OVAM

Evaluation of the R1 formula for determination of energy efficiencies of waste incineration plants for municipal solid waste

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For

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LIST OF USED ABBREVIATIONS

% DM	:	% Dry Matter
Bara	:	Bar absolute
BREF	:	Reference Document on Best Available Techniques
CMA	:	Compendium voor Monsterneming en Analyse
MWhe	:	MWh electrical
NCV	:	Net Calorific Value
TPY	:	Tons Per Year
VITO	:	Vlaamse Instelling voor Technologisch Onderzoek
WFD	:	Waste Framework Directive

SECTION 1 EXECUTIVE SUMMARY

The R1 energy efficiency factor as stated in the Waste Framework Directive 2008/98/EC gives rise to many questions regarding its interpretation.

In a first step, the potential interpretation difficulties have been evaluated and listed.

Secondly, a fictional plant was created in order to be used for simulation of different possible interpretations.

As a result, it is clear that different interpretations can result in a wide range of energy efficiency factor values from 0,29 to 0,99 (without having adapted the factors in function of the exergy content).

Finally, suggestions for possible interpretations (including taking into account exergy) have been made.

SECTION 2 INTRODUCTION

2.1 OBJECTIVE

The objective of the study is to critically review the R1 formula as stipulated by the Waste Framework Directive 2008/98/EC as it contains many uncertainties and several interpretations are possible. In order to do so, a fictional plant is created.

2.2 HISTORY OF THE R1 FORMULA

Since April 1993, the Waste Framework Directive contains a hierarchy of waste management methods. Since then, there have been issues concerning the definitions of recovery (R1) and disposal (D10) of waste that are incinerated and used as a source of energy. Two examples are the European Court of Justice cases against Luxembourg and Germany. The European Court came to the conclusion that the main objective of the incineration (disposal or recovery) determines the R1 status. However, in many cases the main objective is unclear.

During the revision of the Waste Framework Directive (2005 – 2008), there was a lot of discussion on how to determine the difference between recovery and disposal. Clarification was given by introducing a new definition for recovery, stating that the principal result of the waste treatment process determines its status.

The new Waste Framework Directive (WFD) 2008/98/EC also contains a new provision that clarifies the difference between R1 and D10 for specific installations, based on an energy efficiency formula. The formula itself needs further clarification via guidelines to be prepared by the European Commission. There is also the possibility that the formula is further specified via comitology according to the provisions laid down in article 38 of the new WFD.

2.2.1 The R1 formula in the Waste Framework Directive 2008/98/EC

R1 is classified as a recovery operation using waste principally as a fuel or other means to generate energy.

This includes incineration facilities dedicated to the processing of municipal solid waste only where their energy efficiency is equal or above:

- 0,60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009
- 0,65 for installations permitted after 31 December 2008

Using the following formula:

Energy efficiency factor = [Ep – (Ef + Ei)] / [0,97 * (Ew + Ef)]

In which:

- Ep means annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2,6 and heat produced for commercial use multiplied by 1,1 (GJ/year)

- Ef means annual energy input to the system from fuels contributing to the production of steam (GJ/year)
- Ew means annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)
- Ei means annual energy imported excluding Ew and Ef (GJ/year)
- 0,97 is factor accounting for energy losses due to bottom ash and radiation

This formula shall be applied in accordance with the reference document on Best Available Techniques for Waste Incineration.

Additionally, there is the possibility to specify the R1 formula via a comitology procedure so as to take into account

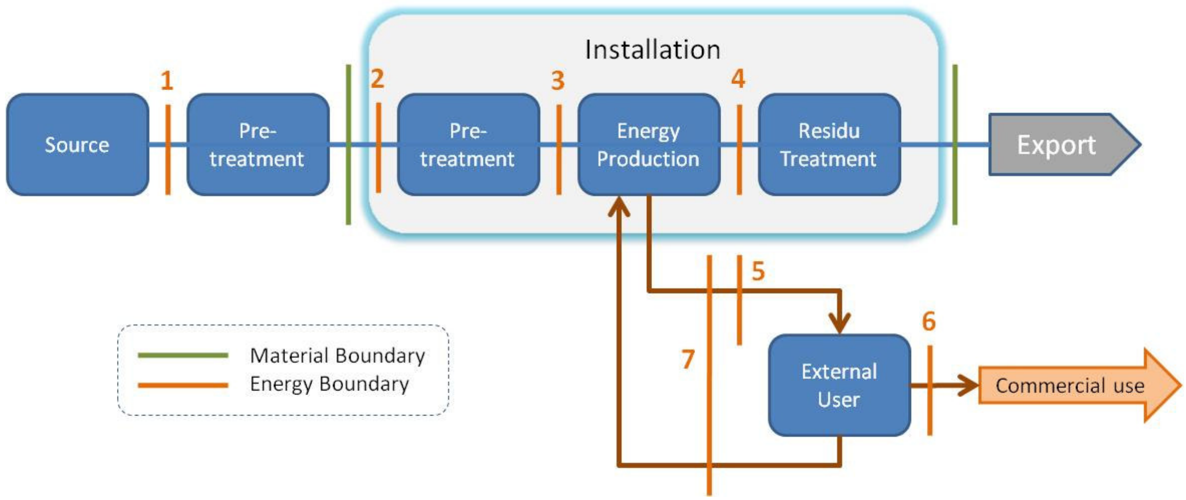
- local climatic conditions, such as the severity of the cold and the need for heating insofar as they influence the amounts of energy that can technically be used or produced in the form of electricity, heating, cooling or processing steam
- local conditions of the outermost regions as recognized in the fourth subparagraph of article 299 (2) of the Treaty and of the territories mentioned in article 25 of the 1985 act of accession.

SECTION 3 POTENTIAL DIFFICULTIES AND UNCERTAINTIES

3.1 GENERAL POTENTIAL DIFFICULTIES AND UNCERTAINTIES

3.1.1 Boundary limits

It is only possible to compare different installations if the boundary limits are set in the same way for each installation. This can easily be done for the material flows, e.g. waste arriving at the gate of the site and materials leaving the site. However for energy streams, this is less straight forward. The figure below shows an installation and some possible boundary limits regarding material and energy flows.



A few issues which need to be taken into account when setting the boundary limits are:

- What is the final destination of the energy leaving the site?
- What to do with an installation that exports steam to a third party producing electricity? Should this be seen as a heat or electricity supply?
- How does one determine the energy which has already been used to pretreat the waste (for instance RDF)?
- What to do with the electricity and heat demands of the flue gas cleaning system? Are these to be taken into account as well (for instance, selective catalytic reduction/selective non catalytic reduction?
- Should double accounting of energy flows be permitted or not?

3.1.2 Environmental issues

How does the formula take into account the emissions of the installation? What to do with installations that have emissions far below the European standards laid down in the waste incineration directive or have a zero-discharge? These low emissions have as a consequence that the energy consumption of these plants is higher. Should the extra energy consumption be considered in a different way?

3.1.3 Correction factors

Certain correction factors may be introduced, for instance to take into account local climatic conditions (see above). Is it necessary to introduce other factors as well (e.g. the presence of cooling water)?

3.1.4 Exergy

Exergy qualifies the way energy is available for further use. For instance, steam at low pressure can contain the same amount of energy as steam of high pressure. However, the high pressure steam can have a higher exergy than the low pressure steam, although both have the same amount of energy. The high pressure steam is of higher value because the energy that it contains can better be transformed in useable forms of energy, such as electricity or mechanical energy. Exergy is unaccounted for in the formula as it is. Is it necessary to include it in the formula? How can this be done?

