: increasing as Q steam -> (flue gas quantity * T°C flue gas after boiler); **after steam MD** - (E in steam used - E out flue gas), (double counted)	classified as Ep;
water for the injection of NH4OH in case of SNCR	use of energy straight out of the combustion chamber (with normal water/waste water)	before MD	((xE out steam in flue gas - 4.1868 kJ/(kg*°C) * xT°C in deionate) kJ/kg *xMg (m3) deionate/Mg MSW)/1000	**(2895 (1 bar/210°C)-4.1868*8)/1000*0.013 = 0.037 GJ/Mg MSW = 0.010 MWh/Mg MSW**	NCV relevant, because injected into the combustion chamber, generally measured by increased humidity (%) in flue gas under operational conditions	classified as Ep;
dry injection of UREA in case of SNCR	use of energy straight out of the combustion chamber; no condensate	before MD	individual determination necessary	**about 10% of water or steam or air injection: = 0.0037 GJ/Mg MSW = 0.001 MWh/Mg MSW**	NCV negligible	classified as Ep;
injection of high pressure air, for NH4OH (no steam or water) or sootblowing	use of energy straight out of the combustion chamber; no condensate	before MD	(1.25 kJ/m3*°C * (xTout-xTin)°C *Σxm3/Mg MSW)/1000000	**((1.25*(210 - 10)*(130 + 3))/1000000 = 0.033 GJ/Mg MSW = 0.009 MWh/Mg MSW**	NCV relevant to be added: increasing as ΣQ air -> (flue gas quantity * (T°C flue gas after boiler-T°C in air))	classified as Ep; 130 m3 air /Mg MSW steam injection; 3 m3/Mg MSW sootblowing

Abbreviation: MSW= municipal sold waste, Mg=tonne=ton, E=enthalpy or energy, T=temperature, MD=steam (heat) measuring device, NCV=net calorific value, WI=waste incineration, x = data to be filled in **(REIMANN 2012)**

ANNEX D, part 2

Overview of application and method to determine the self used heat for the thermal waste treatment related to the different kind of processes - basic formula, necessary measured data, approaches for the calculation of self used heat with examples, necessary correction by double or not counted energy flows on the NCV results of MSW based on the NCV formula from BREF Waste Incineration for the CEWEP Energy Efficiency Report (Status 2007-2010)

