CEWEP Energy Report
(Status 2001 - 2004)

Results of Specific Data for Energy, Efficiency Rates and Coefficients, Plant Efficiency factors and NCV of 97 European W-t-E Plants and Determination of the Main Energy Results

by
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1. General introduction

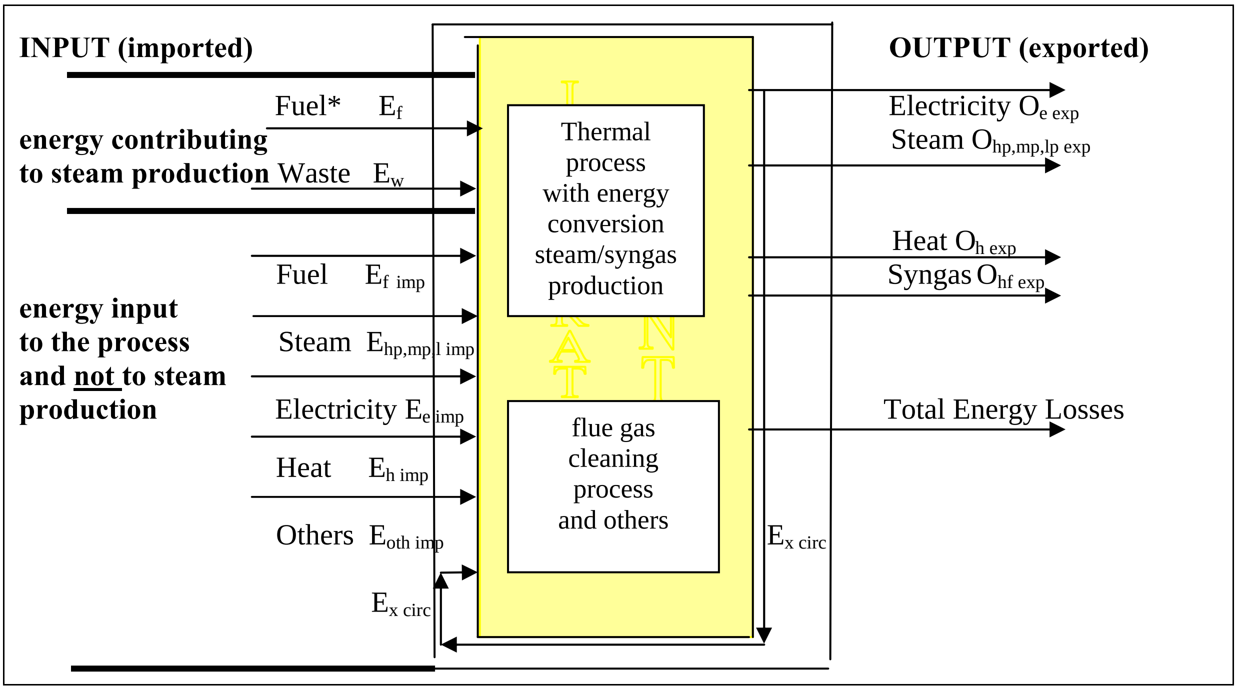
For 97 Waste-to-Energy plants (W-t-E) from 10 European countries without e.g. France, including national associations, plant efficiency factors, energy utilization rates/coefficients and NCV were calculated according to the BREF "Waste Incineration" (in the following text abbreviated to BREF) [1], ECJ judgement "C-458/00" (in the following text abbreviated to ECJ) [2] and the Draft of Waste Framework Directive 2005 (in the following text abbreviated to WFD) [8], also in order to prove good quality processing and plant operation in accordance to Directive 2000/76/EC [3].

For the calculations in this report the equations and formulas worked out and laid down in BREF and described in par. 32-34 of the ECJ and in WFD for R1 classification are used.

As basic principle the special energy questionnaire, as shown in the Annexes of BREF [1a] was used for the energy calculation method. It had to be filled out only with measured or calculated energy figures, which are normally available to the operators of every W-t-E plant, because these figures are needed to prove the good processing and operation of a plant.

The calculation method itself is based upon the fact that energy input must correspond with the energy output as shown in diagram 1 [1b].

Diagram 1: Summary of the system inputs and outputs according to BREF



* fuel for auxiliary burners

This energy evaluation should be carried out at least once a year for every individual W-t-E plant.

The assessment should always be carried out using the same method e.g. as used in this report to avoid possible mistakes, to get comparable energy results worldwide for benchmarking and by this to evaluate different technologies (e.g. flue gas treatment systems etc.) and to increase the acceptance for waste incineration. This proves the positive effects on resources and climate protection, and serves as help to control the operation process as well as to decide the necessity of investigations for optimisation and improvements of the plant and its facilities.

By repeating this calculation method in a defined time period (proposed every calendar year by BREF) changes in processing and/or in net calorific value (in the following text abbreviated to NCV) of the waste can be detected very precisely and in a short time. This calculation may even be used to check energy figures which are determined by other methods.

2. Investigation of energy data for 97 W-t-E plants in 10 European countries

The energy questionnaires [1a] completed by the operators of the 97 investigated W-t-E plants for municipal solid waste (in the following text abbreviated to MSW), from 10 European countries, were received up to the end of September 2005. The questionnaires were checked, and the calculation of the specific data for energy, efficiency rates/coefficients, plant efficiency factors and NCV of the W-t-E plants as well as determination of the main energy data for the W-t-E plants using these results (status 2001-2004) were carried out on behalf of CEWEP.

Because the investigated plants delivered data during the time period 2001 to 2004, and some did not up-date old data to 2004 figures, the energy results for the W-t-E plants are indicated with the quantity of incinerated waste for the corresponding year. For this 4 years period, **each plant is only taken into account once** with its actual data even if several annual energy calculations were carried out during this time period.

2001: 21 W-t-E plants	4.708.297 Mg	19,6 %
2002: 14 W-t-E plants	2.849.890 Mg	11,8 %
2003: 21 W-t-E plants	5.020.356 Mg	20,9 %
2004: 41 W-t-E plants	11.491.592 Mg	47,7 %
total 2001-2004: 97 W-t-E plants	**24.070.136 Mg**	**100 %**

The **24.070.136 Mg/a** have been taken into account as the basis for the determination of the energy results in this report.

The comparison of this amount **24.070.136 Mg/a** of incinerated waste investigated with official figures of the total waste throughput by incineration in **2003** (at that time available figures were provided by CEWEP), the percentage is represented as follows:

CEWEP members (in 2003)	31,273 mio Mg(t)	76,9 %
EU 25:	48,84 mio Mg(t)	49,3 %
EU 25 +CH+N:	52,60 mio Mg(t)	45,8 %

By this high accordance the results of this study can be generalised favourably at least for all the CEWEP W-t-E plants.

The prognosis for the total energy results will be based on a capacity of 48,84 and 52,60 mio Mg incinerated waste in the year 2003 as reported by CEWEP.

3. Weighted and not weighted figures/results

Weighted figures not only take into account the number of plants investigated - as not weighted results do - but also consider the influence of the NCV, specific or percentage data with its corresponding waste quantity in comparison to the summarized waste throughput of the investigated plants.

Weighted figures should always be used for general designations such as NCV or mean values, for several groups of investigated W-t-E plants (e.g. CHP) or if there are large differences in the throughput and single results of the investigated group of plants.

Weighted mean values are used in this report for the comparison of energy input in all the following energy results mean values (specific and in percentages), even concerning single W-t-E plants.

4. Heat value (NCV) of the incinerated waste

For the NCV calculation the formula, a very simple but precise calculation method for incinerated mono- and mixed waste based on energy exergy, was applied from the BREF [1c-1d] (equation for "NCV" see Appendix 1).

The data required for the calculation were generally available in the energy questionnaires completed by the W-t-E plants investigated, and were either measured or calculated from dimensioning figures such as steam and/or heat parameters.

To obtain relevant NCV results high accuracy in the quantity of steam produced is necessary. This is difficult to achieve using simple orifice flow measurements, but easy to achieve using pitot tubes [e.g. 9] with the additional advantage of a very low pressure drop, and low investment.

Double counting of measured steam e.g. for SNCR, soot blowing or heating up of primary air, must be avoided if the steam is taken after the measuring device.

The NCV calculation according to BREF and the corresponding NCV results given by the operators of the 97 European W-t-E plants investigated are shown in Figure 1.

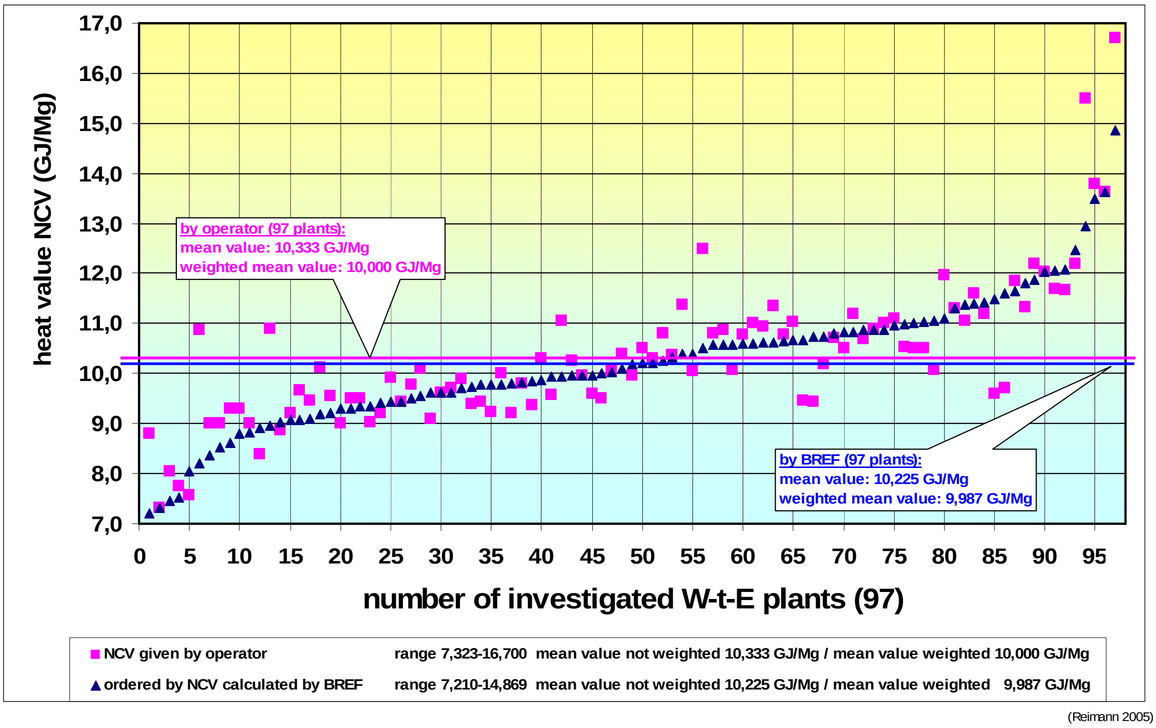


Figure 1: Net Calorific Value (NCV)
- calculated using the BREF-formula as well as indicated by the operator including NCV mean values weighted and not weighted for 97 W-t-E plants (status 2001-2004)

The weighted NCV can only be presented as an average value, and may be compared with the mean value of the not weighted NCV.

The not weighted NCV results are exclusively for the waste incinerated (imported energy excluded). This can be summarized for the 97 European W-t-E plants for the period 2001 - 2004 as follows:

calculated according to BREF:

7,210 – 14,869 average 10,225 GJ/Mg or rather 2,840 MWh/Mg

as indicated by the operators:

7,323 – 16,700 average 10,333 GJ/Mg or rather 2,870MWh/Mg

One of the main reasons for the relatively high range of the single NCVs from the plants investigated may be caused by the influence of greater amounts of high calorific fractions (e.g. trade or industrial waste) in the waste to be incinerated in a plant. For the lower results, a high content of green waste (vegetables) may be the reason.

The corresponding **weighted** NCV results are **exclusively** for the waste incinerated in 2001 – 2004 (imported energy excluded), they can be summarized as follows:

calculated according to BREF:

average 9,987 GJ/Mg or rather 2,774 MWh/Mg

(averages 2001: 9,881 GJ/Mg mainly central Europe;
averages 2002: 10,996 GJ/Mg mainly northern Europe;
averages 2003: 9,961 GJ/Mg mainly central Europe;
averages 2004: 9,792 GJ/Mg mainly central and southern Europe)

as indicated by the operators:

average 10,000 GJ/Mg or rather 2,778 MWh/Mg

The results of the weighted NCV distributed over the corresponding individual years 2001 – 2004 show quite similar figures in central and southern Europe (see 2001, 2003 and 2004), which seem to be quite constant over that time period. The higher NCV in 2002 is related to northern Europe where waste is used mainly for heating purposes, and in general has a higher biomass content e.g. by wood chips.

The results of the weighted and not weighted NCV mean values calculated according to BREF and according to the operators are in principal identical. However, this does not mean that the single NCV values of the different plants are congruent between BREF and the operator, because some of them show important deviations which can be seen in figure 1 with the NCV results calculated according to BREF (in ascending order).

The BREF results do not show systematically higher or lower deviations (+ and -) in comparison to the NCVs given by operators. This allows the conclusion that the NCV results calculated according to BREF are very realistic, and by application of this easily standardized calculation method the problem of determining the NCV can be solved and uncertainties in NCV results can be avoided, because some of the NCVs indicated by operators are only rough estimates and/or are not calculated in detail.

Weighted NCV mean values are used in this report for the comparison of energy input for all the following energy results mean values (specific and in percentage), and in the figures 7 and 16 for all results.

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The use of state of the art steam and heat measurement systems (e.g. pitot tubes) with high accuracy and low pressure drop, low investment and low installation costs could have a positive effect on the real energy and NCV results.

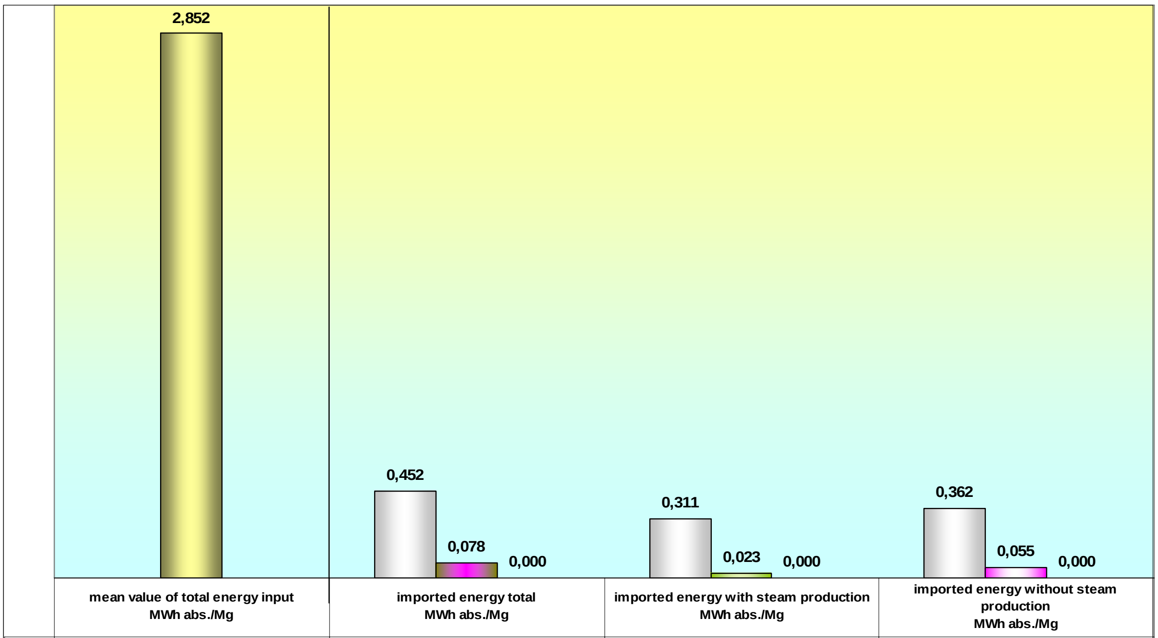
5. Demand of imported energy

The total energy input includes the energy from the waste, and often additional energy such as electricity and/or as (primary) fuels which is imported in order to run a proper incineration process in accordance with the regulations. Imported energy is normally only needed to cover the energy self demand for the combustion process if self produced energy is not sufficiently available. This happens e.g. during start up, shut down, keeping the incineration temperature > 850 °C or heating up flue gas e.g. for SCR or during revision times.