3.1.5 Time frame and basis for calculating the energy efficiency

- How long is the R1 status valid? Does it need to be reviewed on a yearly basis?
- How do we calculate the energy efficiency for new installations? Do we base it on design conditions and review it after some time of operation?
- Do we base the calculations of the energy efficiency on optimal operating conditions? Or do we base it on operating conditions as they have appeared in practice? How do we treat unforeseeable variations in energy production or consumption? For instance, do we take into account the time span in which part of the installation is out of order? Do we take into account weather conditions in case of installations that are used for producing energy for heating purposes? How do we deal with a situation in which e.g. an external user suddenly does not need any energy any more due to e.g. another energy source or due to an economical situation in which that user needs less energy?

3.2 POTENTIAL DIFFICULTIES AND UNCERTAINTIES REGARDING E_P

It is unclear in the formula how the energy streams must be calculated exactly. What should be taken into account and what not?

- Should the gross electricity production be used or should the consumption of the plant be subtracted (net energy produced)?
- How must “commercial use” be interpreted? To which extent can own consumption be seen as “commercial use”?
- Is the gross exchanged thermal energy to be used or the net (subtraction of internally used thermal energy)?
- If the gross energy is used, how should a possible backflow be counted for?
- What to do with heat that is sent to a third party but is destroyed?
- What if the third party doesn’t accept the agreed amount of energy and the rest must be destroyed?
- What to do with heat that is transformed to electricity by a third party?

3.3 POTENTIAL DIFFICULTIES AND UNCERTAINTIES REGARDING E_F

- What is the exact definition of fuels? Should RDF be considered as a fuel?
- How does one determine from and until which moment the fuel contributes to the steam production?

3.4 POTENTIAL DIFFICULTIES AND UNCERTAINTIES REGARDING E_I

- How should incoming electricity and heat flows be calculated?
- Should the factors 2,6 and 1,1 also be used here?
- Should circulating heat and electricity for own consumption be interpreted as Ei?

3.5 POTENTIAL DIFFICULTIES AND UNCERTAINTIES REGARDING E_W

As the Ew-parameter counts for a large part in the R1 formula, it is very important that this parameter is calculated correctly.

It is however not easy to determine the net calorific value (NCV) of waste. Sampling and analyzing of the waste is very difficult and not always reliable. For this reason, almost each installation has its own calculation program to calculate the NCV of the processed waste. This calculation is often based on steam parameters and boiler efficiency. There are however some assumptions that need to be made for this calculation (e.g. boiler heat losses through radiation) which have a great effect on the NCV.

How often should the NCV be recalculated?

Or should the net caloric value be estimated by sampling of the waste itself?

SECTION 4 CASE STUDY

4.1 REFERENCE INSTALLATION

In order to calculate the R1 formula using difference boundary limits and interpretations, a fictional reference installation was created.

4.1.1 Waste input

In order to explore the formula using different interpretation scenarios, a reference installation was created. The installation is fed with a mixture of municipal solid waste, commercial waste and digested or industrial sludge in the following quantities.

Waste type	Quantity [TPY]	Net Calorific Value [kJ/kg]	Energy Content [GJ/year]
Municipal Waste	140.000	9.700	1.358.000
Commercial Waste	55.000	11.000	605.000
Sludge (25 % DM)	1.000	1.000	1.000

4.1.2 Fuel input

Natural gas is used for the start up and shut down of the installation as well as for the auxiliary burners in the following amounts.

Fuel type	Quantity [TPY]	Net Calorific Value [kJ/kg]	Energy Content [GJ/year]
Natural Gas for Auxiliary Burners	190	42.000	8.000
Natural Gas for start up and shut-down	381	42.000	16.000

4.1.3 Energy Consumption

The energy consumption of the plant is the following

Type	Quantity [MWh]	Quantity [GJ/year]
Furnace-Boiler Unit	10.000	36.000
Flue Gas Cleaning	13.000	46.800

4.1.4 Internal Energy

The installation produces steam at 400 °C and 40 bara. The steam is sent to a turbine to produce electricity. The turbine is foreseen with a tap to provide steam at 200°C and 11 bara to an air preheater and the deaerator.

Internal Steam	Quantity [TPY]	Temperature [°C]	Pressure [bara]	Energy Content [GJ/year]
Total Gross Steam production	600.000	400	40	1.928.624
Total Condensate Return	600.000	46	5	115.826
Air preheater	20.000	200	11	56.445
Condensate Return Air preheater	20.000	120	5	10.080
Deaerator	35.000	200	11	98.779

4.1.5 Exported Energy

The electricity produced by the turbine is put on the grid. There are two third party steam consumers. One first steam consumer uses high pressure steam (400 °C and 40 bara) and returns the condensate (120 °C and 10 bara) while the other consumer uses steam from the turbine tap (200 °C and 11 bara) without returning the condensate.

Exported Energy	Quantity [TPY/MWhe]	Temperature [°C]	Pressure [bara]	Energy Content [GJ/year]
Electricity	80.000	-	-	288.000
Steam Consumer 1 (gross)	90.000	400	40	289.294
Condensate Return Steam Consumer 1	90.000	120	10	45.391
Steam Consumer 2	20.000	200	11	84.668

4.2 INTERPRETATION SCENARIOS

Several possible interpretations of the E-parameters of the formula were tested.

Efficiency = [Ep – (Ef + Ei)] / [0,97 * (Ew + Ef)]

Ep = 2,6 * Ep-electricity + 1,1 * Ep-heat

For each scenario, a schematic figure is included showing the flows that were taken into account in the R1 calculation using line colors in accordance with the colors of the E-parameters above. Full lines indicate that the energy content is added, dashed lines are subtracted. E.g. a full red line goes to External User 1 and a dashed red line returns from the user to the installation, this means the net heat exchanged with the external user is used in the Ep-heat parameter (= gross – return).

4.2.1 Scenario 1

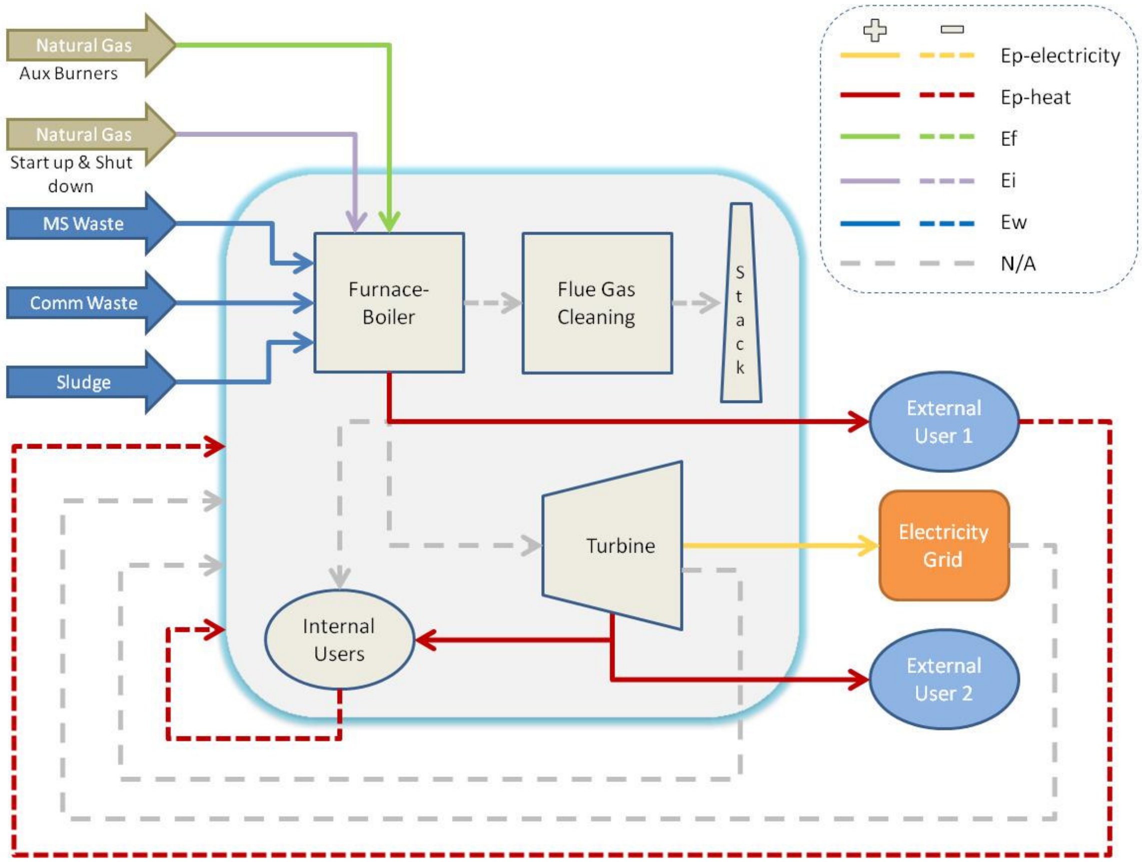
In this scenario we assume that the electricity production is done by the waste operator. So the waste operator is selling electricity to third parties.