purpose of energy self use	type of self used heat	heat taken before or after steam Measuring Device (MD)	determination method of heat self used (Ep) [GJ/Mg MSW] or (GJ/Mg)/3.6 [MWh/Mg MSW]: general formula with data necessary measured	determination method of heat self used (Ep) [GJ/Mg MSW] or (GJ/Mg)/3.6 [MWh/Mg MSW]: approaches with mean practical data in the CEWEP Energy Report III	double or not counted energy flows included in the NCV determination according to BREF WI in the CEWEP Energy Report III	remarks
soot blowing	steam straight into the combustion chamber (from deionate); no condensate	before and after MD	((xE out steam in flue gas) kJ/kg * xMg steam/Mg MSW)/1000	**(2895 (1 bar/210°C))/1000*0.0026 = 0.007 GJ/Mg MSW = 0.002 MWh/Mg MSW**	NCV relevant **before or after** steam MD to be added: increasing as Q steam -> (flue gas quantity * T°C flue gas after boiler); **after steam MD** - (E in steam used - E out flue gas), (double counted)	classified as Ep;
heating up of flue gas after cross heat exchanger from wet scrubbing before fabric filter (ΔT about 18°C)	use of steam indirectly by heat exchanger with condensate effluent	before and after MD	(140 kJ/m3*°C * (xT after cross heat exchanger in flue gas - xT flue gas in fabric filter)°C * xm3 flue gas (humide) before fabric filter/Mg MSW)/1000000	**((1.4*(120-102)*(5700+200+1*500) /1000000 = 0.161 GJ/Mg MSW = 0.045 MWh/Mg MSW**	extraction straight from the boiler **before steam MD**: 100% NCV relevant; after steam MD: NCV relevant = zero	(5.7(flue gas humid after boiler)+0.2 (add. humidity by wet scrubber)+1*0.5 (increase of O2 content in flue gas after scrubber by 1% point)
heating up of flue gas after cross heat exchanger before CAT (ΔT about 22°C)	use of steam indirectly by heat exchanger with condensate effluent	before and after MD	(140 kJ/m3*°C * (xT after cross heat exchanger in flue gas - xT flue gas in CAT)°C * xm3 flue gas (humide) before CAT/Mg MSW)/1000000	**((1.4*(220-198)*(5700+200 +2*500) /1000000 = 0.213 GJ/Mg MSW = 0.059 MWh/Mg MSW**	extraction straight from the boiler **before steam MD**: 100% NCV relevant; after steam MD: NCV relevant = zero	classified as Ep; (5.7(flue gas humid after boiler)+0.2 (add. humidity by wet scrubber)+2*0.5 (increase of O2 content in flue gas before CAT by 2% point)
internal evaporation of waste water from wet scrubbing in the flue gas	energy use straight from the flue gas, no condensate	after MD	((xE out steam in flue gas - 4.1868 * xT°C in flue gas H2O) kJ/kg * xMg (m3) waste water/Mg MSW)/1000	**(2895-4.1868*40)/1000*0.095 = 0.259 GJ/Mg MSW = 0.072 MWh/Mg MSW**	extraction from flue gas **after steam MD**: NCV relevant = zero	classified as Ep; about 0.150 m3 waste water/Mg MSW
external evaporation of waste water from wet scrubbing by steam	use of steam indirectly by heat exchanger with condensate effluent	in general: after MD	((xE out steam in flue gas - 4.1868 * xT°C in waste water) kJ/kg * xMg (m3) Cl-waste water/Mg MSW(/1000	**(2783 (11 bar/185°C)- 4.1868*20)/1000*0.095 = 0.258 GJ/Mg MSW = 0.072 MWh/Mg MSW**	extraction from flue gas **after steam MD**: NCV relevant = zero	classified as Ep; about 0.107 m3 Cl-waste water/Mg MSW
blow down water from quantity of deionate (fresh boiler water)	hot boiler water straight from the boiler; no condensate	before MD	4.1868 * ((1-x) deionate) Mg(m3)/Mg MSW * x(Tout-Tin)°C hot water from boiler)/1000	**(4.1868*(0.0135*3.1-0.0026-0.013)*(270-8))/1000) = 0.029 GJ/Mg MSW = 0.008 MWh/Mg MSW**	extraction straight from the boiler **before steam MD**: 100% NCV relevant;	classified as Ep; about 1.35% of steam e.g. minus used deionate for sootblowing, deaeration, water injection
steam driven turbo pump for boiler water	straight use of steam with effluent as steam	in general: before MD	((xE in steam - xE out steam)kJ/kg * xMg steam/Mg MSW)/1000	**(2875 (27 bar/245°C)-2783 (11 bar/185°C))/1000*0.220 = 0.020 GJ/Mg MSW = 0.006 MWh/Mg MSW**	generally extraction straight from the boiler **before steam MD**: 100% NCV relevant; after MD=zero	classified as Ep;
sealing steam for flue gas closures	straight use of steam with effluent into flue gas	in general: after MD	(xE (steam)GJ/Mg steam * xMg steam/Mg MSW)/1000	**(2783 (11 bar/185°C)*0.008 /1000) =0.022 GJ/Mg MSW =0.006 MWh/Mg MSW**	extraction from flue gas **after steam MD**: NCV relevant = zero	classified as Ep;
turbo blower for keeping vacuum in the air condensor	straight use of steam with effluent as steam	in general: after MD	((xE in steam - xE out steam)kJ/kg * xMg steam/Mg MSW)/1000	**(3214 (40 bar/400°C) - 2783 (11 bar/185°C))/1000*0.012 = 0.005 GJ/Mg MSW = 0.001 MWh/Mg MSW**	generally extraction straight from the boiler **before steam MD**: 100% NCV relevant; after MD=zero	classified as Ep;
used of steam (heat) without measuring device	different	in general: before MD	**0,10 GJ/Mg MSW only as approach,** individual data necessary	**= 0.10 GJ/Mg MSW = 0.03 MWh/Mg MSW**	extraction straight from the boiler **before steam MD**: 100% NCV relevant;	classified as Ep;
other energy demands not listed before	**individual data necessary because not possible to generalize it as approaches because too special e.g. demand for steering of steam turbine, evaporation of lime milk in case of dry or semi-dry flue gas installation, steam driven turbo compressors, strippi**				**generally not NCV relevant / negligible**	might be classified as Ep, but in CEWEP Energy Report III not included because too special