Depending on the kind of application the imported energy may also be producing steam. Examples for steam production are start up situations e.g. > 650 °C or keeping temperature > 850 °C by using auxiliary burners. Imported energy without steam production means the use of external electricity or in general of fuel for start up and revision situations e.g. < 650 °C or for the SCR process which are always energy losses.

Because of the possibility of using imported energy in these two different ways a strict separation is necessary, which was included in the energy questionnaire to avoid mistakes in the NCV and energy calculation.

In figure 2 the correlation and distribution of imported energy for the 97 European W-t-E plants are shown in which the mean value of imported energy is 0,078 MWh/Mg equivalent to 2,7 % at a mean value of NCV total of 2,852 (2,774+0,078) MWh/Mg.



	mean value of total energy input MWh abs./Mg	imported energy total MWh abs./Mg	imported energy with steam production MWh abs./Mg	imported energy without steam production MWh abs./Mg
Reihe1		max 0,452	0,311	0,362
Reihe2	weighted 2,852	mean weighted 0,078	0,023	0,055
Reihe3		min 0,000	0,000	0,000

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Figure 2: Demand of imported energy with and without steam production - max-mean-min specific energy data in MWh abs/Mg for 97 European W-t-E plants (status 2001-2004)

The ratio between the imported energy with steam production and the one without steam production is about 1:2,5.

6. Equivalent factors and values for comparing energy assessment

Equivalent factors and values according to WFD and to BREF have to be used for the calculation of energy recovery efficiency (utilization) coefficients, plant efficiency factors and if different qualities of energy have to be summarized e.g. for reason of benchmarking. Only in this way different kinds of energy can be evaluated and summarized to a comparable energy mix output of e.g. heat, steam and electricity.

Therefore conversion factors as equivalents are needed for comparison of self produced energy with energy sources generated externally to W-t-E, assuming an over all European average of 38 % conversion efficiency for external electrical energy generation in power plants and 91 % in external district heating plants. For the use of energy e.g. in a fuel or as steam the possible utilization rate is 100 %.

The comparison of different energy measurement units i.e. MWh, $MWh_{e,}$ MWh_h must be taken into account. This should be carried out using the following equivalent (conversion) factors as indicated in BREF [1e] and in parenthesis in WFD:

1 MWh_e abs = 2,6316 (2,6) MWh equ
1 MWh_h abs = 1,0989 (1,1 if commercial used) MWh equ
1 MWh steam abs = 1,0 (1,0 if not commercial used) MWh equ (exact 0,91*1/0,91)
If the results are needed in GJ abs or GJ equ the MWh achieved must be multiplied by the conversion factor 3,6.

For example only with this equivalent method can it be shown that a W-t-E plant with e.g. 18 % electricity production (WFD equ 0,468) is congruent with a W-t-E plant with e.g. 42,5 % utilization of district heat (WFD equ 0,468) or a plant with 42,5 % (WFD equ 0,468) commercial use of steam.

7. Specific figures and percentages for energy self demand, electricity and heat production as well as export

The following data and figures show the **specific production and export** as well as the energy self demand of electricity and heat **in correlation to 1 Mg (ton) of waste incinerated** [5-7]. For better appreciation of the rate of recovered energy, which is taken as correlation, the total specific energy input consisting of energy from waste and imported energy is illustrated on the left side of the following figures. For the determination of these specific figures the NCV is not needed. Nevertheless its influence results indirectly in higher or lower produced and exported energy rates.

To make energy results comparable between the W-t-E plants and to show the influence of different technologies used (e. g. for benchmarking) not specific data but energy results in **percentages (%)** should be applied. In this case the correct determination of the heat value (NCV) of the waste incinerated, which can be done easily using the NCV formula from the BREF, is needed. By taking the corresponding quantity of waste into account the energy input of the waste is determined by multiplying the NCV and the waste quantity, which is further used as basis for the calculation of energy percentages**.**

Beside the specific data the **percentages (%)** of energy demand and recovery are also shown, whereas all mean values are given as <u>weighted</u> figures as described in chapter 3.

Only min- and max-figures are related to single results, because weighing of single values is not possible.

Concerning the energy self demand beside the mean imported energy, split into steam (energy producing) and not steam producing (total energy losses), the self produced and spent energy from waste are taken into account.

In the following text and figures numbers written normally mean energy data in absolute, while numbers in italic indicate equivalent data.

By using data in absolute the total efficiency figure is the sum of electricity efficiencies, recovered heat and utilized steam. This sum can never exceed 100 %, with a theoretical maximum in the range of the boiler efficiency (e.g. 85 %). If for example in a W-t-E plant with CHP 20 % of energy is produced as electricity, 45 % is utilized as district heating and 5 % is used for self demand the summarized efficiency is 70 % of the total energy input in absolute.

Calculating the same example according to the WFD with equivalent values, which is the only accurate method, the total and by this the comparable efficiency coefficient will be (0,20*2,6 + 0,45*1,1+0,05*1,000) = 1,065 of the total energy input in this case in equivalent. In special cases, depending on the local conditions, efficiency coefficients in equivalent > 1,00 up to about 1,40 are possible.

8. Categorising depending on the kind of energy recovery in correlation to energy demand, heat and electricity production/export

8.1 Categories of plants

Beside the general results from the 97 European W-t-E plants three extra categories of W-t-E plants are indicated with a distinction between:

- plants with **mainly electricity** production (25 out of the 97 investigated plants)
  Classification: with >17,5 % electricity production and < 5 % exported heat or <17,5 % electricity production and < 2 % exported heat
- plants with **mainly heat** production (28 out of the 97 investigated plants)
  Classification: with > 60 % heat utilization with < 5 % exported electricity or < 60 % heat utilization and < 2 % exported electricity
- plants with **CHP** production (44 out of the 97 investigated plants)
  Classification: with electricity production and heat utilization but not falling under 1) or 2)

The results for the four groups are listed in detail in Appendix A under 8.2 – 8.5

9. Energy efficiencies in percent

If calculating energy efficiencies in percent different reference values are possible, this leads to diversity in efficiency results.

To avoid any ambiguity in the interpretation of the efficiencies in percent in this report, only the specifications and formulae indicated in the WFD, BREF and described by ECJ are used, whereas the reference values are described in the relevant articles.

Mean values are given as weighted results.

9.1 Boiler efficiency

The boiler efficiency rate represents the ratio of released energy from produced steam in correlation to the NCV of the waste plus external energy with steam production. There is no difference if absolute or equivalent figures are used.

Using this calculation method the results of boiler efficiency are too low because losses of energy such as radiation, sensible and latent heat in the solids and unburned gases and solids are not taken into account.

That is the reason why not 100 % of the NCV of the waste plus external energy with steam production is put into the nominator, but only 97 % as a flat rate (0,97*(NCV + steam producing external energy) as described in BREF [1g]. Only this reduced energy potential is available for the boiler. Figure 11 shows the boiler efficiencies of the 97 European W-t-E plants calculated according to BREF and as required by BREF in comparison to those provided by the operators. The BREF results deliver realistic figures (max 92,7 %) and no systematically higher or lower deviations compared to the data from the operators. For single plants deviations up to +/- 15 % to the BREF results where found. These differences are normally caused e.g. by insufficient accuracy of the measured steam data, not taking into account steam producing imported energy and double measurement of steam quantities or by using old or wrong (> 100 %) data.

The mean value of boiler efficiency according to BREF is 81,8 % and according to the operators it is also 81,9 %, which are nearly the same. This means that the BREF value can be considered as representative.

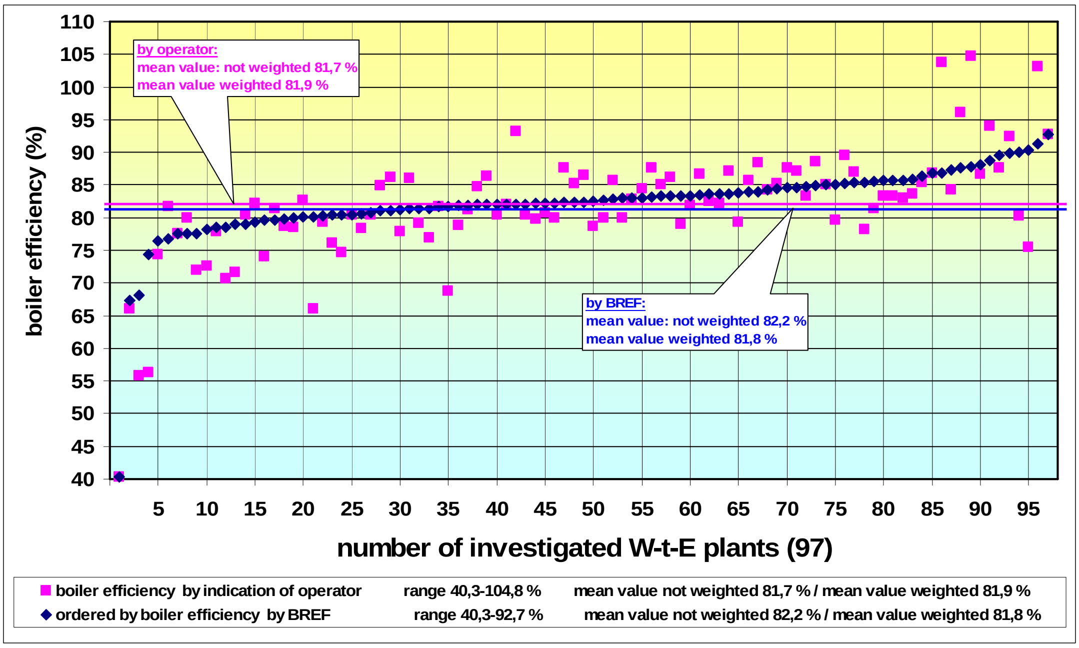

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Figure 11: Boiler efficiency
- as correlation between produced energy as steam to 97 % of the steam producing imported energy plus NCV of waste in one case NCV according to BREF and as indicated by the operator (status 2001-2004)

The use of new steam and heat measurement systems with high accuracy and low investment and installation costs could have a positive effect on these results.

9.2 Recovery efficiency rate (coefficient) by WFD and ECJ (equ) for R1 as recovery

Recovery efficiency coefficients must always be calculated with equivalents according to BREF or WFD and not with absolute data **in order to make the results comparable.** The recovery (utilization) efficiency rate (coefficient) expresses the ratio between produced (utilized) energy (as electricity, district heat and/or utilized) and 0,97*(NCV plus steam producing imported energy) (equation for "recovery efficiency coefficient" see Appendix 2).

In order to meet the ECJ criteria indicated in par 34 as a basis for being classified as a R1 (recovery) W-t-E plant, the recovery efficiency coefficient should be > 0,50 **for generated energy, calculated by (Ep)/(0,97*(Ew+Ef)).**

For WFD a R1 value of 0,6 for existing and 0,65 for new plants (after 31.12.08) **for generated minus imported energy** is in discussion**, calculated by (Ep-(Ef+Ei))/(0,97*(Ew+Ef)).**

As can be seen in figure 12

> **87 (89,7 %) out of the 97 investigated plants reach a recovery efficiency coefficient > 0,50 as necessary for R1 by ECJ and with equivalents by BREF.**
>
> **67 (69,1 %) out of 97 plants reach a recovery efficiency coefficient > 0,60 as in discussion for R1 by WFD with equivalents by WFD.**

so that their main purpose is energy recovery. The plants with < 0,50 by ECJ and accordingly < 0,60 by WFD have some local problems or no market in using and selling their energy.

To influence the results in a positive way the amount of imported energy (Ef and Ei) should be as low as possible, because the aim of waste incineration should be to run the total incineration process with as little external energy as possible. With no imported energy the remaining R1-formular would become **Ep/(0,97*Ew).**

As an average for the 97 European W-t-E plants investigated the mean recovery efficiency coefficient by WFD is weighted 0,735 and not weighted 0,715 (>0,60 as reference value) for produced energy **minus imported energy**.

As an average for the 97 European W-t-E plants investigated the mean recovery efficiency coefficient by ECJ is weighted 0,766 and not weighted 0,755 (>> 0,50 as reference value) for produced energy only.

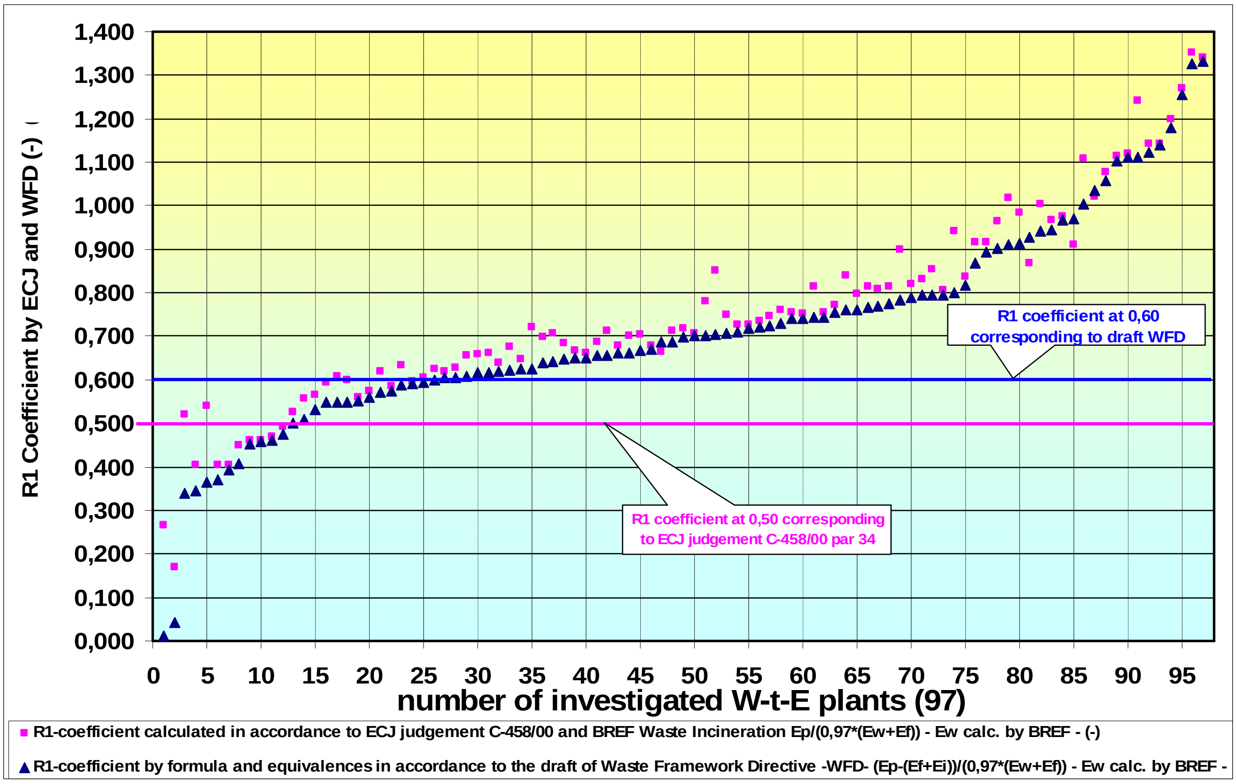

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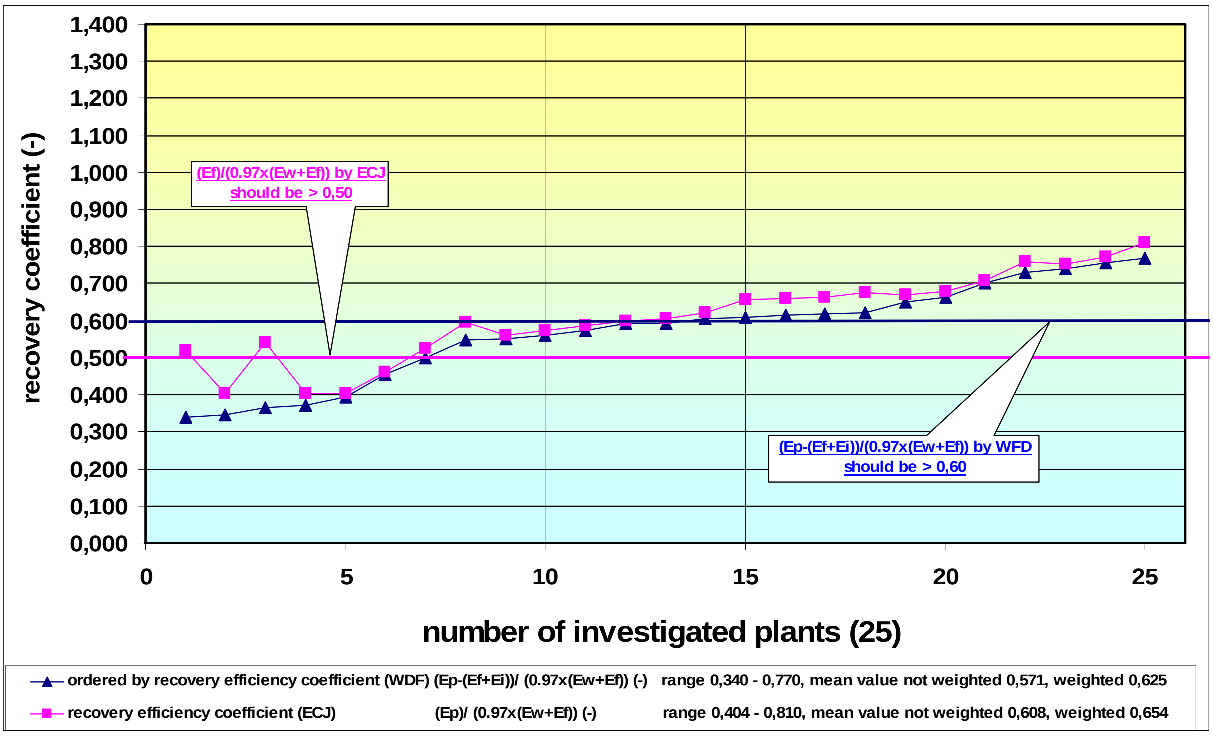
Figure 12: Comparison of the R1 results of 97 CEWEP W-t-E plants investigated during 2001-2004 in accordance to the R1 formula of the draft of Waste Framework Directive (status Dec. 2005) and in accordance to ECJ judg. C-458/00 - equivalences of WFD/BREF Waste Incineration

As an average for the 25 European W-t-E plants investigated mainly electricity producing the mean recovery efficiency coefficient by WFD is weighted 0,625 and not weighted 0,571 (around 0,60 as reference value) for produced energy **minus imported energy**.