The electricity that the incineration plant uses for its own consumption is ignored.

The steam that is produced is sold to external third parties. The steam for External User 1 circulates in a closed circuit. In other words, the steam/condensate comes back to the waste incineration plant after the steam has been used by this third party. This means that we can actually measure how much energy has been extracted from the steam by the third party. It is only the actually extracted amount of energy that is regarded as the heat used for commercial purposes.

External User 2 doesn’t return the condensate. Therefore no heat is returned to the waste plant.

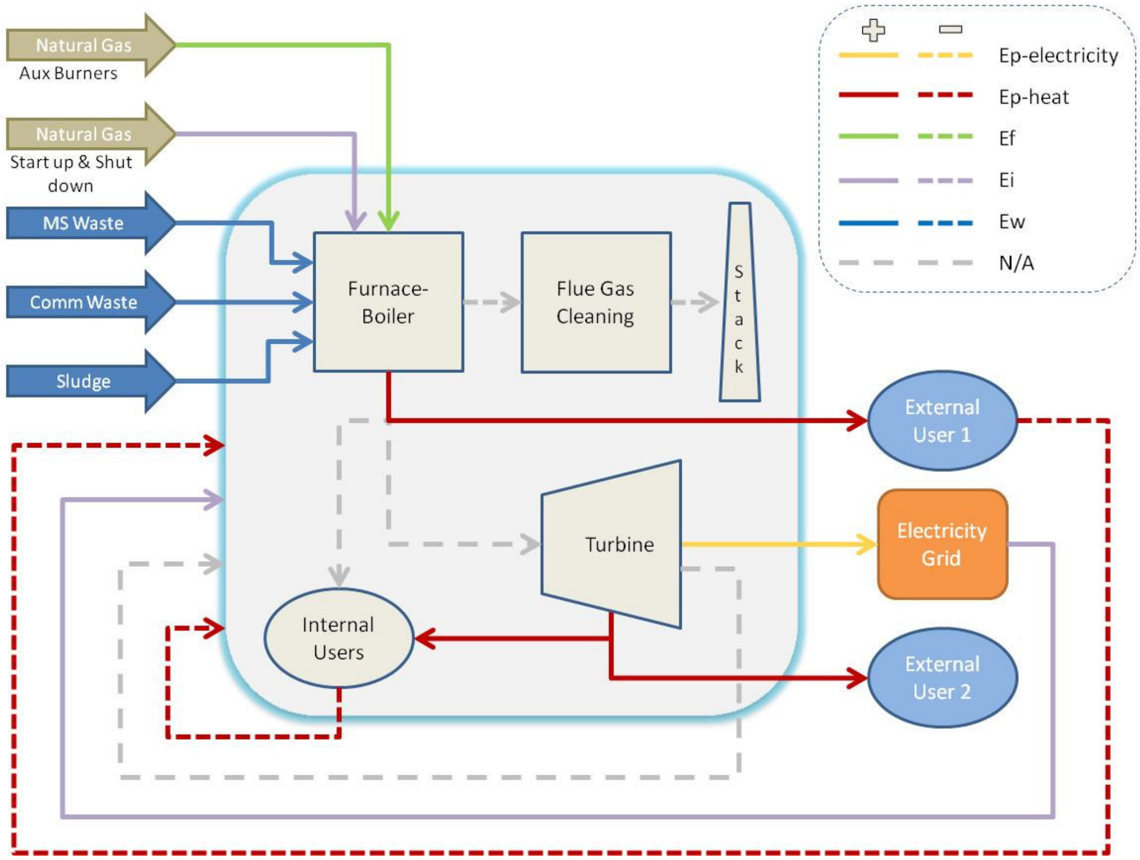
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down	16.000
Ew	All waste received	1.964.000
Efficiency = 0,651		



4.2.2 Scenario 2

The difference with scenario 1 is that we do take into account the electricity that is consumed by the waste operator. It is included in the factor Ei.

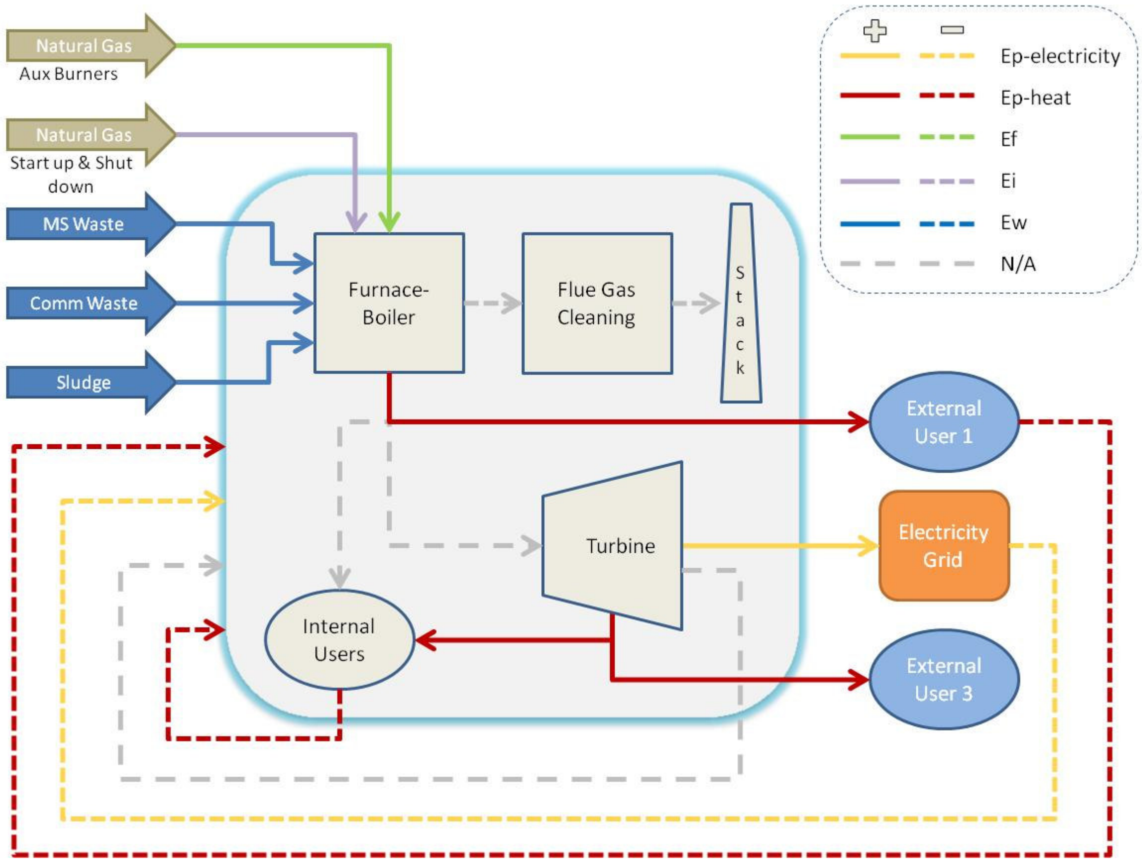
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption	98.800
Ew	All waste received	1.964.000
R1 Efficiency = 0,608		