Abbreviation: MSW= municipal sold waste, Mg=tonne=ton, E=enthalpy or energy, T=temperature, MD=steam (heat) measuring device, NCV=net calorific value, WI=waste incineration, x = data to be filled in **(REIMANN 2012)**

ANNEX E, part 1

CEWEP Checklist of devices used in individual WtE plants

as basis for the calculation of the self used energy of an individual WtE plant

CEWEP checklist as basis for the determination of NCV and R1-efficiency factors of W-t-E plants by overall approaches			
Name of the plant:			**line(s): 1 to …**
General information			
Name of the plant			
Name of company			
Address			
Contact person			
Telephone		Mobil	
Fax			
E-mail			

Please take note of the following remark:
It is sufficient, if only the relevant datalines of the plant will be answered with "yes" by deleting "no". All for the plant not relevant datalines should be left with "yes/no" or "yes" should be deleted.

Specific information		comments	answers		
Are the following information applicable for the whole plant	if no, please fill out additional checklists for all different systems (lines)		yes		
if no: is it only applicable for one or more lines with < 30% of the total steam(heat)production				*yes*	*no*
if no: is it only applicable for one or more lines with > 30% - 60% of the total steam(heat)production				*yes*	*no*
if no: is it only applicable for one or more lines with > 60% of the total steam(heat)production				*yes*	*no*
Co-incineration of wet sewage sludge(< 30% DS)				no	
Co-incineration of dry sewage sludge(> 30% in general >70% DS)			yes		
Demand of primary (imported) fuels for start up/shut down operations			yes		
Demand of primary (imported) fuels primarily used for keeping combustion temperature > 850°C				no	
Demand of primary (imported) fuels primarily used for heating up flue gases (e.g. before SCR cat)				no	
Demand of imported electricity				no	
Imported heat (steam) for other purposes (e.g. from an industry for electr. production)				no	
Wet scrubber for flue gas cleaning (waste water free)				no	
Wet scrubber for flue gas cleaning (with waste water effluent)				no	
Dry flue gas cleaning system			yes		
Sem-dry (sem-wet) flue gas cleaning system				no	
ESP dry for dedusting				no	
ESP wet for dedusting and reduction of aerosols				no	
Fabric filter for dedusting			yes		
Water cooled grade without energy recovery				no	
Water cooled grade with energy recovery (e.g. heating up primary air or boiler feed water)			yes		
SCR with heating up of flue gases by a mix of imported fuels and self produced steam				no	
SCR with heating up of flue gases by gas/gas heat exchanger with self produced steam		with steam before the boiler steam measuring device		no	
SCR with heating up of flue gases by gas/gas heat exchanger with self produced steam		with steam after the boiler steam measuring device		no	
SCR cat at an operation temperature < 220°C				yes	

ANNEX E, part 2

CEWEP Checklist as basis for the calculation of the self used energy of an individual WtE plant

Name of the plant:		linie(n): 1 to …		
Please take note of the following remark: It is sufficient, if only the relevant datalines of the plant will be answered with "yes" by deleting "no". All for the plant not relevant datalines should be left with "yes/no" or "yes" should be deleted.				
Specific information	**comments**	**answers**		
SNCR NH4OH injection in combination with steam	with steam before the boiler steam measuring device		no	
SNCR NH4OH injection in combination with steam	the boiler steam measuring device		no	
SNCR NH4OH injection in combination with water			no	
Use of steam for stripping NH_3/NH_4OH out of fluegas in combination with SNCR and wet scrubbing			no	
Heating up of condensate and fresh as well hot water with high pressure (HP)-steam			no	
Heating up of condensate and fresh as well hot water with medium/low pressure (MP/LP) steam		yes		
Heating up of combustion air by heat recovery out of the fluegas	T °C decrease in flue gas		no	
Heating up of primary combustion air with steam (or hot water)	with steam before the boiler steam measuring device	yes		
Heating up of primary combustion air with steam (or hot water)	the boiler steam measuring device	yes	no	
Primary air: part of the total combustion air: > 50%			*yes*	
Primary air: part of the total combustion air: < 50%				*no*
Heating up of secondary or tertiary air with steam (or hot water)		yes		
Use of energy from fluegas by cross heat exchanger e.g. heating up of flue gas after wet scrubbe	T °C decrease in flue gas		no	
Use of recirculated flue gas		yes		
Use of energy from blow down water of boiler		yes		
Use of condensing energy out of the steam in the fluegas e.g. for heating up condensate from the air or water condensor or backfow of district heat			no	
Sootblowing with high pressure (HP)-steam	with steam before the boiler steam measuring device	yes	no	
Sootblowing with high pressure (HP)-steam	with steam after the boiler steam measuring device	yes	no	
Water addition before or into the boiler e.g. for cleaning or cooling purpose			no	
Turbo pump, turbo blower or turbo compressor driven with steam			no	
Evaporation of cleaned scrubber waste water by internal injection into the hot flue gas			no	
External treatment of residues from scrubber waste water, recovery of xxCl or evaporation of waste water			no	
Air condensor for steam condensing after turbine		yes		
Evacuation blower of air condensor for start up and during operation		yes		
Water condensor for steam condensing after turbine			no	
Extraction of steam or hot water out of the boiler without a measuring device		yes	no	
Heating for buildings, silos, pipes of the plant with steam or hot water		yes		
Others, not listed up before, as steam/heat demand e.g. for boiler-/hot water heating up		yes	no	