As an average for the 25 European W-t-E plants investigated mainly electricity producing the mean recovery efficiency coefficient by ECJ is weighted 0,654 and not weighted 0,608 (>> 0,50 as reference value) for produced energy only.



(Reimann 2006)

Figure 12a : Comparison of the R1-results of 25 out of the 97 CEWEP W-t-E plants investigated with mainly electricity production (all in abs: > 17,5 % electricity production and add. < 5 % heat exported or < 17,5 % electricity production and add. < 2 % heat exported) **in accordance to the R1 formula of the draft of Waste Framework Directive (status Dec. 2005) and to ECJ judg. C-458/00 - equivalences of WFD/BREF Waste Incineration (status 2001-2004)**

The range between min and max of recovery efficiency rates is presented at the bottom of figure 12a.

As an average for the 28 European W-t-E plants investigated mainly heat producing the mean recovery efficiency coefficient by WFD is weighted 0,705 and not weighted 0,718 (>0,60 as reference value) for produced energy **minus imported energy**.

As an average for the 28 European W-t-E plants investigated mainly heat producing the mean recovery efficiency coefficient by ECJ is weighted 0,797 and not weighted 0,809 (>> 0,50 as reference value) for produced energy only.

The range between min and max of recovery efficiency rates is presented at the bottom of figure 12b.

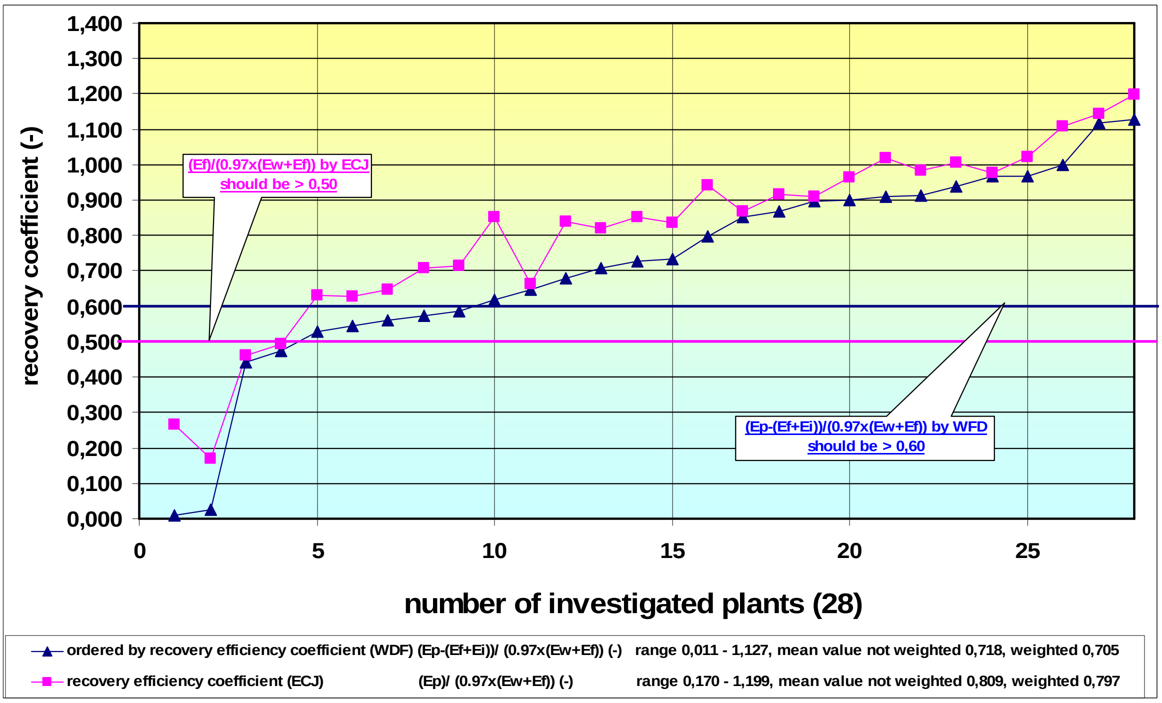


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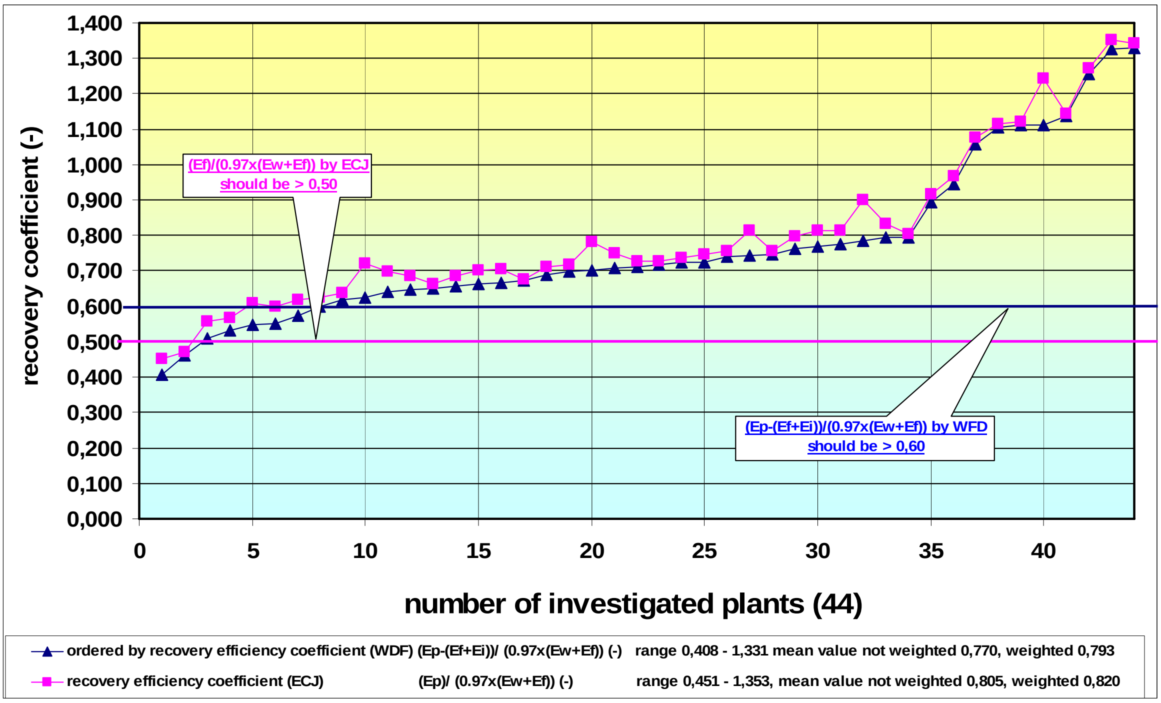
Figure 12b : **Comparison of the R1-results of 28 out of the 97 CEWEP W-t-E plants investigated with mainly heat/steam production** (all in abs: with > 60 % heat utilization with < 5 % exported electricity or < 60 % heat utilization and < 2 % exported electricity) **in accordance to the R1 formula of the draft of Waste Framework Directive (status Dec. 2005) and to ECJ judg. C-458/00 - equivalences of WFD/BREF Waste Incineration (status 2001-2004)**



(Reimann 2006)

Figure 12c : **Comparison of the R1-results of 44 out of the 97 CEWEP W-t-E plants investigated with mainly CHP production** (with electricity production and heat utilization but not falling under high electricity or heat production) **in accordance to the R1 formula of the draft of Waste Framework Directive (status Dec. 2005) and to ECJ judg.C-458/00 - equivalences of WFD/BREF Waste Incineration (status 2001-2004)**

The range between min and max of recovery efficiency rates is presented at the bottom of figure 12c.

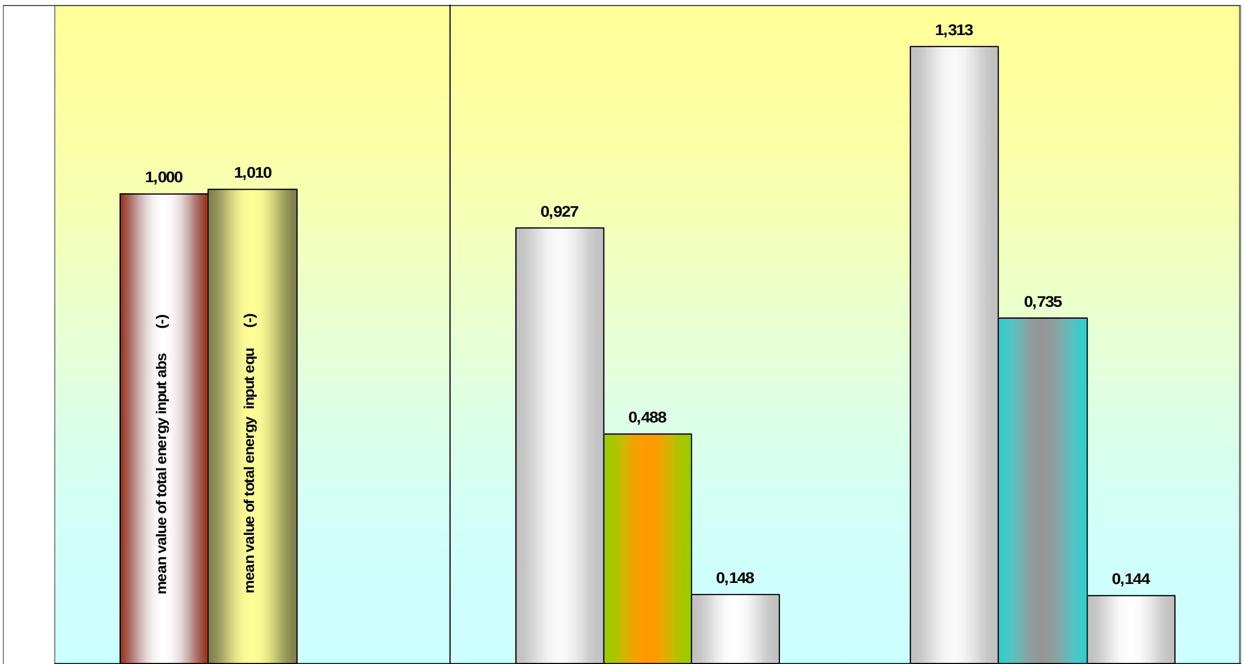
As an average for the 44 European W-t-E plants investigated with CHP production the mean recovery efficiency coefficient by WFD is weighted 0,793 and not weighted 0,770 (> 0,60 as reference value) for produced energy **minus imported energy**.

As an average for the 44 European W-t-E plants investigated with CHP production the mean recovery efficiency coefficient by ECJ is weighted 0,820 and not weighted 0,805 (>> 0,50 as reference value) for produced energy only.

9.3 Comparison of the total energy efficiency rates absolute and equivalent

Figure 13 shows the summarized weighted mean values for electricity and heat production as total energy efficiency rates in correlation to the energy input of the 97 European W-t-E plants, which are highlighted in colour.

Min- and max-values in grey present the lowest and highest results of a particular plant in this group (see also article 8.2). These results from the common group may differ a little from those of the special groups according to article 8.3 to 8.5, because the corresponding NCV is different.



	mean values of total energy input in absolut and equivalent in (-)		sum of produced and used energy absolut in (-)	sum of produced and used energy equivalent in (-)
Reihe1	1,000	max	0,927	1,313
Reihe2	1,010	mean weighted	0,488	0,735
Reihe3		min	0,148	0,144

(Reimann 2006)

Figure 13: Energy input/electricity/heat production and export by 97 European W-t-E plants - max/mean/min energy data as part (-) of total energy input for the sum of electricity and heat recovery efficiencies in absolute and equivalent calculated by BREF (status 2001-2004)

Only for information the sum of efficiency rates in absolute is included in figure 13 because the summarized total energy recovery of plants is still used by some operators, even if it is not correct. For the correct energy assessment the sum of efficiency rates in equivalent by BREF (see chapter 6) is shown at the right side of figure 13.

The corresponding energy input is set out for better understanding on the left side of figure 13 in absolute and in equivalent by BREF.

Taking the absolute efficiency results as basis, the total recovery rate range in this group is between 0,148 (14,8 %) and 0,927 (92,7 %) with a mean value of 0,488 (48,8 %) for all 97 W-t-E plants calculated by BREF.

Instead of using absolute, the correct results **in equivalent by BREF** are used. The sum of the recovery rate for this entire group of plants as mean value is 0,735 with a range from 0,144 to 1,313.

9.4 Optimisation potential for the increase of energy utilisation

In the case of all balancing measurements it is crucial and an essential pre-condition to have suitable, low-loss and accurate measuring instruments (with the lowest permissible fault tolerance), which register the pertinent energy-specific data correctly and in its entirety, at least for steam measurements. Incorrectly measured steam quantities are the cardinal reason for most deviations in the results of NCV and all corresponding efficiencies.

In the case of energy distribution flow there are four areas that have an essential influence on the increase of energy production and utilisation, while necessary or additional investment or operation costs must be taken into account.

1. Optimisation of process methods for thermal treatment (very low to medium investment)
2. Increase in electricity production (medium to high investment)
3. Increase in heat utilisation (medium to high investment)
4. Methods to decrease the need for primary energy (low to medium investment)

In the case of differing optimisation units it is important to differentiate between existing and planned installations. The optimization of old installations usually requires more expenditure. New installations should take optimisation essentials such as their size, energy required for maximum operational efficiency and energy-saving flue-gas cleaning into account from the outset so that optimisation does not result in extra costs.

As the evaluation of the questionnaires has shown, measurement inaccuracies cause the most discrepancies.

Thus a basic balancing prerequisite is that feeder water and steam tally (process-technically non-feasible surplus quantities of steam produced as against the quantity of feeder water used can nearly always be attributed to inaccurate or even faulty measuring). Apart from this steam-specific data, an increase in the accuracy of energy-specific calculations according to BREF can also be achieved in steam measurements for air pre-heating, soot blowing, SNCR, SCR, flue-gas re-heating, as long as they have a major influence on the energy balance.