4.2.3 Scenario 3

The difference with scenario 2 is that the electricity which is consumed by the waste operator is not included in Ei, but is subtracted from Ep so that Ep is turned into the net electricity production.

Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Net electricity for grid (gross production - consumption)	205.200
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.054.606
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down	16.000
Ew	All waste received	1.964.000
R1 Efficiency = 0,539		



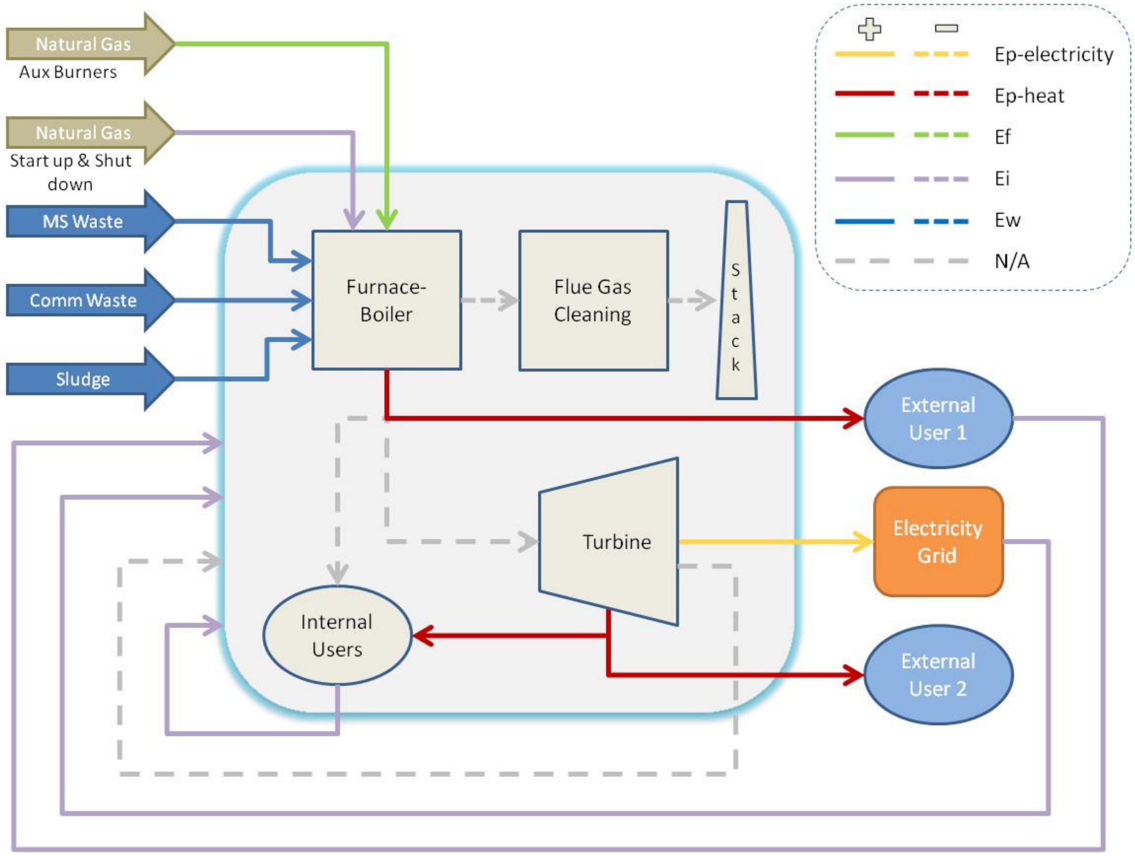
4.2.4 Scenario 4

The difference with scenario 2 is that the heat extracted by the waste operator from the steam that returns from an external user as low energy steam/condensate, is included in Ei instead of subtracting it from the heat that is produced for commercial use.

Therefore, the gross production of heat in the steam either for own consumption or external users is used instead of the net exchanged heat in the Ep-heat parameter, resulting in a higher value than in scenario 2.

Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Gross steam for external and internal users	529.186
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.330.904
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption + Condensate return internal & external users	154.271

Ew	All waste received	1.964.000
R1 Efficiency = 0,611		

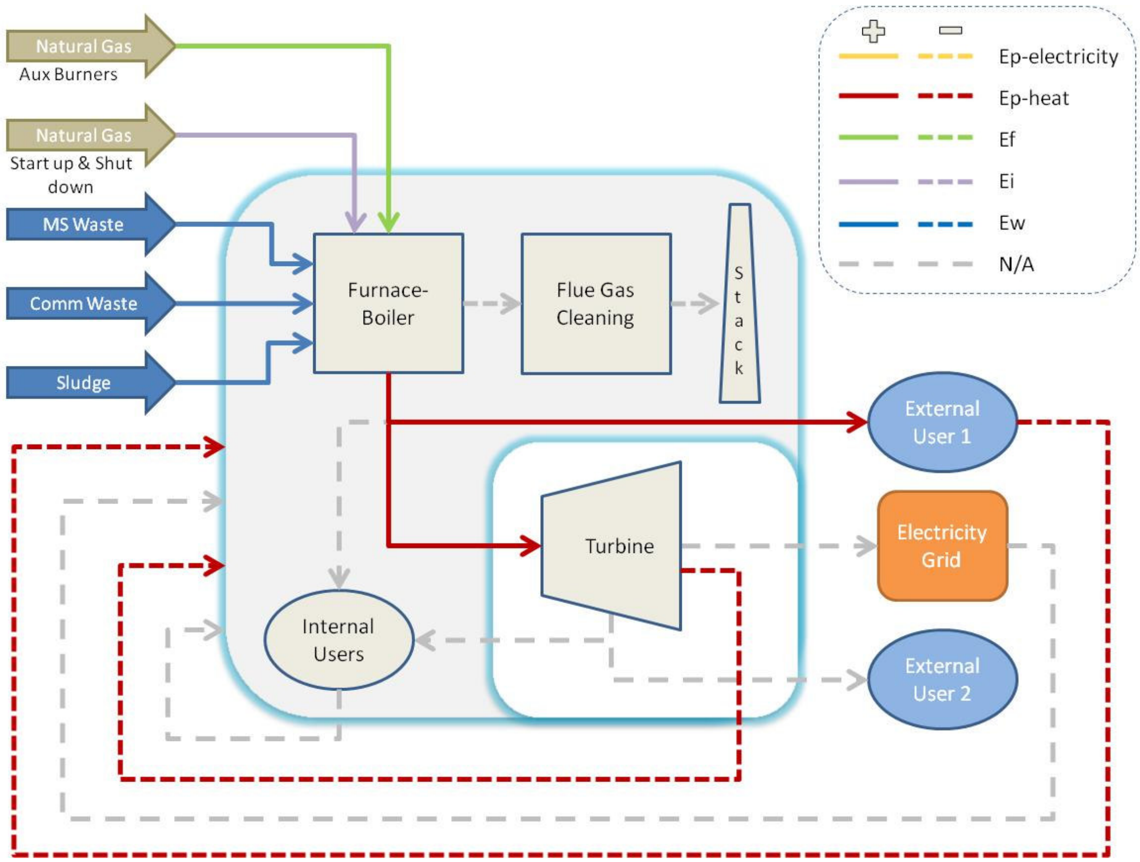


4.2.5 Scenario 5

The difference with scenario 2 is that the waste operator doesn't produce electricity, but produces steam that goes to a third party that decides to make electricity out of it.