questions in italic written text not necessary to be answered but helpful for CEWEP statistics if filled out

Status 2011

ANNEX F

CEWEP energy questionnaire as basis for the calculation of NCV and R1 of An individual WtE plant

Annual CEWEP Energy Questionnaire on Energy related Data during Normal Operation Conditions

General

Basic data

Country:	
Plant:	
Website:	

Responsible contact person

Name:			
Street:		Number:	
Postal Code:		City:	
Telephone:		Fax:	
E-Mail:		Mobil:	

Input of waste and primary fuels

Reference year:		year
Number of lines in operation:		number

Waste

Total amount of waste incinerated:				[t(Mg)/a]
included in the total amount as mixed municipal waste:				[t(Mg)/a]
included in the total amount as commercial, industrial, trade wastes etc:				[t(Mg)/a]
included in the total amount as sewage sludge:	dewatered	dry		[t(Mg)/a]

Imported primary fuels and electricity and other kind of imported energy

fuel as light or heavy oil in t(Mg) **or** m^3:	as received		[t(Mg)/a]		[m^3/a]
fuel as natural gas in MWh **or** Nm^3:	as received		[MWh/a]		[10^3Nm^3/a]
other primary fuels in t(Mg) **or** MWh: kind of fuel:			[t(Mg)/a]		[MWh/a]
imported heat as steam or hot water in t(Mg) **or** MWh:	as received		[t(Mg)/a]		[MWh/a]
imported electricity:					[MWh/a]

Energy generation and use

Amount of generated steam or hot water

Produced energy (mass) through the boiler; measured:	if as steam		if as hot water		[t(Mg)/a]
Additional produced energy (mass): but not measured:	as produced		[t(Mg)/a]		[MWh/a]
Mean temperature of the steam related feed (boiler) water :	if as steam e.g. 130°C		if as hot water		[°C]
Mean pressure of the produced steam or hot water:	if as steam e.g. 40 bar		if as hot water		[bar]
Mean temperature of the produced steam or hot water:	if as steam e.g. 400°C		if as hot water		[°C]
Annual mean input temperature of combustion air:	from outside e.g. 10°C		fr. bunker e.g. 25°C		[°C]
Mean temperature of combustion air **if heated up**:	primary air e.g. 100°C		sec. air e.g. 80°C		[°C]
Annual mean temperature in the flue gas after the steam/hot water measuring device of the boiler e.g. 220°C:					[°C]

Heat / steam export	mean annual temperature of condensate from steam or hot water for exported heat after its utilization or in back flow e.g. 70°C:		[°C]

Amount of exported heat as district heat or steam:	if as steam		if as hot water/ district heat		[MWh/a]
Additional amount of exported heat **(only if not included above):**	if as steam		if as hot water/ district heat		[MWh/a]

Electricity generation	annual temperature of condensate after air or water condensor e.g. 55°C:		[°C]

Installed generator performance in total:	number of turbines		total		[MW]
Amount of produced electricity:					[MWh/a]
Amount of exported electricity:					[MWh/a]

CO_2 emission

Continuous measuring CO2 (also non-gauged results):	Yes		No		
If yes, please state concentration:					[Vol.-%]

Status 2011