The periods of time relevant for balancing should not be too short (e.g. one month) in order to take into account process-technical linkages and fluctuations.
Individual possibilities for optimisation in the incineration process may be discussed bilaterally between the operator of an interested plant and the author of this report.

10. Plant efficiency (Pl_{ef}) according to the ECJ (equ) for R1 and to BREF for BAT

Plant efficiency factors (Pl_{ef}) must always be calculated with equivalents as indicated in BREF and not with absolute data in order to make the results comparable. Mean values are shown as weighted, and only for comparison as not weighted.

Waste incineration in W-t-E plants can be qualified as conforming with **BAT** if the plant delivers energy to third parties, but only in the case that **more energy is exported than the plant needs as self demand plus imported energy for the total incineration process** - energy recovery included. Imported energy (gas, oil, electricity etc.) has to be subtracted from the exported energy.

Taking the ECJ case as basis **for R1, more energy must be produced than the plant needs as self demand plus imported energy for the total incineration process** - energy recovery included. Imported energy (gas, oil, elect. etc.) has to be subtracted from the utilized energy.

The plant efficiency (Pl_{ef}) according to BREF should be calculated using the formula indicated in the BREF [1f;1g] where the amount of exported energy (E_{exp}) minus imported energy is the part of the numerator. The plant efficiency (Pl_{ef}) according to the ECJ judgement C-458/00 par. 33 [2] has to be determined using the BREF formula [1f;1g], but instead of E_{exp} the amount of produced (utilized) energy E_{prod} has to be used as main part of the numerator (equation for “plant efficiency factor” see Appendix 3).

This calculation of Pl_{ef} does not require knowledge of the energy content (NCV) of the waste. However, the result will mainly be influenced by the energy content of waste, and it can be expected that wastes with higher energy content will result in higher energy production and hence higher values of $Pl_{ef.}$

In the case of $Pl_{ef} > 1$ calculated using the ECJ interpretation with E_{prod} in the numerator as basis for classification as R1 (recovery) [8] more energy equivalents out of waste minus imported energy equivalents must be produced (utilized) than are needed to run the complete incineration process including energy production.

In the case of $Pl_{ef} > 1$ calculated in the sense of BREF with E_{exp} (instead of E_{prod}) in the numerator of the Pl_{ef} equation to become in energy concern a BAT-plant it is necessary to export more energy sequivalents out of waste minus imported energy equivalents than are needed to run the complete incineration process including energy production.

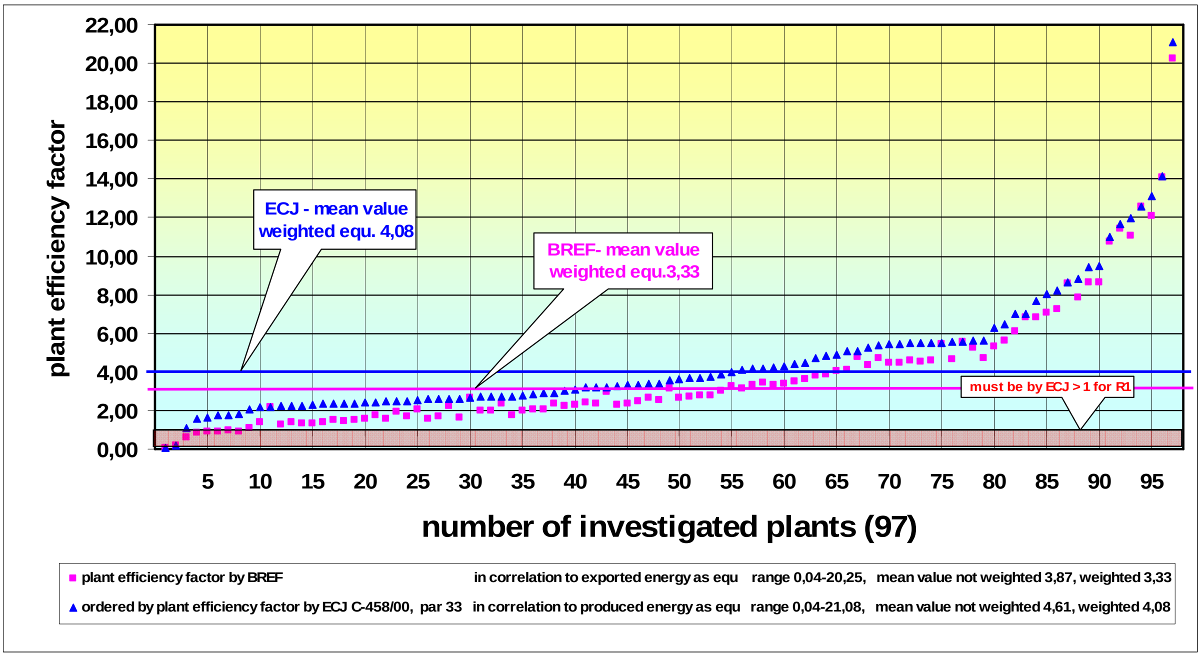
The correlation of the results between $Pl_{ef} > 1$ calculated using the ECJ interpretation and $Pl_{ef} > 1$ calculated using the BREF meaning indicates the energy self demand of the plant, and can be determined in percentage by division of (Pl_{ef} ECJ / Pl_{ef} BREF)*100, which may be quite informative for some plants.

In figure 14 the plant efficiency results for BREF and ECJ of the 97 W-t-E plants are presented.

> **95 out of the 97 investigated plants meet the R1 demand >1** and
> **89 out of the 97 meet also the BAT requirement >1**.

The BREF averages for BAT of all 97 plants is weighted 3,3 and not weighted 3,9 >>1 and for the ECJ weighted 4,1 and not weighted 4,6 >>1, which proves the importance of W-t-E plants as suppliers of energy, whereas the weighted figures are the energy relevant ones.

The results of the Pl_{ef} during this period are not higher in some countries because of the influence of highly efficient flue gas cleaning technologies combined with a relatively high energy self demand and the disadvantage that in general only a small part of the available heat energy can be used due to local and climate conditions.



(Reimann 2005)

Figure 14: Plant efficiency factors - calculated according to BREF and the ECJ-judgement with equivalents in correlation to exported/produced energy as BAT and R1 proof for ECJ C-458/00 for the 97 EuropeanW-t-E plants investigated (status 2001-2004)

11. Comparison of the total specific energy self demand and divided into specific electricity/heat demand depending on the throughput (size) of a plant

In this chapter the question if W-t-E plants with high throughput need less energy than smaller W-t-E plants do, will be answered. If there is a difference to what part of energy does it belong: heat and fuel or electricity demand? For this comparison the calculated results of the 97 W-t-E plants were used as the basis of this investigation.

Three plant size categories were distinguished:

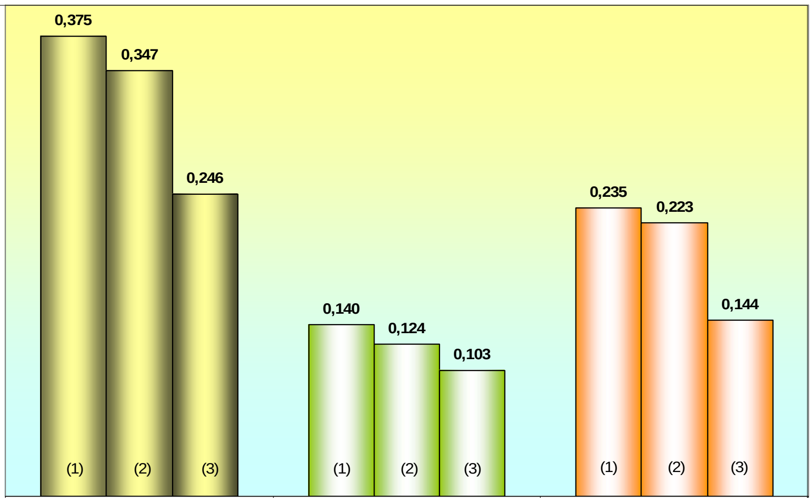
(1) plants with a throughput < 150.000 Mg/a (36 out of 97)
(2) plants with a throughput > 150.000 - < 300.000 Mg/a (29 out of 97)
(3) plants with a throughput > 300.000 Mg/a (32 out of 97)

The results are shown in the following figure 15.

Plants under (1) have the highest total specific energy demand with 0,375 MWh_{h+e}/Mg waste (108 % of (2)) , those under (2) show a lower demand with 0,347 MWh_{h+e}/Mg waste (shown as 100 %), those under (3) have the lowest energy demand with 0,246 MWh_{x}/Mg waste (71 % of (2)), which seems to be logical and realistic.

While evaluating these figures it must be kept in mind that not only the amount of throughput, but even the kind of flue gas cleaning system and by this the level of emission into the air influence the total specific energy demand of a plant. In general lower emissions into the air are combined with a higher energy demand.

The results after dividing the energy demand into specific electricity and heat (fuel) demand are even more interesting.



	total energy demand (external + circulated) MWhe + MWhh abs/Mg waste	total demand of electricity MWhe abs/Mg waste	total demand of heat MWhh abs/Mg waste
(1) Quantity of incinerated waste as annual throughput <150.000 Mg/a (36 W-t-E plants) as average 92.050 Mg/a	weighted 0,375	weighted 0,140	weighted 0,235
(2) Quantity of incinerated waste as annual throughput >150.000 till <300.000 Mg/a (29 W-t-E plants) as average 209.566 Mg/a	weighted 0,347	weighted 0,124	weighted 0,223
(3) Quantity of incinerated waste as annualthroughput >300.000 Mg/a (32 W-t-E plants) as average 458.716 Mg/a	weighted 0,246	weighted 0,103	weighted 0,144

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Figure 15: Mean values of energy demand in MWhe and MWhh abs/Mg for 97 European W-t-E plants in correlation to the annual throughput of the plants (status 2001-2004)

The specific demand for electricity decreases from 0,140 MWh_e/Mg of waste (1) (113 % of (2)) to 0,124 MWh_e/Mg of waste (2) (shown as 100 %) and 0,103 MWh_e/Mg of waste (3) (83 % of (2)).

The specific demand for heat decreases insignificantly from 0,235 MWh_h/Mg of waste (1) (105 % of (2)) to 0,223 MWh_h/Mg of waste (2) (shown as 100 %) and 0,144 MWh_h/Mg of waste (3) (65 % of (2)), which seems logical for (2) and (3).

The disadvantage for smaller plants (< 150.000 Mg/a) is often caused by a high level of energy self demand combined with a reduction of the plant efficiency coefficients and utilization rate, according to the WFD, ECJ or BREF.

12 Summary and conclusions

'Waste-to-Energy' (W-t-E) plants generate electricity and heat through the thermal treatment of municipal solid waste. In some EU Member States Waste-to-Energy (W-t-E) plants, even today, are still classified as disposal facilities, not taking into account the energy they produce and export, their contribution to energy supply, to saving resources (primary fuels) and the possibility of reducing emissions of CO_2 as a greenhouse gas (climate relevant).

In order to present the current and future energy potential of waste incineration this investigation uses a computer program applying the equations and formulae and energy questionnaire worked out and laid down in the BREF "Waste Incineration" from 2005 (in the following text abbreviated to BREF).

12.1 Amount of waste investigated and incinerated

The summary and conclusions of this report are based on the results of 97 CEWEP W-t-E plants from whole of Europe for the time period 2001-2004. The amount of waste being incinerated as announced by the operators of the plants taking part in this investigation was given as **24.070.136 Mg/**a, representing 76,9 % of CEWEP members (31,273 mio Mg(t)/2003), 49,3 % of EU 25 (48,84 mio Mg(t)/2003) or 45,8 % of EU 25 +CH+N (52,60 mio Mg(t)/2003). France with its plants was not included in this study because at this time it has not yet been member of CEWEP. This amount was taken into account as basis for the energy calculations in this report. **Each plant was only taken into account once** with its actual annual data even if during the time period several annual energy calculations were carried out.

By this high accordance the results of this investigation on energy can be generalised favourably at least for all the CEWEP W-t-E plants, however all the results will be used in the energy prognosis for all W-t-E plants in Europe excluding France (see chapter 2 of this report). Consequently the accuracy of the energy results may not be so high for the other W-t-E plants in Europe.

The combustion efficiency is shown at 97 % and the mean value of boiler efficiency is 81,8 %, in correlation to 97 % out of the sum of the energy input related to the NCV (calculated according to BREF) plus steam producing imported energy (see chapter 9,1 of this report).

12.2 NCV of investigated waste incinerated and imported energy demand

The mean value of **NCV exclusively from waste** weighted over the total amount being incinerated in the 97 W-t-E plants and calculated according to BREF results in 2,774 MWh/Mg of waste incinerated (9,987 GJ/Mg).

NCV ranges of the individual W-t-E plants can be seen in figure 1, while the blue triangles are calculated according to BREF, which are relevant for this study.

Corresponding to this NCV the additional imported energy demand is 0,078 MWh/Mg, which requires primary fuels. About 30 % of this imported energy demand is also used for steam production (see chapter 5 of this report).

The mean value of the total energy input adds up to 2,852 MWh/Mg or 10,267 GJ/Mg.

12.3 Energy input/output/demand specific and in % for all and the 3 different categories of W-t-E plant

In the following specifications, comparisons and assessments only the weighted mean values are taken into account, as being relevant for the determination of energy and climate considerations.

For this study all the 97 CEWEP W-t-E plants were investigated together, and they were also divided into the 3 following categories for energy recovery (more details see chapter 8)

1) plants mainly producing **electricity** (25 out of the 97 investigated plants)
   Classification: with >17.5 % electricity production and < 5 % exported heat
   or <17.5 % electricity production and < 2 % exported heat
2) plants mainly producing **heat** (28 out of the 97 investigated plants)
   Classification: with > 60 % heat utilization with < 5 % exported electricity
   or < 60 % heat utilization and < 2 % exported electricity
3) plants with **CHP** production (44 out of the 97 investigated plants)

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Classification: with electricity production and heat utilization but not falling under 1) or 2)

The following list shows the **specific production and export** as well as the energy demand for electricity and heat **in correlation to 1 Mg (ton) of waste incinerated**. For the determination of these specific figures the NCV is not needed. Nevertheless, indirectly its influence results in higher or lower amounts of specific produced and exported energy.

The specific energy data is listed in MWh_{abs} of energy in correlation of Mg waste incinerated as figures in absolute **(see chapter 8, article 8.2 – 8.5).**

	97 plants total	28 plants mainly prod. electricity	25 plants mainly prod. heat	44 plants CHP	
waste incinerated	**24,070** (100%)	**5,706** (23,7%)	**7,001** (29,1%)	**11,363** (47,2%)	**mio Mg/a**
energy input total (incl. import)	**2,852**	**2,782**	**2,879**	**2,882**	**MWh/Mg**
electricity produced	**0,401**	**0,605**	**0,062**	**0,447**	**MWh_e/Mg**
electricity exported	0,302	0,492	0,019	0,326	MWh_e/Mg
heat produced and utilized	**0,992**	**0,143**	**1,955**	**1,032**	**MWh_h/Mg**
heat exported	0,878	0,073	1,818	0,901	MWh_h/Mg
total energy demand (sum)	**0,292***	**0,241**	**0,323***	**0,308***	**MWh_{e+h}/Mg**
whereas this total energy demand is covered by:					
imported energy (demand)	0,078	0,058	0,144	0,057	MWh_{e+h}/Mg
produced electricity (self demand)	0,099	0,113	0,043	0,121	MWh_e/Mg self
produced heat/steam (self demand)	0,114	0,070	0,137	0,131	MWh_h/Mg

* Differences in total energy demand to the sum of demand of imported energy + self demand of produced electricity + self demand of heat/steam are resulting from rounding effect

To make energy results comparable between the W-t-E plants and to show the influence of different technologies used (e. g. for benchmarking) not specific data but energy results in percentages (%) should be applied. In this case the correct determination of the NCV of the waste incinerated, which can easily be determined using the NCV formula from the BREF, is needed.