Parameter	Interpretation	Value [GJ/year]
Ep-electricity	No electricity production (e.g. turbine owned by third party)	0
Ep-heat	Net steam produced by boiler (calculated using difference in enthalpy between steam and condensate return)	1.812.798
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.994.078
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity	98.800

	consumption	
Ew	All waste received	1.964.000
	R1 Efficiency = 0,987	



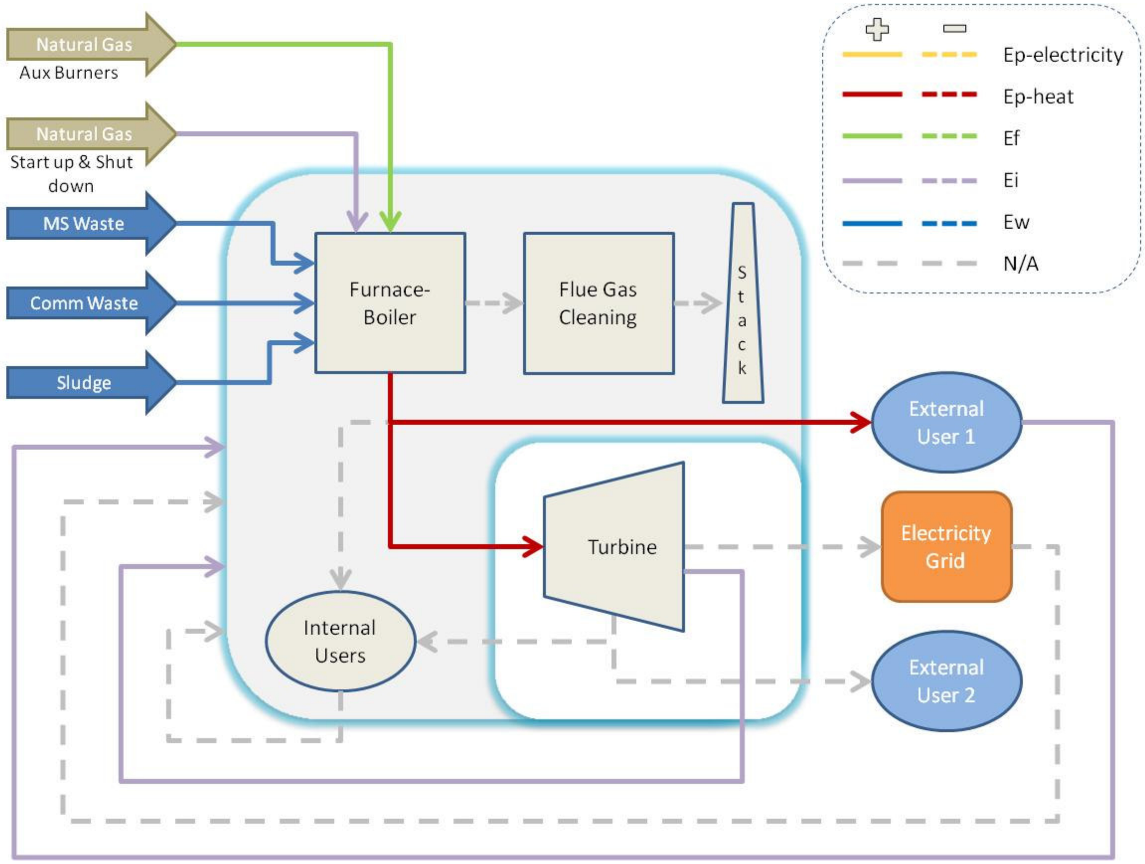
Note: The graphic representation is not entirely correct as Ep-heat takes into account the total amount of steam exit boiler (i.e. to turbine and to external user 1) and the temperature and pressure entering the steam condensate system (i.e. 45 °C and 5 bara) also for the total steam flow.

4.2.6 Scenario 6

The difference with scenario 4 is that the waste operator doesn't produce electricity, but produces steam that goes to a third party that decides to make electricity out of it.

Parameter	Interpretation	Value [GJ/year]
Ep-electricity	No electricity production (e.g. turbine owned by third party)	0
Ep-heat	Gross steam produced by boiler	1.928.624

Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	2.121.487
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption + condensate return	214.626
Ew	All waste received	1.964.000
R1 Efficiency = 0,993		

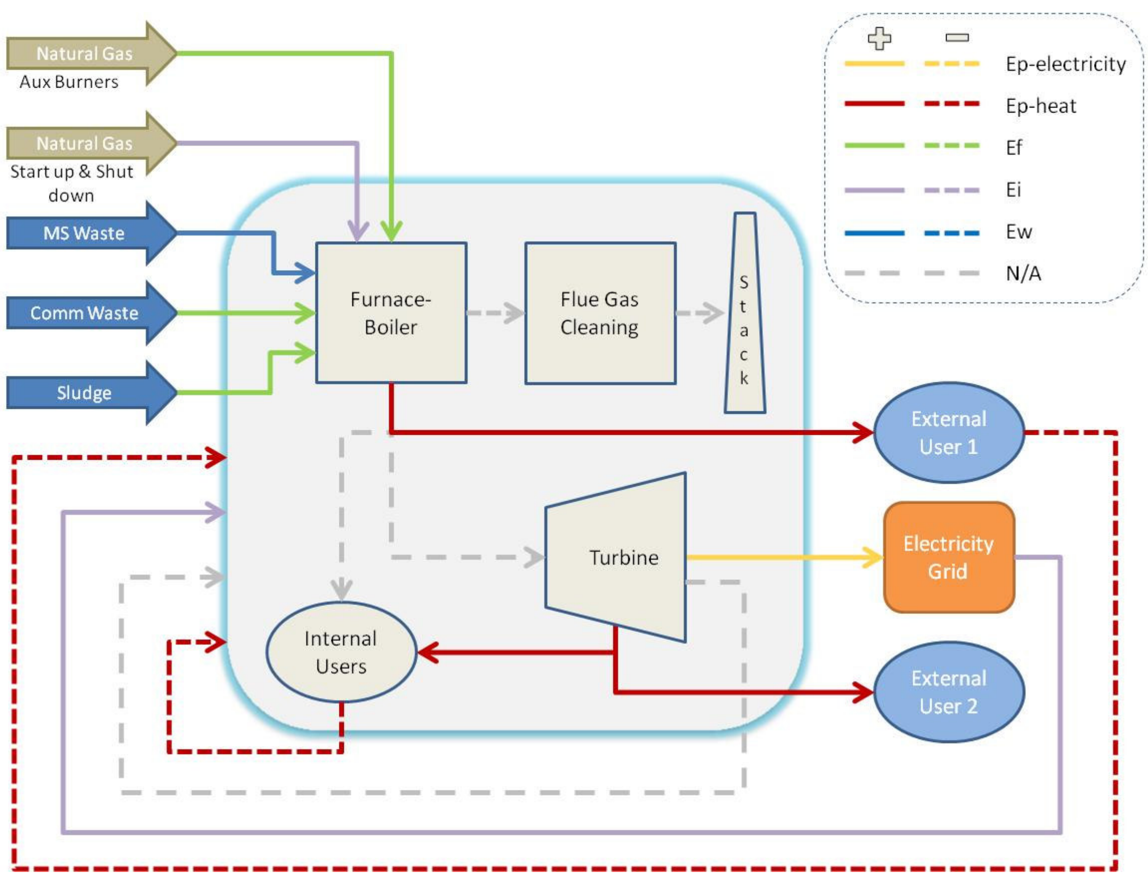


Note: The graphic representation is again not entirely correct as the total amount of steam exit boiler (i.e. to turbine and to external user 1) is used for Ep-heat and the temperature and pressure entering the steam condensate system (i.e. 45 °C and 5 bara) also for the total steam flow are used in Ei.

4.2.7 Scenario 7

The difference with scenario 2 is that the energy contained in the fractions commercial waste and sludge are included in the parameter Ef, based on the assumption that commercial waste and sludge are no solid municipal waste and need to be considered as auxiliary fuels.

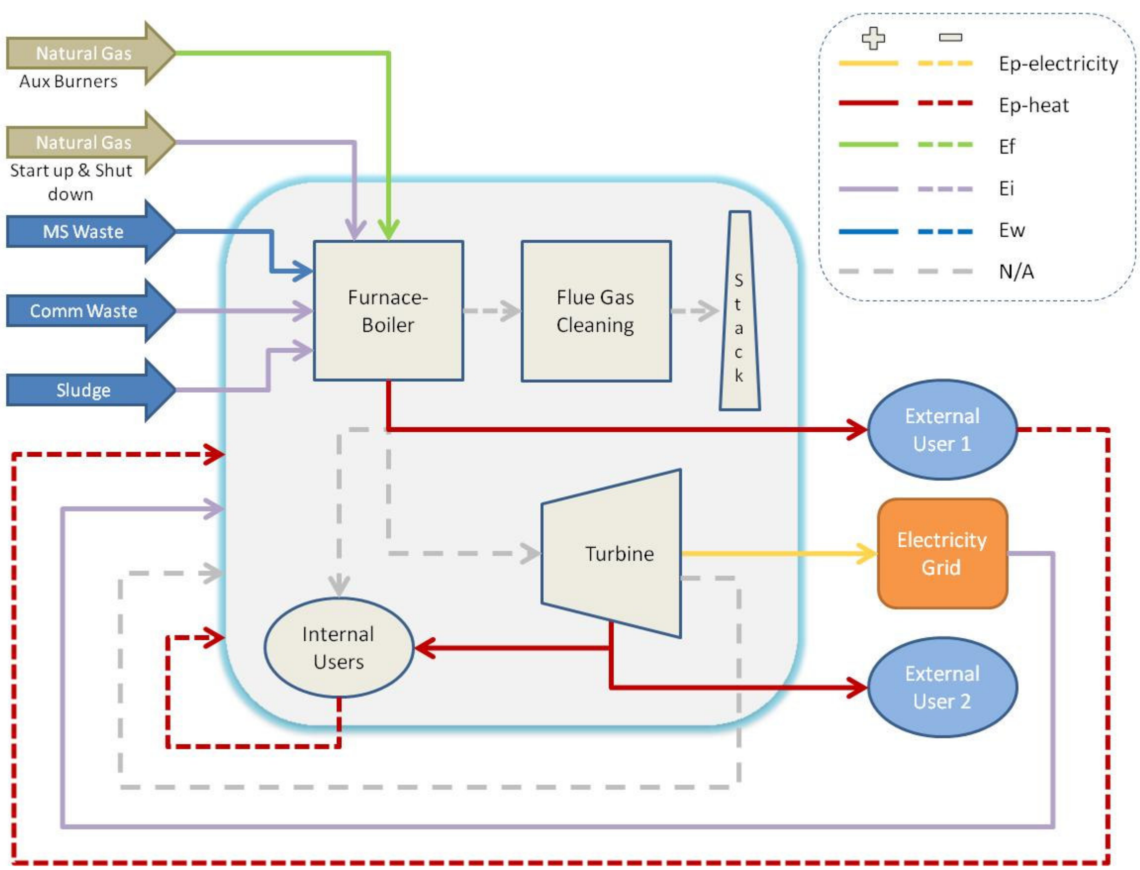
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners + Commercial waste + Sludge	614.000
Ei	Natural gas for start up and shut down + Electricity consumption	98.800
Ew	Municipal Solid Waste	1.358.000
R1 Efficiency = 0,291		



4.2.8 Scenario 8

The difference with scenario 7 is that commercial waste and sludge are not regarded as fuels contributing to the production of steam, but are regarded as other sources of energy included in the parameter Ei.

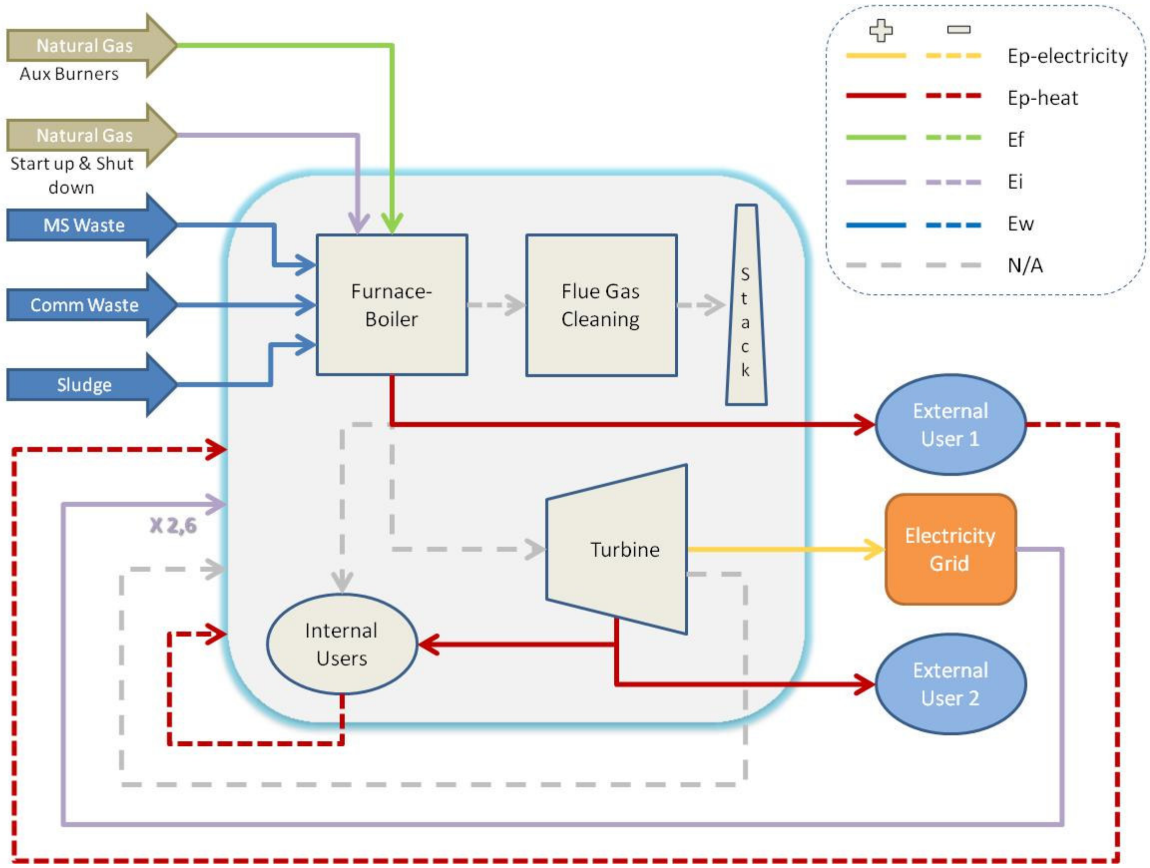
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption + Commercial waste + Sludge	704.800
Ew	Municipal solid waste	1.358.000
R1 Efficiency = 0,420		