	97 plants total	28 plants mainly prod. electricity	25 plants mainly prod. heat	44 plants CHP	
waste incinerated	**24.070** (100%)	**5.706** (23,7%)	**7.001** (29,1%)	**11.363** (47,2%)	**mio Mg/a**
energy input total (incl. import)	**100**	**100**	**100**	**100**	**% abs**
electricity produced	**14,1**	**21,8**	**2,1**	**15,5**	**% abs**
Electricity exported	10,6	17,7	0,7	11,3	% abs.
Heat produced and utilized	**34,8**	**5,1**	**67,9**	**35,8**	**% abs**
Heat exported	30,8	2,6	63,1	31,3	% abs
Total energy demand (sum)	**10.2***	**8,7**	**11,2***	**10,7**	**% abs**
whereas this total energy demand is covered by:					
imported energy (demand)	2,7	2,1	5,0	2,0	**% abs**
produced electricity (self demand)	3,5	4,1	1,4	4,2	% abs
produced heat/steam (self demand)	4,0	2,5	4,8	4,5	% abs

* Differences in total energy demand to the sum of demand of imported energy + self demand of produced electricity + self demand of heat/steam are resulting from rounding effect

The list above shows the mean values of efficiencies in % calculated by MWh_{abs} of energy in correlation to MWh_{abs} of total energy input as figures in absolute.

In figure 16 the results from these two lists are combined with specific energy data and percentages as average values for all 97 W-t-E plants.

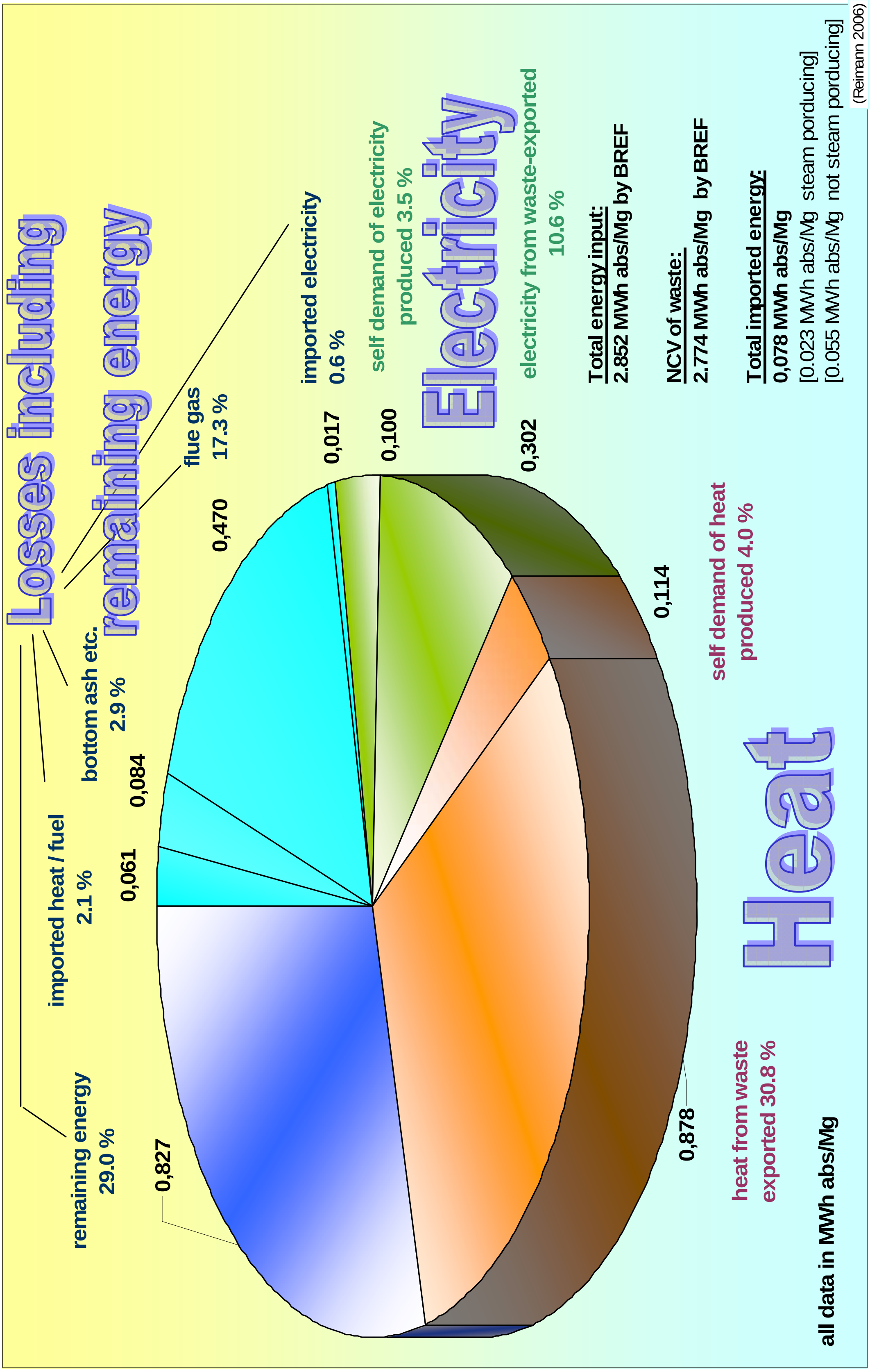

Figure 16: Mean distribution of energy as a pie chart of specific data and their percentages of the total energy input all weighted figures, using BREF-formulae for the 97 European W-t-E plants investigated (status 2001-2004)

12.4 Sum of energy recovery rates in % absolute for all and the 3 different categories of W-t-E plants

The sum of total mean efficiency rates of heat plus electricity produced and exported in figures **absolute as MWh_{abs}** in percent of total energy input in MWh_{abs} are listed as follows. This summarising method is not in accordance with BREF because the quality rating equivalents are missing.

	97 plants total	28 plants mainly prod. electricity	25 plants mainly prod. heat	44 plants CHP	
waste incinerated	**24,070** **(100%)**	**5,706** **(23,7%)**	**7,001** **(29,1%)**	**11,363** **(47,2%)**	**mio Mg/a**
Σ electricity and heat prod of (Ew+Ef+Eimp)	**48,8***	**26,9**	**70,1***	**51,3**	**% abs.**
Σ electricity and heat exp of (Ew+Ef+Eimp)	**41,3**	**20,3**	**63,8**	**42,6**	**% abs.**
Total energy demand of 0,97(Ew+Ef)	**7,6**	**6,6**	**6,2**	**8,6***	**% abs.**

* Differences in total energy demand to the sum of demand of imported energy + self demand of produced electricity + self demand of heat/steam are resulting from rounding effect

The evaluation of these results gives the impression that heat production and heat export is the best and electricity production and export the worst option for energy recovery from waste. However, the fact that this is not the case can be seen in the following list of evaluated results of the different kinds of energy, as indicated in BREF.

12.5 Sum of energy recovery rates in equivalent for all and the 3 different categories of W-t-E plants in accordance to WFD and ECJ

Equivalent factors and values indicated in WFD or BREF should always be used for calculating energy recovery (utilization) coefficients, plant efficiency factors and if different qualities of energy have to be summarized e.g. for benchmarking. Only in this way different kinds of energy can be evaluated and summarized to a comparable energy mix output of e.g. heat, steam and electricity.

The equivalent factors are for 1 MWh_e abs =2,6 MWh equ by WFD and 2,6316 MWh equ by BREF; 1 MWh_h abs = 1,1 MWh equ by WDF if commercial used and 1,0989 MWh equ by BREF and 1 MWh steam abs =1,1 MWh equ by WDF if commercial used and 1,0 MWh equ by BREF. For example only with this equivalent method can it be shown that a W-t-E plant with e.g. 18 % electricity production (WFD equ 0,468) is congruent with a W-t-E plant with e.g. 42,5 % utilization of district heat (WFD equ 0,468) or a plant with 42,5 % (WFD equ 0,468) commercial use of steam.

The combustion of waste constitutes an energy recovery operation where the waste fulfils a useful function as a means of generating energy, replacing the use of a primary energy source which would have been needed to fulfil that function.

One of the main criteria in order to be classified as a recovery plant (as R1 of Annex II of the draft Waste Framework Directive-WFD) is met if the energy generated by, and reclaimed from, combustion of the waste (minus imported energy) is equal to or > 0,60 in comparison to 0,97 of the energy input out of waste plus steam producing imported primary fuels (see formula in Appendix 2)

The general formula to calculate the energy recovery rate is shown in Appendix 2. It is based on the calculation of boiler efficiency from BREF.

If instead of produced (generated) the exported energy is taken into account then the energy recovery rates will be lower.

The following table 1 shows the energy recovery coefficients in **accordance to ECJ** for produced energy **with equivalents by BREF** and in **accordance to WFD with equivalents by WFD** for produced minus imported energy as mean (weighted and not weighted), min and max values and their differences to each other for all and 3 different categories of W-t-E plants.

The following table 2 shows the number of plants out of the 97 investigated European W-t-E plants falling into the classes with recovery efficiency coefficients < 0,50, > 0,50 - < 0,60 and > 0,60 by ECJ and by WFD.

By comparing the weighted figures in equivalent with those in absolute the conclusion can be drawn that in reality CHP with 0,793 (weighted) by WFD or 0,820 by ECJ is the best solution. Comparing the mean values of the energy recovery rates of the 3 different categories they are now on a similar level for energy generated between 0,625 – 0,793 (weighted) by WFD and 0,654 – 0,820 (weighted) by ECJ.

Table 1 : Comparison of R1 results calculated in accordance to ECJ judgement C-458/00 par 34 and calculated in accordance to R1 formula by draft WFD (12/05)

Calculation of R1of 97 different CEWEP W-t-E plants with energy data out of 2001-2004										difference between ($R1_{WFD}$-$R1_{ECJ}$)						remarks
number of W-t-E plants	in accordance to ECJ judgement C-458/00 (without subtraction of imported energie from Ep) as figures (-)				$R1_{ECJ}$ weighted average minus imported energy[1]	by R1 formula of Draft WFD (12/05) as figure (-)				R1 arithmetic averages		R1 weighted averages		$R1_{ECJ}$[1] weighted aver. minus imp. energy		
	$R1_{ECJ}$ arithm. average	$R1_{ECJ}$ weighted average	$R1_{ECJ}$ min	$R1_{ECJ}$ max		$R1_{WFD}$ arithm. average	$R1_{WFD}$ weighted average	$R1_{WFD}$ min	$R1_{WFD}$ max	absolut	% of $R1_{WFD}$	absolut	%	absolut	% of $R1_{WFD}$	Different equivalence factors in ECJ by BREF and WFD
total 97 W-t-E plants	**0,755**	**0,766**	0,170	1,353	**0,722**	**0,715**	**0,735**	0,011	1,331	**-0,040**	-5,6	**-0,031**	-4,2	**0,013**	1,8	
thereof 25 mainly elecricity producing	**0,608**	**0,654**	0,404	0,810	**0,630**	**0,571**	**0,625**	0,340	0,770	**-0,037**	-6,5	**-0,029**	-4,6	**-0,005**	-0,8	
thereof 28 mainly heat producing	**0,809**	**0,797**	0,170	1,199	**0,703**	**0,718**	**0,705**	0,011	1,127	**-0,091**	-12,7	**-0,092**	-13,0	**0,002**	0,3	high difference caused by imported electricity (3%abs)
thereof 44 CHP producing	**0,805**	**0,820**	0,451	1,353	**0,798**	**0,770**	**0,793**	0,408	1,331	**-0,035**	-4,5	**-0,027**	-3,4	**-0,005**	-0,6	

[1] **illustrated in the figures 12, 12a, 12b, 12c of the CEWEP energy report 2001-2004 (blue coloured line) as mean values weighted for possible comparison reason as preview in anticipation of the expected WFD**

(Reimann 2006)

Table 2 : Comparison of R1 results calculated in accordance to ECJ judgement C-458/00 par 34 and calculated in accordance to R1 formula by draft WFD (12/05)

Amount of the 97 different CEWEP W-t-E plants investigated with energy data out of 2001-2004 classified by their achievable R1 levels															
number of W-t-E plants	in accordance to ECJ judgementC-458/00						in accordance to the draft of WFD						delta R1 classified by ECJ and WFD (basis WDF numbers)		
	R1 0 < 0,50		R1 > 0,50 - < 0,60		R1 > 0,60		R1 0 < 0,50		R1 > 0,50 - < 0,60		R1 > 0,60				
	number of total	% of total numb.	number of total	% of total numb.	number of total	% of total numb.	number of total	% of total numb.	number of total	% of total numb.	number of total	% of total numb.	R1 0 < 0,50	R1 > 0,50 - < 0,60	R1 > 0,60
total 97 W-t-E plants	**10**	100,0	**10**	89,7	**77**	79,4	**12**	100,0	**18**	87,6	**67**	69,1	2	8	-10
thereof 25 mainly elecricity produc	**4**	100,0	**7**	84,0	**14**	56,0	**6**	100,0	**7**	72,0	**12**	48,0	2	0	-2
thereof 28 mainly heat producing	**4**	100,0	**0**	85,7	**24**	85,7	**4**	100,0	**5**	85,7	**19**	67,9	0	5	-5
thereof 44 CHP producing	**2**	100,0	**3**	95,5	**39**	88,6	**2**	100,0	**6**	95,5	**36**	81,8	0	3	-3
number and % of total 97 W-t-E plants reaching R1 level > 50 %			**87**	89,7					**85**	87,6					
number and % of total 97 W-t-E plants reaching R1 level > 60 %					**77**	79,4					**67**	69,1			

(Reimann 2006)

12.6 Plant efficiency factor according to ECJ as R1 criteria and to BREF as BAT criteria for W-t-E-plants

Plant efficiency factors (Pl_{ef}) must always be calculated with equivalents as indicated in BREF and not with absolute data in order to make the results comparable (see formulae in Appendix 3).

Waste incineration in W-t-E plants can be qualified as conforming with BAT if the plant allows delivery of energy, but only in the case if more energy is exported than the plant needs as self demand plus imported energy for the operation of the total incineration process - energy recovery included – which is proven if $Pl_{ef} > 1$.

Imported energy (gas, oil, electricity etc.) has to be subtracted from the exported energy.

Taking the ECJ case as basis **for R1, more energy must be produced than the plant needs as self demand plus imported energy for the total incineration process** - energy recovery included - which is proven if $Pl_{ef} > 1$. Imported energy (gas, oil, elect. etc.) has to be subtracted from the utilized energy.

The result from dividing the total produced energy minus imported energy in equivalent by BREF MWh_{equ} by the total energy demand to run the incineration process in a correct way in equivalent MWh_{equ} (see chapter 6 of this report) is the basis to prove another ECJ R1 criteria. The calculation is carried out with weighted mean values.

The criteria for R1 [8] given **by ECJ judgement C-458/00 par 33: recovery efficiency rate should be > 1; in this case another main purpose of recovery is achieved** (see chapter 10 of this report).

	97 plants total s. 8.2.2	28 plants mainly prod. electricity s. 8.3.2	25 plants mainly prod. heat s. 8.4.2	44 plants CHP s . 8.5.2	
waste incinerated	**24,070** (100%)	**5,706** (23,7%)	**7,001** (29,1%)	**11,363** (47,2%)	**Mio. Mg/a**
Plant efficiency factor (ECJ-prod):	***4,1***	***3,9***	***3,8***	***4,3***	***(-) equ.***
Plant efficiency factor (BREF-exp):	***3,3***	***3,0***	***3,4***	***3,5***	***(-) equ.***

95 out of the 97 investigated plants meet the R1 demand $Pl_{ef} > 1$ by ECJ;
89 out of the 97 meet the BAT requirement $Pl_{ef} > 1$.

12.7 Optimisation potential of energy recovery and saving resources by W-t-E plants

To improve energy recovery and by this increase the recovery rate and plant efficiency factor, plant optimisation actions should be taken. These measures can be divided into 4 categories:

1. Optimisation of process methods for thermal treatment (very low to medium investment)
2. Increase in electricity production (medium to high investment)
3. Increase in heat utilisation (medium to high investment)
4. Methods to decrease the need for primary energy (low to medium investment)

In every case, for all balancing measurements it is crucial and an essential precondition to have suitable low pressure loss and accurate measuring instruments (with very low permissible measurement tolerances, e. g. +/- 0.5 % of the actual measurement) which register the pertinent energy specific data correctly and in their entirety, at least for steam and boiler water measurements [e.g. 9]. Incorrect measurement of steam quantities is the cardinal reason for most of the deviations in the results of NCV and all corresponding efficiencies.