4.2.9 Scenario 9

The difference with scenario 2 is that the electricity that is consumed by the waste operator and that is included in the term Ei, is multiplied with 2,6. The reasoning behind this is that if the electricity has to be taken from the electricity grid, you need 2,6 times as much energy (as an average –as used in the formula) to produce this electricity.

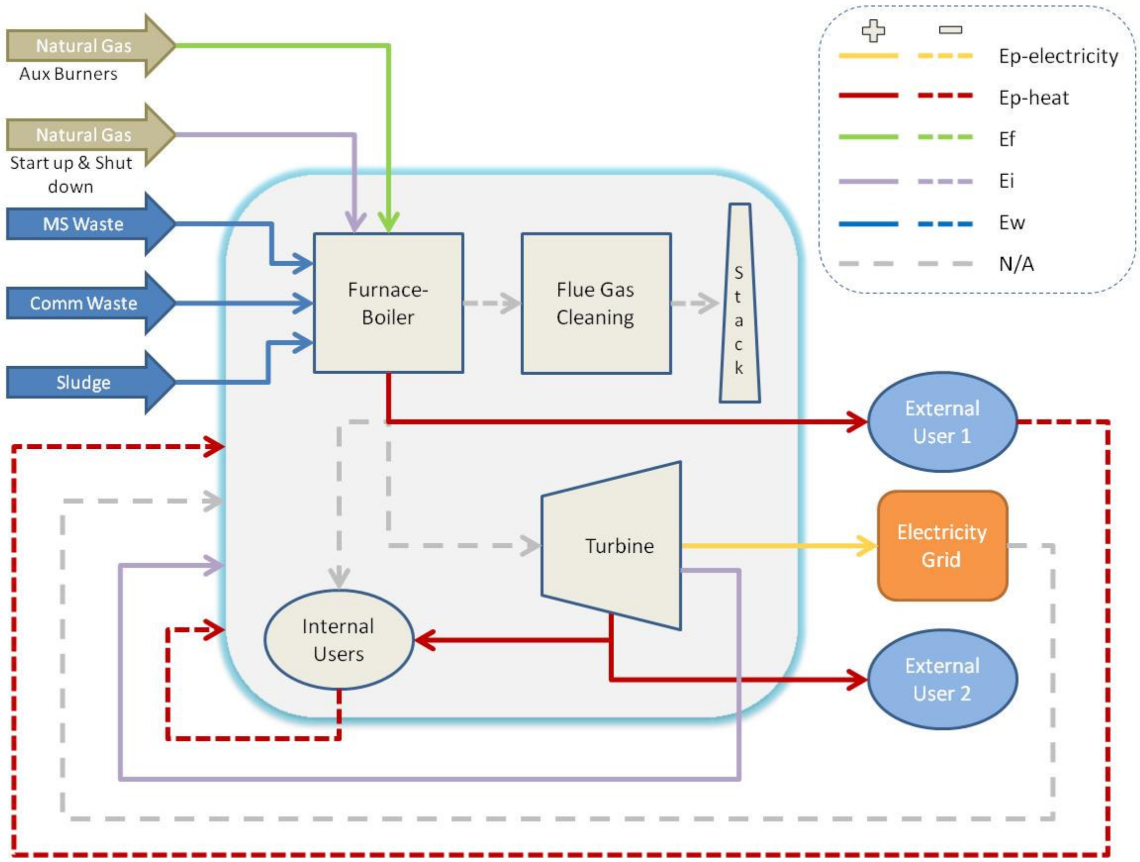
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + 2,6*Electricity consumption	231.280
Ew	All waste received	1.964.000
R1 Efficiency = 0,539		



4.2.10 Scenario 10

The difference with scenario 1 is that the energy contained in the condensate coming from the turbine is accounted for in the term Ei. In scenario 1 the energy contained in the condensate is simply ignored.

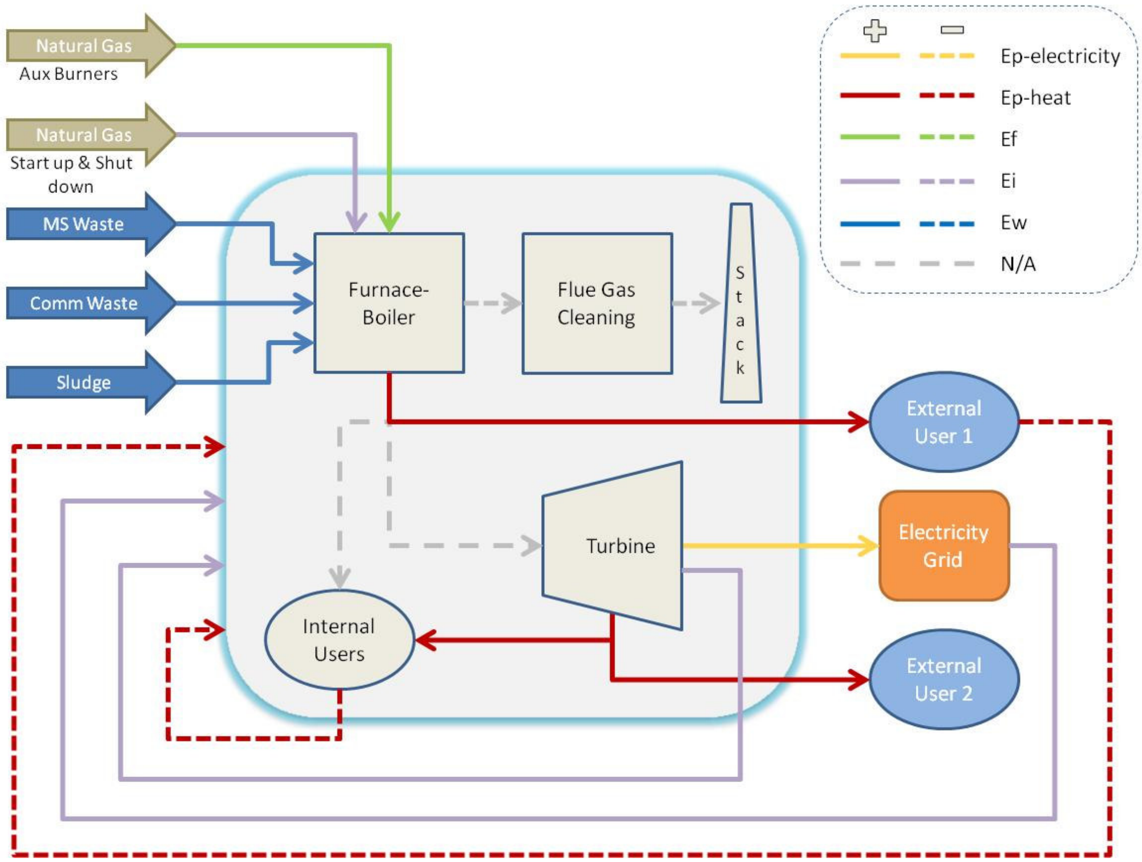
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + condensate return from turbine	121.209
Ew	All waste received	1.964.000
R1 Efficiency = 0,596		



4.2.11 Scenario 11

The difference with scenario 2 is that the energy contained in the condensate coming from the turbine is accounted for in the term Ei. In scenario 2 the energy contained in the condensate is simply ignored.