The possible potential to increase the energy recovery in W-t-E plants may be seen in the goal that each plant within its group of classification as mainly producing electricity, mainly producing heat or CHP producing should reach the recent corresponding mean energy recovery results as indicated in the previous lists, but at least an energy recovery coefficient of 0,60 (still under discussion). A further solution to achieve better energy results is to increase the heat recovery rate in the group of mainly producing electricity and by this to move into the CHP group. This is also possible for the group mainly producing heat recovery, but not so effective if the installation of a turbine is necessary to produce electricity in addition to heat. Even if the heat recovery rate itself will be decreased through this change, the value of produced energy will be increased.

The previously described goals can only be realised if the local conditions and situation permit these solutions and that there is a demand and an economically viable market for the kind of additional energy produced. For district heating the access to the grid and the infrastructure respectively are very important because district heat, unlike electricity, cannot be transported long distances. In the majority of cases an increase in energy recovery rates will be combined with medium or high level of investment.

By optimising the process and minimizing the consumption of imported energy the energy demand for operating the incineration process can often be reduced. An energy saving potential may be achievable if the energy consumption will be in the average listed previously for the different groups. This is most important for the W-t-E plants only producing heat, because they have to import most of their energy demand, mainly electricity.

A prognosis of the possible amount of additional energy recovery that exists in most European W-t-E plants needs special investigations for each individual plant, and therefore cannot be generalised with sufficient accuracy at this time.

Other possibilities to reduce the specific energy demand are the size (throughput) of a plant as well as the kind of flue gas cleaning system. If less energy is needed to run the incineration process the more energy can be exported mainly electricity.

12.8 Influence of the size of a W-t-E plant on energy demand

As shown in chapter 10 of this report the size (throughput) of a plant as well as the kind of flue gas cleaning system are decisive for the specific energy demand. Energy demand figures of around 0,35 MWh/Mg are needed for running a proper incineration process plants under the existing local conditions in Europe at a throughput of > 150.000 Mg/a. Plants with a throughput > 300.000 Mg/a show an energy demand with about 0,25 MWh/Mg that means about 20-35 % less energy demand than those of > 150.000 Mg/a. Divided into heat and electricity demand, the ratio is about 1:1,5.

12.9 CO_2-reduction potential by waste incineration with energy recovery

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

The part of <u>renewable carbon</u> (C) in municipal solid waste is in general <u>50 – 80 %</u> (figures are still under investigation; a study by the Öko-Institut found that it is 62 %). This means, in the case of waste incineration this part is considered as CO_2 neutral, and thus without any negative influence on the climate.

The most important fact is that waste incineration produces different kinds of energy, which no longer have to be provided by dedicated plants using primary fuels for energy production of electricity or heat. Thanks to W-t-E plants the consumption of primary fuel with a content of 100 % fossil carbon used in dedicated energy producing industries can be substituted.

By using energy from waste in comparison with energy from power- and/or heating plants the achievable reduction potential of fossil CO_2-emissions is < 600 -1200 kg / MWh electricity and 250 - 600 kg / MWh heat (depending on the kind of primary fuel mix for electricity or heat/district heat production, and that the energy is used as basic supply).

Through these CO_2-savings W-t-E plants are receiving a CO_2-bonus depending on the kind and quantity of produced energy from waste, the demand of imported energy and by this are not CO_2-producers, but reducers of CO_2.

To increase this amount of CO_2-savings through reduction of imported energy and higher energy recovery rates from waste incineration should be the goal of every plant operator. This should also be the concern of the responsible authorities to help increase the production of energy from waste incineration through support to enable necessary investments.

12.10 Annual energy results of the 97 W-t-E plants for the investigated time period 2001-2004 and prognosis of the annual energy recovery potential for the total waste incinerated in Europe in 2003

The total annual energy input, energy output produced and exported as well as the energy demand to run the incineration process by imported energy and by energy self demand can be summarised as follows:

	specific averages from 97 plants status 2001-2004	energy input/output out of (EU 25) 48,84 mio Mg/a waste incinerated	(EU 25+CH+N) 52,60
	MWh/Mg (% abs.)	MWh/a	MWh/a
energy input total (incl. import)	**2,852 (100 %)**	**139.292.000**	**150.015.000**
electricity produced	**0,401 (14,1 %)**	**19.585.000**	**21.093.000**
electricity exported	0,302 (10,6 %)	**14.750.000**	**15.885.000**
heat produced and utilized	**0,992 (34,8 %)**	**48.449.000**	**52.179.000**
heat exported	0,878 (30,8 %)	**42.882.000**	**46.183.000**
total energy demand (sum)	**0,292 (10,2 %)**	**14.261.000**	**15.359.000**
whereas this total energy demand is covered by:			
imported energy (demand)	0,078 (2,7 %)	**3.810.000**	**4.103.000**
produced electricity (self demand)	0,099 (3.5 %)	**4.835.000**	**5.207.000**
produced heat (self demand)	0,114 (4,0 %)	**5.568.000**	**5.996.000**

These energy results do not include optimisation measures as described already or the increase of waste and its quality to be treated in W-t-E plants. In any case these actions would improve the energy production by W-t-E plants in connection with savings of resources as primary fuels and reduction of CO_2 emissions as a greenhouse gas.

13. Final remarks

MSW, as the main fraction of waste burnt in European W-t-E plants, consists to a great extent of biogenous matter, which is neutral for the environment **because this fraction does not generate CO_2** emissions as greenhouse gas. Problematic CH_4 emissions from landfilling MSW can be avoided. The demand on resources such as primary fuels must be reduced as far as possible. Additional energy recovery as far as it is economically viable and technically feasible, taking the local conditions into account, is always environmentally and often economically advantageous, because of the augmentation of energy production.

The assessment should always be carried out using the same method e.g. as used in this report to avoid possible mistakes, to get comparable energy results worldwide and by this improve the acceptance of waste incineration. This proves its positive effects on resources and climate protection and helps operators to decide the necessity of investments for optimisation and improvements of a plant.

With this calculation method not only the NCV of every incinerated waste is known but even the influence of needed or intended changes in the operation of a plant can be anticipated. For existing plants the controlling of the energy efficiencies can be done in a minimum of time, as well as for new plants in the design stage.

If operators of the European W-t-E plants would like perform the energy calculation as shown in this report themselves, a computer program is available under www.reimann-abfallenergie.de and can be ordered by e-mail info@dr-reimann-bamberg.de.

Individual possibilities for optimisation of the incineration process may be discussed bilaterally between the operator of an interested plant and the author of this report.

On request, and assuming the CEWEP approval it will be possible to highlight the results of a single plant in the drawings and graphs of this report with its anonymous figures and by this find its position in comparison with all the other investigated plants.

References

[1] BREF/BAT Waste Incineration for Integrated Pollution Prevention and Control (IPPC), "Draft Reference Document on the Best Available Techniques for Waste Incineration", EUROPEAN COMMISSION, EIPPC Bureau Sevilla, May (2005)

[1a] of BREF - energy questionnaire: Annexes 10.4, article 10.4.3, pg. 593-595

[1b] of BREF - energy systems: Annexes 10.4, article 10.4.1, pg. 590

[1c] of BREF - formula for NCV: Chapter 2, article 2.4.2, pg. 83-84

[1d] of BREF - example for NCV calculation: Annexes 10.4, article 10.4.2, pg. 591-592

[1e] of BREF - equivalence factors: Chapter 3, article 3.5.3, pg. 194

[1f] of BREF - formula for plant efficiency: Chapter 3, article 3.5.6, pg. 199

[1g] of BREF - example for plant efficiency calculation: Annexes 10.4, article 10.4.5, pg. 599-60

[2] ECJ judgement "C-458/00" par. 32-34 in the case Strasbourg/Luxembourg C-458/00 dated 13.02 (2003)

[3] Directive 2000/76/EC for waste incineration (2000)

[4] Reimann, D.O.; Hämmerli, H.: „Verbrennungstechnik für Abfälle in Theorie und Praxis", Schriftenreihe: Umweltschutz Bamberg (1995)

[5] Reimann, D.O.: „Energetische Bilanzierung von Müllverbrennungsanlagen", Beiträge zur Umweltgestaltung A 157 „Abfall, Energie und Klima", Johnke, Scheffran, Soyez (Hrgs.) Erich Schmitt Verlag ISBN 3 503 08324 3 (2004)

[6] Reimann, D.O.: „Ermittlung und Bedeutung von Kennzahlen zur Energie und Anlagennutzung sowie zu Wirkungsgraden für die Abfallverbrennung", Fachzeitschrift Müll und Abfall, Heft 10 (2003)

[7] IPCC-Richtlinie: „Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories – IPCC/OECD/IEA Programme" , WMO Intergovernmental Panel on Climate Change UNEP, July(2000)

[8] Annex II A and B of Council Directive 75/442/EEC on waste, as amended by Commission Decision 96/350/EC, 15.07.(1975) / 24.05.(1996) and in the draft of WFD Dec. (2005)

[9] Poettersonde: www.pvt-tec.de

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Appendix A

Appendix A contains the following results to the chapter 8:

8.2: Energy results from 97 European W-t-E plants without any specification of energy recovery

8.3: Energy results from 25 European W-t-E plants with mainly electricity production as energy recovery

8.4: Energy results from 28 European W-t-E plants with mainly heat production as energy recovery

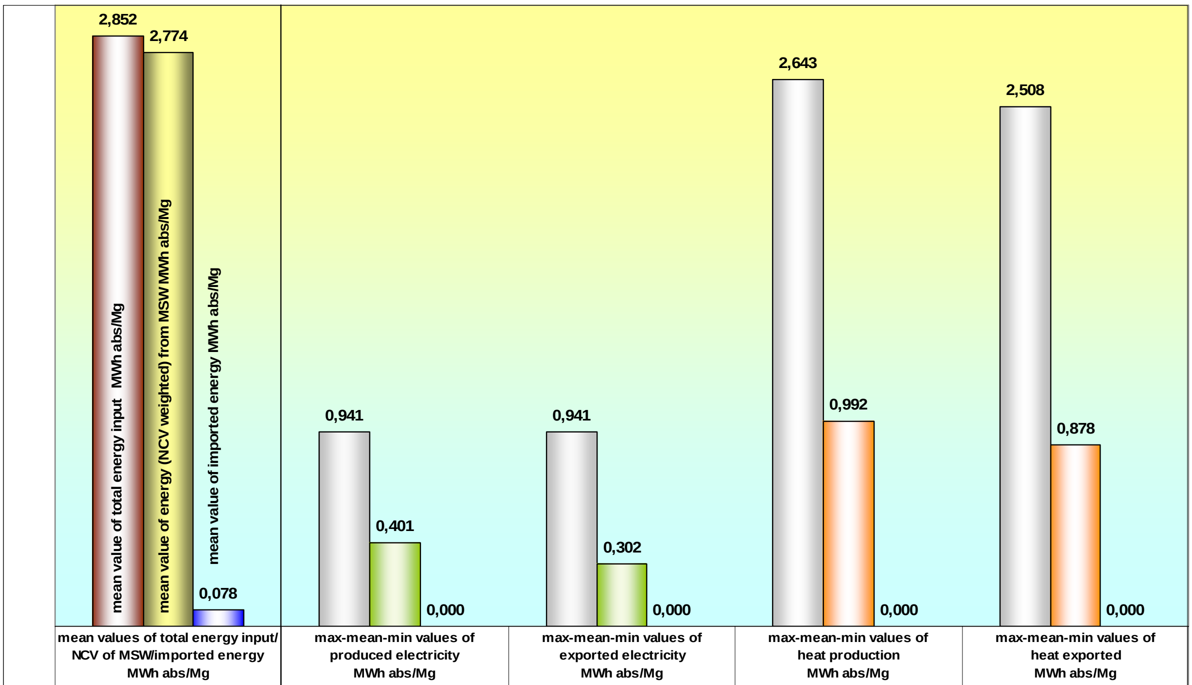
8.5: Energy results from 44 European W-t-E plants with CHP as energy recovery

8. Categorising of W-t-E plants depending on the kind of energy recovery in correlation to energy demand, heat and electricity production/export

8.2 Energy results of 97 European W-t-E plants without any specification of energy recovery (status 2001-2004)

The results for the 97 investigated European W-t-E plants equipped with grade firing systems for an amount of **24.070.136** Mg/a waste incinerated at a weighted mean NCV of waste of 9,987 GJ/Mg plus imported energy 0,281 GJ/Mg = 10,268 GJ/Mg equivalent to (2,774 + 0,078) = 2,852 MWh/Mg are shown in the following figures 3 - 7 and are listed in the following text. For easier understanding of all the figures are presented in MWh/Mg (if using GJ/Mg results have to be multiplied with the conversion factor 3,6):

8.2.1 Specific energy data per Mg(t) waste incinerated of 97 European W-t-E plants without any specification of energy recovery



	mean values of total energy input/ NCV of MSW/imported energy MWh abs/Mg		max-mean-min values of produced electricity MWh abs/Mg	max-mean-min values of exported electricity MWh abs/Mg	max-mean-min values of heat production MWh abs/Mg	max-mean-min values of heat exported MWh abs/Mg
Reihe1	2,852	max	0,941	0,941	2,643	2,508
Reihe2	2,774	mean weighted	0,401	0,302	0,992	0,878
Reihe3	0,078	min	0,000	0,000	0,000	0,000

(Reimann 2006)

Figure 3: Energy input/electricity and heat production and export in absolute - max-mean-min specific energy data in MWh abs/Mg for 97 W-t-E plants (status 2001-2004)

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- spec. production of electricity:

in absolute: mean weighted **0,401 MWh_e /Mg waste** (min 0,000 / max 0,941)

- spec. export of electricity:

in absolute: mean weighted **0,302 MWh_e /Mg waste** (min 0,000 / max 0,941)

- spec. production/utilization of steam and heat:

in absolute: mean weighted **0,992 MWh_e /Mg waste** (min 0,000 / max 2,843)

- spec. export of steam and heat:

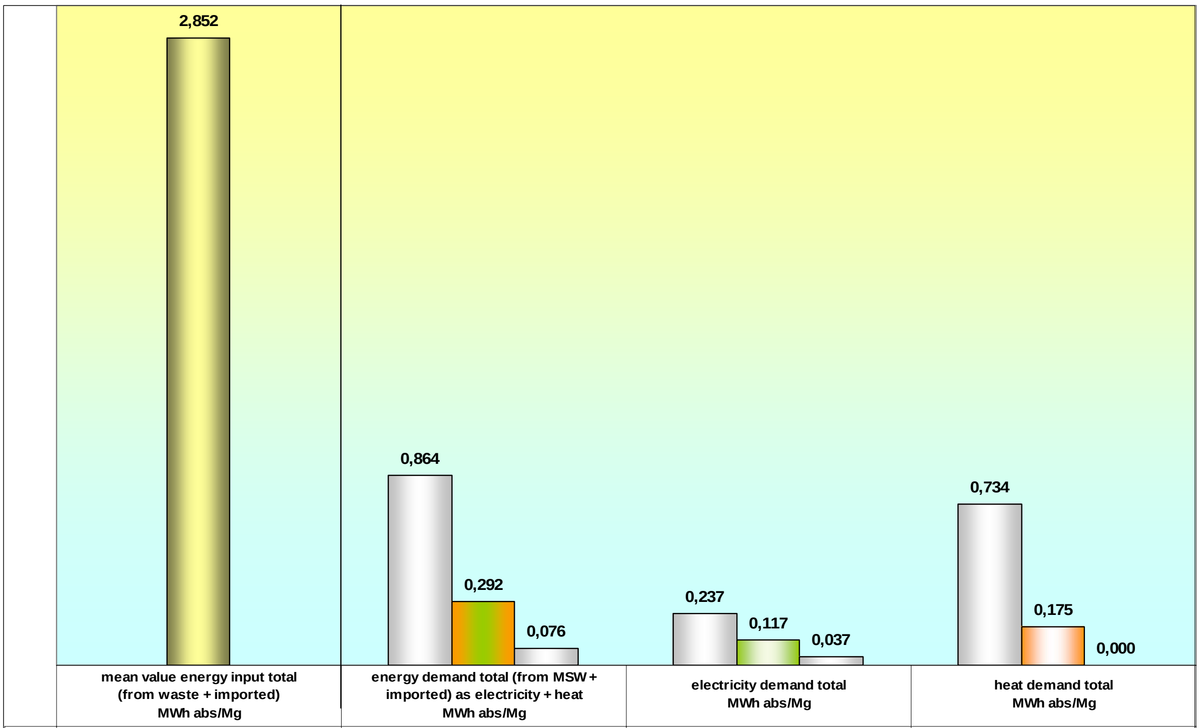
in absolute: mean weighted **0,878 MWh_e /Mg waste** (min 0,000 / max 2,608)

- total spec. energy demand for running the process:

in absolute: mean weighted **0,292 MWh_e /Mg waste** (min 0,076 / max 0,864)

- spec. energy demand imported included in the total spec. energy demand:

in absolute: mean weighted **0,078 MWh_e /Mg waste** (min 0,000 / max 0,452)



	mean value energy input total (from waste + imported) MWh abs/Mg	energy demand total (from MSW + imported) as electricity + heat MWh abs/Mg		electricity demand total MWh abs/Mg	heat demand total MWh abs/Mg
Reihe1		max	0,864	0,237	0,734
Reihe2	2,852	mean weighted	0,292	0,117	0,175
Reihe3		min	0,076	0,037	0,000

(Reimann 2006)

Figure 4: Energy demand for running the incineration process - max-mean-min specific energy data in MWh abs/Mg for 97 European W-t-E plants (status 2001-2004)

8.2.2 Energy efficiencies in percent (%) in relation to the total energy input (see figure 6 also) calculated with BREF formulae from Annexes 10.4 [1] for the 97 European W-t-E plants without any specification of energy recovery:

- electricity production in percent:

in absolute: mean weighted **14,1 %** (min 0,0 / max 27,9)

- electricity export in percent:

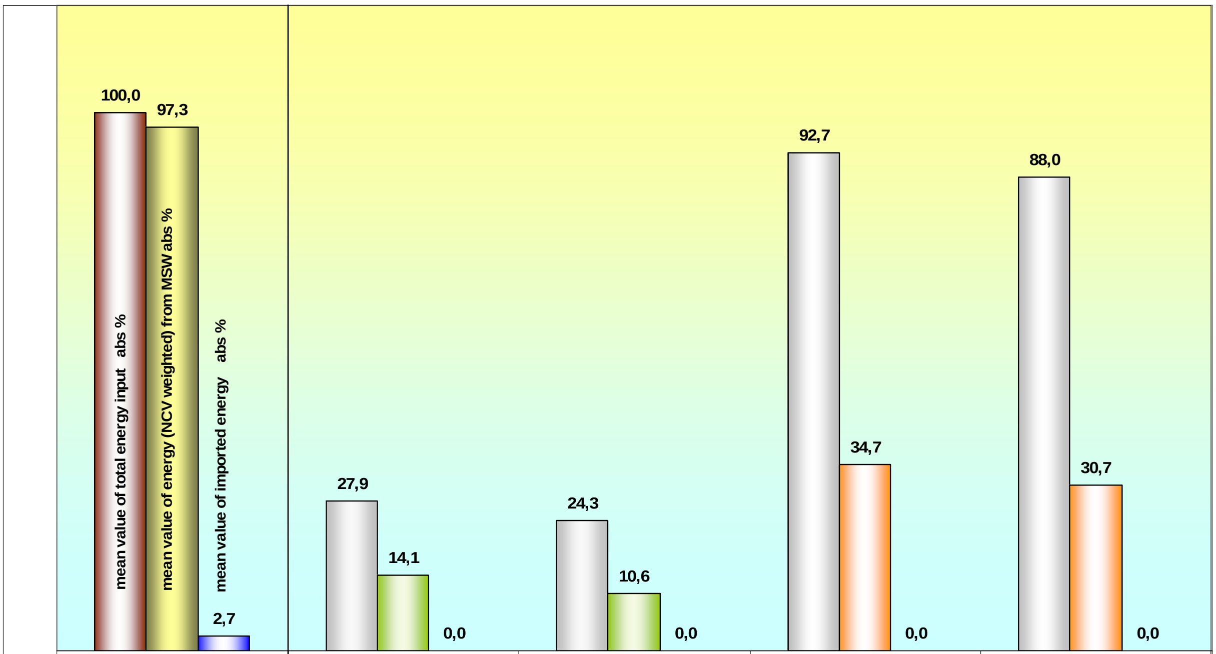
in absolute: mean weighted **10,6 %** (min 0,0 / max 24,3)

- heat and/or steam production in percent:

in absolute: mean weighted **34,8 %** (min 0,0 / max 92,7)

- heat and/or steam export in percent:

in absolute: mean weighted **30,8 %** (min 0,0 / max 88,0)



	mean values of total energy input/NCV of MSW/imported energy abs %	max-mean-min values of produced electricity %	max-mean-min values of exported electricity %	max-mean-min values of heat production %	max-mean-min values of heat exported %
Reihe1	100,0	max 27,9	24,3	92,7	88,0
Reihe2	97,3	mean weighted 14,1	10,6	34,7	30,7
Reihe3	2,7	min 0,0	0,0	0,0	0,0

(Reimann 2006)

Figure 5: Energy input/electricity and heat production and export - max-mean-min specific energy data absolute <u>in %</u> for 97 European W-t-E plants (status 2001-2004)

- total energy demand for running the process in percent:

in absolute: mean weighted **10,2 %** (min 2,5 / max 29,1)

- total energy imported included in the total energy demand for running the process in percent:

in absolute: mean weighted **2,7 %** (min 0,0 / max 14,3)

- sum of electricity and heat/steam production in percent:

in absolute: mean weighted **48,9 %** (min 14,8 / max 92,7)

- sum of electricity and heat/steam export in percent:

in absolute: mean weighted **41,3 %** (min 8,4 / max 88,0)

Figure 6 : Not existing

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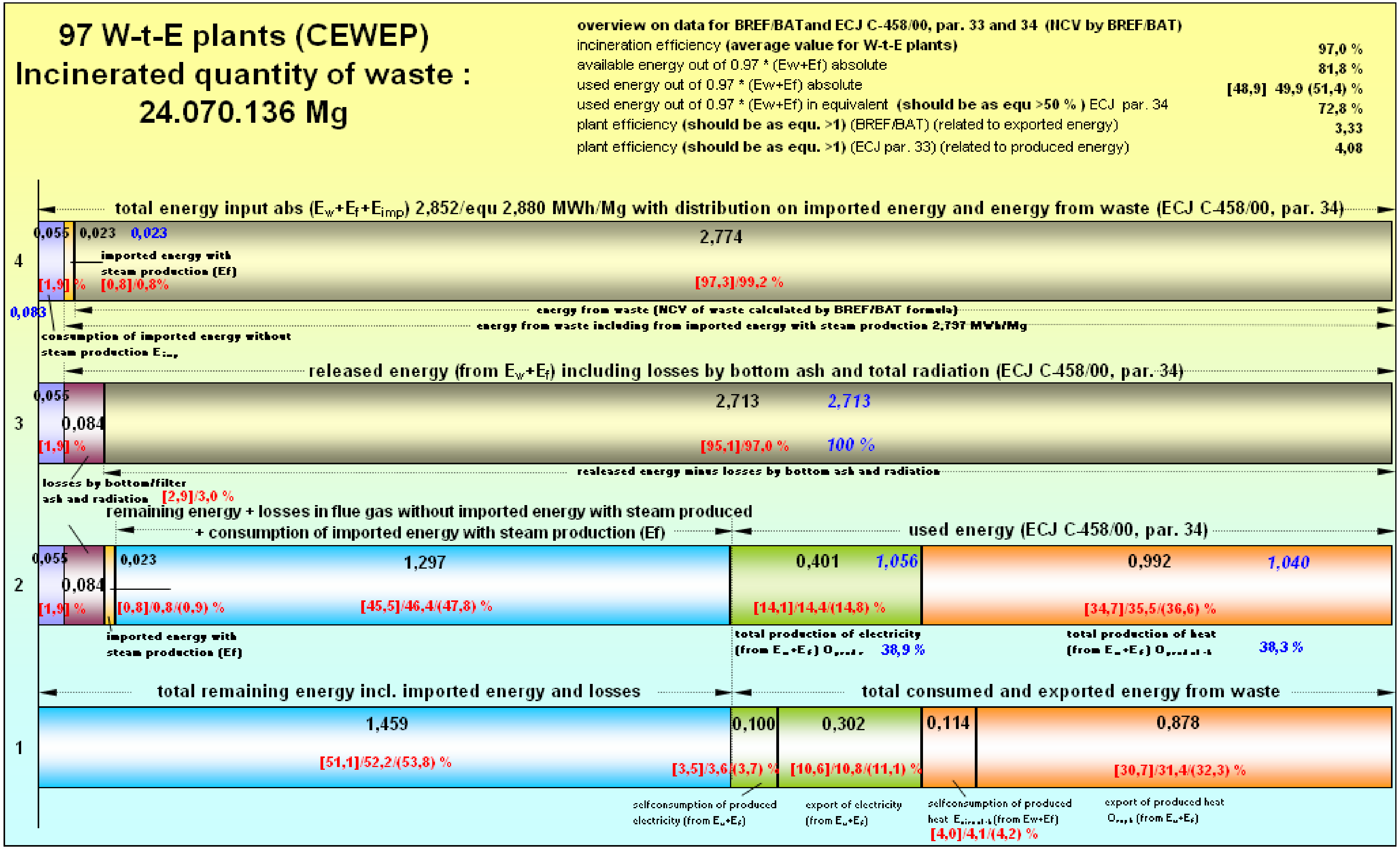

Explanations: [-]: % values abs. are related to the total energy input (Reimann 2005)
without bracket : % values abs. are related to the released energy incl. losses by bottom ash and radiation
(-): % values abs. are related to the released energy minus losses by bottom ash and radiation
in italics: % values and figures are related to the generated energy as **equ. calculated**

all energy figures in MWh/Mg (ton

Figure 7: Mean distribution of energy as a horizontal bar graph for specific data and in percentages <u>all weighted figures</u> by BREF-formulae for the 97 European W-t-E plants (status 2001-2004)

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8.3 Energy results of the <u>25 out of 97 European W-t-E plants</u> <u>with mainly electricity production</u> (> 17,5 % electricity production abs and < 5 % heat exported or < 17,5 % electricity production abs and < 2 % heat exported) (status 2001-2004)

The results of the 25 investigated European W-t-E plants equipped with with grade firing systems <u>with mainly electricity production</u> for an amount of 7.000.881 Mg/a waste incinerated at a weighted mean NCV value of waste of 9,806 GJ/Mg plus imported energy 0,209 GJ/Mg = 10,015 GJ/Mg equivalent to (2,724+ 0,058) = 2,782 MWh/Mg are shown in the following figure 8 and are listed in the following text. For easier understanding of all the figures are presented in MWh/Mg (if using GJ/Mg results have to be multiplied with the conversion factor 3,6):

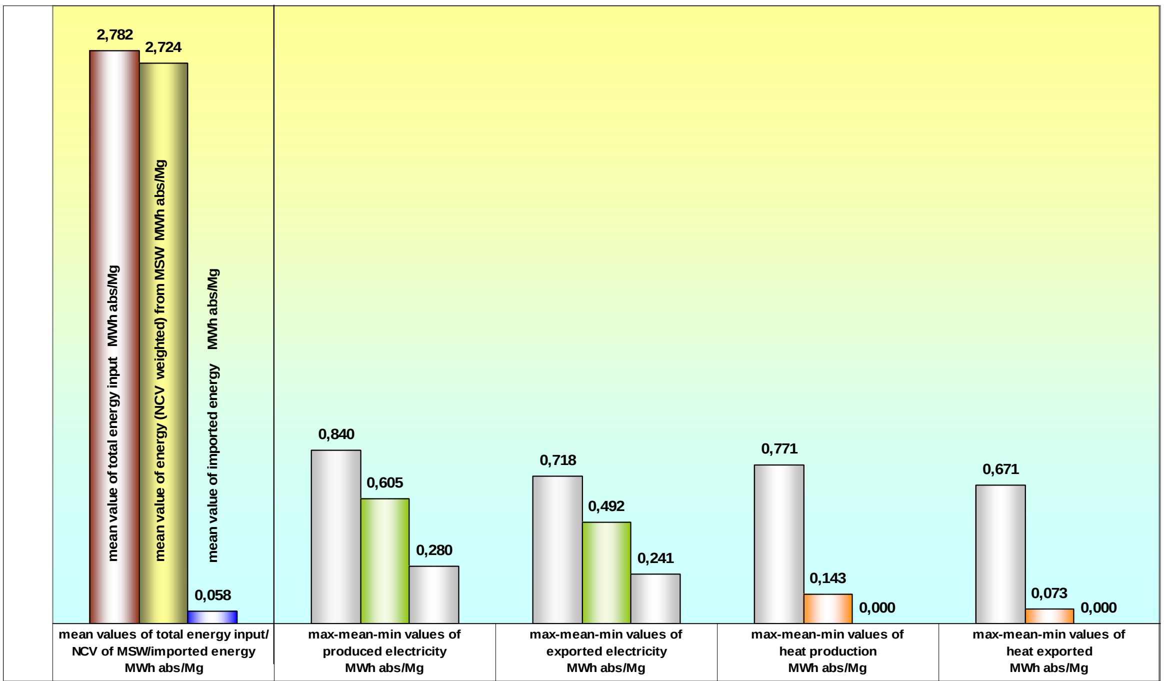
8.3.1 Specific energy data per Mg(t) waste incinerated of the <u>25 out of 97 European W-t-E plants</u> <u>with mainly electricity production</u> (status 2001 - 2004)

- spec. production of electricity:

<u>in absolute</u>: **mean weighted 0,605 MWh_e /Mg waste** (min 0,280 / max 0,840)

- spec. export of electricity:

<u>in absolute</u>: **mean weighted 0,492 MWh_e /Mg waste** (min 0,241 / max 0,718)



Reihe1	2,782	max	0,840	0,718	0,771	0,671
Reihe2	2,724	mean weighted	0,605	0,492	0,143	0,073
Reihe3	0,058	min	0,280	0,241	0,000	0,000

(Reimann 2005)

Figure 8: Energy input/electricity and heat production and export in absolute - max-mean-min specific energy data in MWh abs/Mg for 25 out of 97 European W-t-E plants with <u>mainly electricity production</u> (> 17,5 % electricity prod. abs and < 5 % heat export or < 17,5 % electricity prod. abs and < 2 % heat export) **(status 2001-2004)**

- spec. production/utilization of steam and heat:

<u>in absolute</u>: **mean weighted 0,143 MWh_e /Mg waste** (min 0,000 / max 0,771)

- spec. export of steam and heat:

<u>in absolute</u>: **mean weighted 0,073 MWh_e /Mg waste** (min 0,000 / max 0,671)

- total spec. energy demand for running the process:

in absolute: **mean weighted 0,241 MWh$_e$ /Mg waste** (min 0,097 / max 0,626)

- spec. energy demand imported included in the total spec. energy demand:

in absolute: **mean weighted 0,058 MWh$_e$ /Mg waste** (min 0,000 / max 0,420)

8.3.2 Energy efficiencies in percent (%) in relation to the total energy input of the 25 out of 97 European W-t-E plants with mainly electricity production (status 2001 - 2004)

- electricity production in percent:

in absolute: **mean weighted 21,8%** (min 12,4 / max 27,9)

- electricity export in percent:

in absolute: **mean weighted 17,7 %** (min 8,4 / max 24,3)

- heat and/or steam production in percent:

in absolute: **mean weighted 5,1 %** (min 0,0 / max 22,3)

- heat and/or steam export in percent:

in absolute: **mean weighted 2,6 %** (min 0,0 / max 19,4)

- total energy demand for running the process in percent:

in absolute: **mean weighted 8,7 %** (min 3,9 / max 22,0)

- total energy imported included in the total energy demand for running the process in percent:

in absolute: **mean weighted 2,1 %** (min 0,0 / max 14,3)

- sum of electricity and heat/steam production in percent:

in absolute: **mean weighted 26,9 %** (min 14,8 / max 42,8)

- sum of electricity and heat/steam export in percent:

in absolute: **mean weighted 20,3 %** (min 8,4 / max 35,5)

8.4 Energy results of the 28 out of 97 European W-t-E plants with mainly heat production/ utilization (> 60 % heat production and < 5 % electricity export or < 60 % heat production abs and < 2 % electricity export) (status 2001-2004)

The results for the 28 investigated European W-t-E plants equipped with grade firing systems with mainly heat production/utilization for an amount of 5.705.835 Mg/a waste incinerated at a weighted mean NCV value of waste of 9,845 GJ/Mg plus imported energy 0,518 GJ/Mg = 10,364 GJ/Mg equivalent to (2,735+ 0,144) = 2,879 MWh/Mg are shown in the following figure 9 and are listed in the following text. For easier understanding of all the figures are presented in MWh/Mg (if using GJ/Mg results have to be multiplied with the conversion factor 3,6):

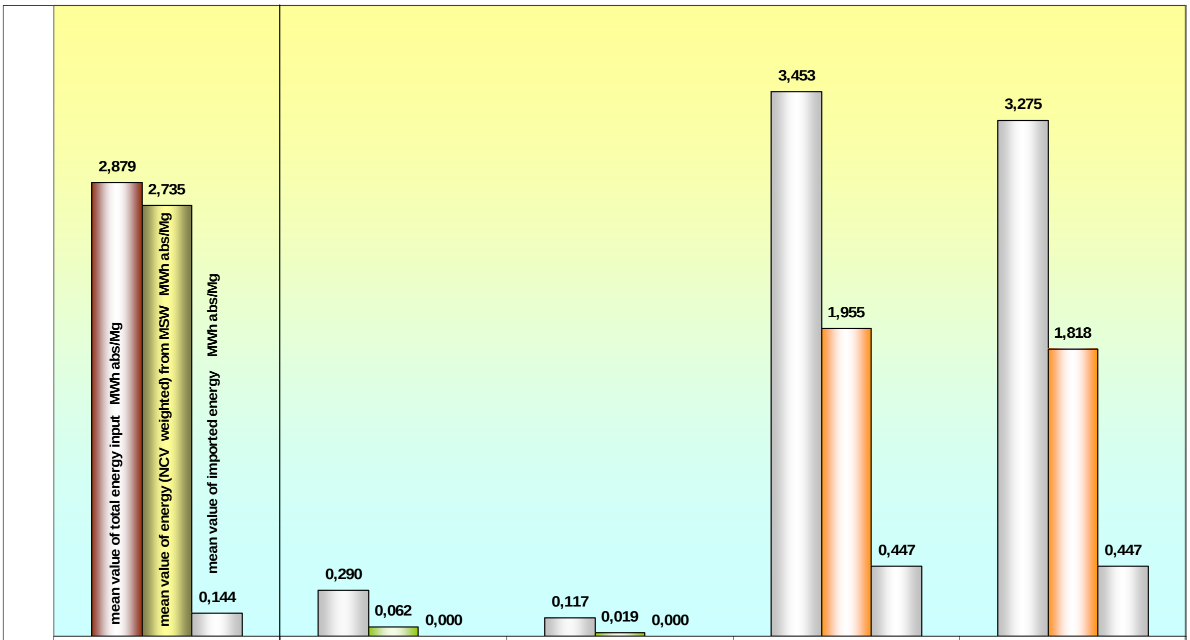
8.4.1 Specific energy data per Mg(t) waste incinerated of the 28 out of 97 European W-t-E plants with mainly heat production/ utilization (status 2001 - 2004)

- spec. production of electricity:

in absolute: **mean weighted 0,062 MWh_e/Mg waste** (min 0,000 / max 0,290)

- spec. export of electricity:

in absolute: **mean weighted 0,019 MWh_e/Mg waste** (min 0,000 / max 0,117)



	mean values of total energy input/ NCV of MSW/imported energy MWh abs/Mg	max-mean-min values of produced electricity MWh abs/Mg	max-mean-min values of exported electricity MWh abs/Mg	max-mean-min values of heat production MWh abs/Mg	max-mean-min values of heat exported MWh abs/Mg
Reihe1	2,879	max 0,290	0,117	3,453	3,275
Reihe2	2,735	mean weighted 0,062	0,019	1,955	1,818
Reihe3	0,144	min 0,000	0,000	0,447	0,447

(Reimann 2005)

Figure 9: Energy input/electricity and heat production and export in absolute - max-mean-min specific energy data in MWh abs/Mg for 28 out of 97 European W-t-E plants with mainly heat production (> 60 % heat production and < 5 % electricity export or < 60 % heat production abs and < 5 % electricity export) (status 2001-2004)

- spec. production/utilization of steam and heat:

in absolute: **mean weighted 1,955 MWh_e/Mg waste** (min 0,447 / max 2,643)

- spec. export of steam and heat:

in absolute: **mean weighted 1,818 MWh_e/Mg waste** (min 0,447 / max 2,508)

- total spec. energy demand for running the process:

in absolute: **mean weighted 0,323 MWh_e/Mg waste** (min 0,076 / max 0,659)

- spec. energy demand imported included in the total spec. energy demand:

in absolute: **mean weighted 0,144 MWh$_e$/Mg waste** (min 0,020 / max 0,452)

8.4.2 Energy efficiencies in percent (%) in relation to the total energy input calculated with BREF formulae from Annexes 10.4 [1] of the 28 out of 97 European W-t-E plants with mainly heat production/ utilization (status 2001 - 2004)

- electricity production in percent:

in absolute: **mean weighted 2,1%** (min 0,0 / max 10,4)

- electricity export in percent:

in absolute: **mean weighted 0,7 %** (min 0,0 / max 4,3)

- heat and/or steam production in percent:

in absolute: **mean weighted 67,9 %** (min 15,6 / max 92,7)

- heat and/or steam export in percent:

in absolute: **mean weighted 63,1 %** (min 15,5 / max 88,0)

- total energy demand for running the process in percent:

in absolute: **mean weighted 11,2 %** (min 2,4 / max 23,0)

- total energy imported included in the total energy demand for running the process in percent:

in absolute: **mean weighted 5,0 %** (min 0,6 / max 13,9)

- sum of electricity and heat/steam production in percent:

in absolute: **mean weighted 70,0 %** (min 15,6 / max 92,7)

- sum of electricity and heat/steam export in percent:

in absolute: **mean weighted 63,8 %** (min 15,6 / max 88,0)

8.5 Energety results of the 44 CHP out of 97 European W-t-E plants with CHP (status 2001 - 2004)

The results for the 44 investigated European W-t-E plants equipped with grade firing systems with high heat production/utilization for the amount of 11.363.419 Mg/a waste incinerated at a weighted mean NCV value of waste of 10,170 GJ/Mg plus imported energy 0,206 GJ/Mg = 10,376 GJ/Mg equivalent to (2,825 + 0,057) = 2,882 MWh/Mg are shown in the following figure 10 and are listed in the following text. For easier understanding of all the figures are presented in MWh/Mg (if using GJ/Mg results have to be multiplied with the conversion factor 3,6):

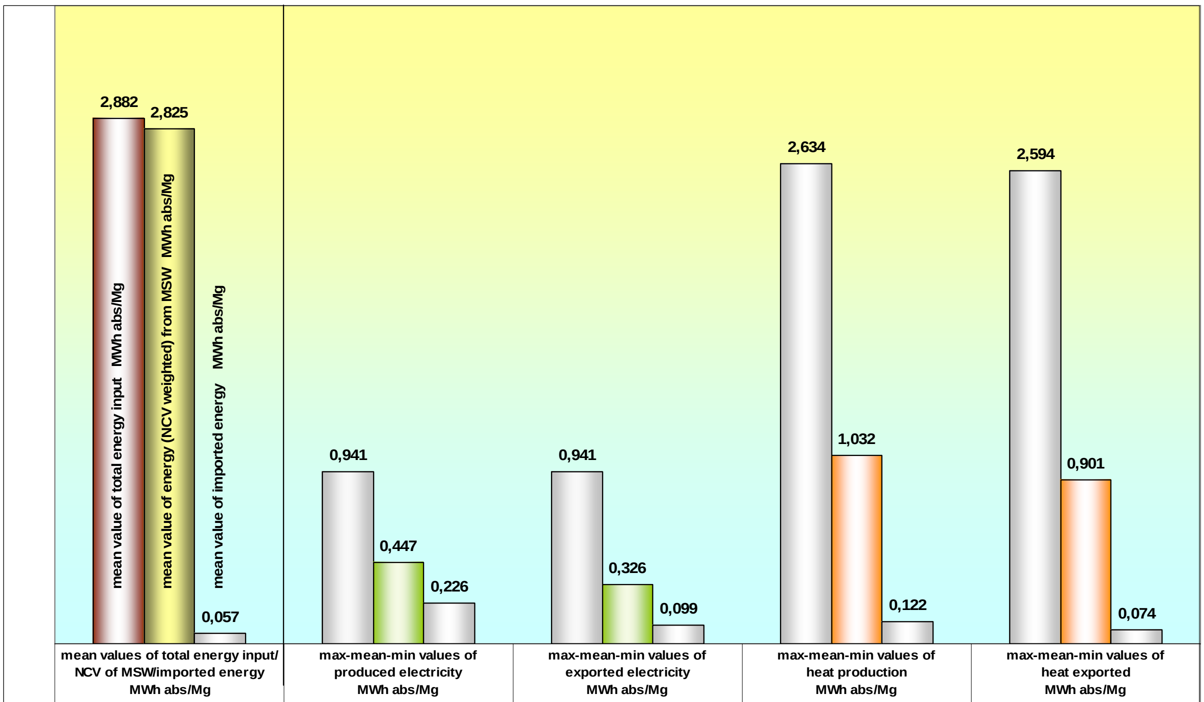
8.5.1 Specific energy data per Mg(t) waste incinerated of the 44 CHP out of 97 European W-t-E plants with CHP (status 2001 - 2004)

- spec. production of electricity:

in absolute: **mean weighted 0,447 MWh_e/Mg waste** (min 0,226 / max 0,941)

- spec. export of electricity:

in absolute: **mean weighted 0,326 MWh_e/Mg waste** (min 0,099 / max 0,941)



	mean values of total energy input/ NCV of MSW/imported energy MWh abs/Mg		max-mean-min values of produced electricity MWh abs/Mg	max-mean-min values of exported electricity MWh abs/Mg	max-mean-min values of heat production MWh abs/Mg	max-mean-min values of heat exported MWh abs/Mg
Reihe1	2,882	max	0,941	0,941	2,634	2,594
Reihe2	2,825	mean weighted	0,447	0,326	1,032	0,901
Reihe3	0,057	min	0,226	0,099	0,122	0,074

(Reimann 2005)

Figure 10: Energy input/electricity and heat production and export in absolute - max-mean-min specific energy data in MWh abs/Mg for 44 out of 97 European W-t-E plants with energy release as CHP (status 2001-2004)

- spec. production/utilization of steam and heat:

in absolute: **mean weighted 1,032 MWh_e/Mg waste** (min 0,122 / max 2,634)

- spec. export of steam and heat:

in absolute: **mean weighted 0,901 MWh_e/Mg waste** (min 0,074 / max 2,594)

- total spec. energy demand for running the process:

in absolute: **mean weighted 0,308 MWh_e/Mg waste** (min 0,117 / max 0,864)

- spec. energy demand imported included in the total spec. energy demand:

in absolute: **mean weighted 0,057 MWh_e /Mg waste** (min 0,000 / max 0,254)

8.5.2 Energy efficiencies in percent (%) in relation to the total energy input of the 44 CHP out of 97 European W-t-E plants with CHP

- electricity production in percent:

in absolute: **mean weighted 15,5 %** (min 7,8 / max 26,9)

- electricity export in percent:

in absolute: **mean weighted 11,3 %** (min 3,4 / max 23,7)

- heat and/or steam production in percent:

in absolute: **mean weighted 35,8 %** (min 4,0 / max 83,9)

- heat and/or steam export in percent:

in absolute: **mean weighted 31,3 %** (min 2,5 / max 82,6)

- total energy demand for running the process in percent:

in absolute: **mean weighted 10,7 %** (min 3,7/ max 29,1)

- total energy imported included in the total energy demand for running the process in percent:

in absolute: **mean weighted 2,0 %** (min 0,0 / max 10,9)

- sum of electricity and heat/steam production in percent:

in absolute: **mean weighted 51,3 %** (min 18,4 / max 98,7)

- sum of electricity and heat/steam export in percent:

in absolute: **mean weighted 42,6 %** (min 13,9 / max 90,5)

Appendix 1

Formula for heat value (NCV) of waste incinerated by BREF
For the NCV calculation the following formula is applied from the BREF on waste incineration:

$$c = (1{,}133 \times (m_{st\,w}/m) \times c_{st\,x} + 0{,}008 * T_b)/1{,}085 \quad \text{(GJ/ton)}$$

c = lower calorific value (NCV) of the incinerated waste with $m_{st\,w}/m \geq 1$ (GJ/ton)

$$m_{st\,w} = m_{st\,x} - (m_f * (c_f / c_{st\,x}) * \eta_b)$$

$m_{st\,w}$ = amount of the produced steam out of waste in the corresponding time period to $m_{st\,x}$ e.g per year (ton/y)
$m_{st\,x}$ = total amount of the produced steam in a defined time period e.g per year (ton/y)
m_f = amount of fuel with steam production (see E_f in checklist) in the corresponding time period to $m_{st\,x}$ e.g per year (ton/y)
m = amount of incinerated waste (see E_w in checklist) in a defined time period to $m_{st\,x}$ e.g per year (ton/y)
$c_{st\,x}$ = net enthalpy of steam (enthalpy of steam minus enthalpy of boiler water) (GJ/ton) see e.g. VDI Steam Tables in general constant for every single plant
c_f = net calorific value of fuel with steam production see table 1 (GJ/ton)
T_b = temperature of flue gas after boiler (at 4 - 12% O_2 in flue gas) (°C)
0,008 = spec. energy content in flue gas (GJ/ton x °C)
1,133 and 1,085 = constant figures by regression equation
η_b = efficiency of heat exchange (as approach 0.80)

Appendix 2

Formulae for recovery efficiency coefficient (equ) by ECJ and WFD
The way how to calculate the recovery efficiency coefficients is shown in the following formulae according to ECJ and WFD and is explained in formulae themselves.

R1-condition by ECJ judgement C-458/00 par. 34 with equivalents by BREF

$$R1 = (Ep) / (0{,}97 * (E_w + E_f))$$

R1-formula by draft of WFD with equivalents by WFD

$$R1 = (Ep - (E_f + E_i)) / (0{,}97 * (E_w + E_f))$$

all figures as equivalents
E_f = annual energy input to the system by imported energy(fuels) with steam production (GJ/y)
E_i = annual imported energy without steam production (GJ/y) (energy from the treated waste E_w is not included)
E_w = annual energy input to the system by waste (GJ/y)
Ep = annual produced and utilised energy from waste (total of heat/steam plus electricity as equivalents) (GJ/y)
0,97 = factor for energy losses which, in general, are not usable in the incinerator by bottom ash, radiation etc

The two formulae are presented in the event that no imported energy for the waste incineration process is needed, with Ef and Ei = 0, the R1 formula will remain in both cases as R1 = Ep / (0,97* Ew).

Appendix 3

Formulae for plant efficiency factors Pl_{ef} (equ) according to BREF and to ECJ
The plant efficiency factor (Pl_{ef}) can be calculated by the following formula with E_p in connection to ECJ judgement C-458/00 par. 33 and to BREF as a BAT plant concerning energy with the same formula as for ECJ but instead of E_p the amount of exported energy E_{exp} has to be used:

$$Pl_{ef} = (E_p - (E_f + E_{imp})) / (E_f + E_{imp} + E_{circ})$$

all figures as equivalents *

E_f = annual energy input to the system by imported fuels <u>with</u> steam production (GJ/y)
E_{imp} = annual imported energy <u>without</u> steam production
(Note: energy from the treated waste E_w is <u>not</u> included) (GJ/y)
E_{circ} = annual energy circulated as losses (GJ/y)
E_p = annual produced energy (combined total of heat plus electricity as equivalents) (GJ/y)

Plant efficiency factor Pl_{ef} (equ) according to BREF:

$$Pl_{ef} = (E_{exp} - (E_f + E_{imp})) / (E_f + E_{imp} + E_{circ})$$

all figures as equivalents *

E_f = annual energy input to the system by imported fuels <u>with</u> steam production (GJ/y)
E_{imp} = annual imported energy without steam production
(Note: energy from the treated waste E_w is <u>not</u> included) (GJ/y)
E_{circ} = annual energy circulated as losses (GJ/y)
E_{exp} = annual exported energy (combined total of heat plus electricity as equivalents) (GJ/y)