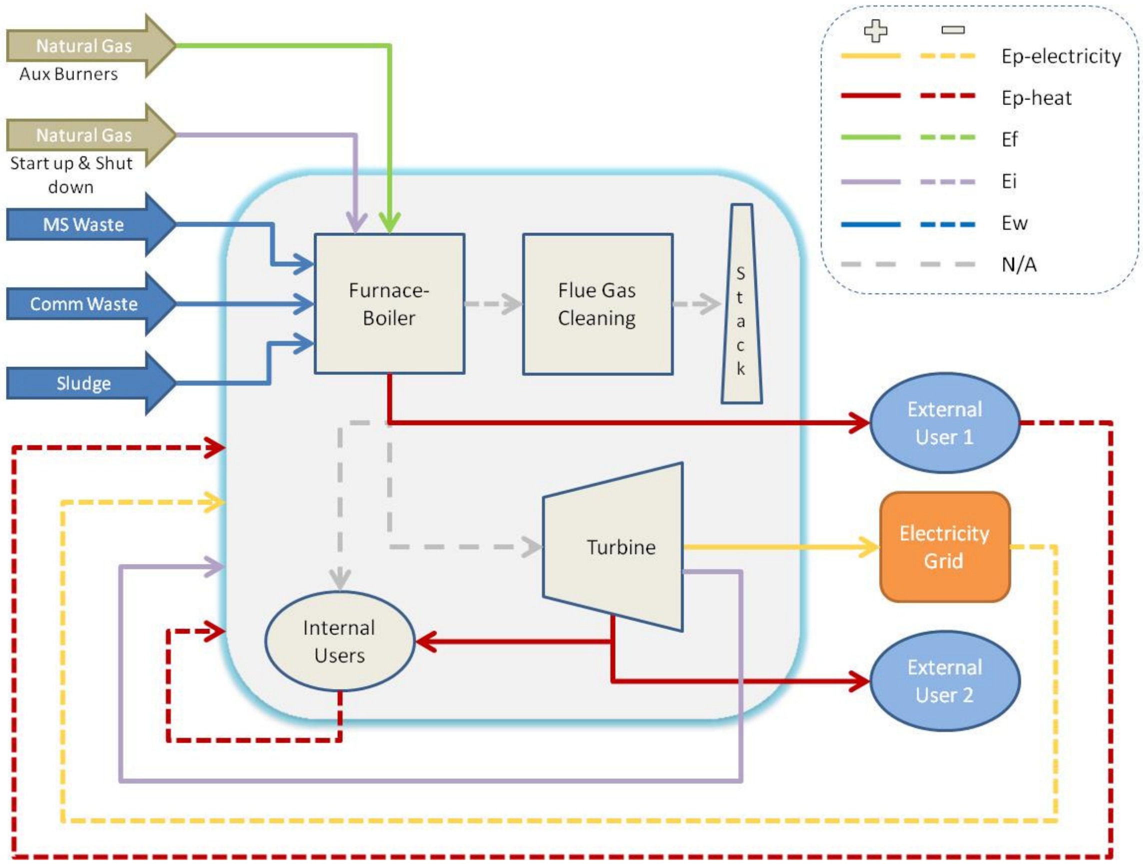
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption + condensate return from turbine	204.009
Ew	All waste received	1.964.000
R1 Efficiency = 0,553		



4.2.12 Scenario 12

The difference with scenario 3 is that the energy contained in the condensate coming from the turbine is accounted for in the term Ei. In scenario 3 the energy contained in the condensate is simply ignored.

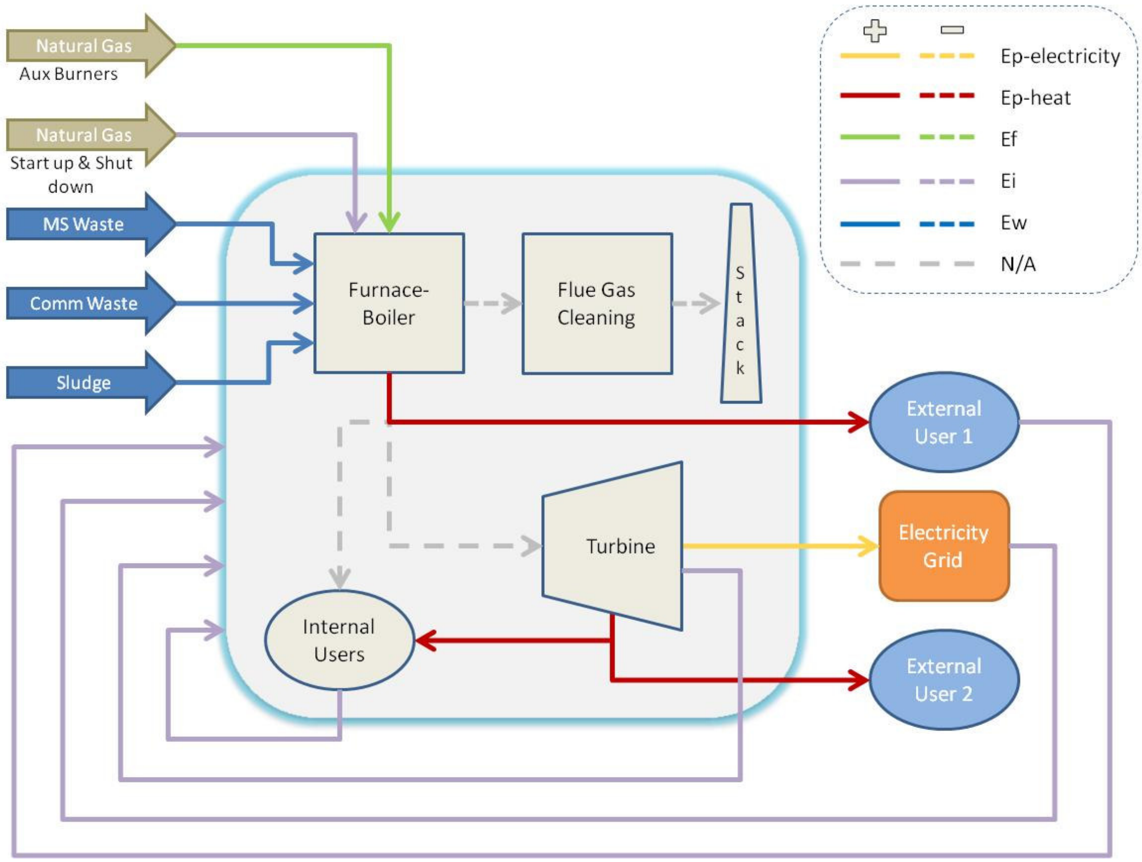
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Net electricity for grid (gross production - consumption)	205.200
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.054.606
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + condensate return from turbine	121.209
Ew	All waste received	1.964.000
R1 Efficiency = 0,484		



4.2.13 Scenario 13

The difference with scenario 4 is that the energy contained in the condensate coming from the turbine is accounted for in the term Ei. In scenario 4 the energy contained in the condensate is simply ignored.

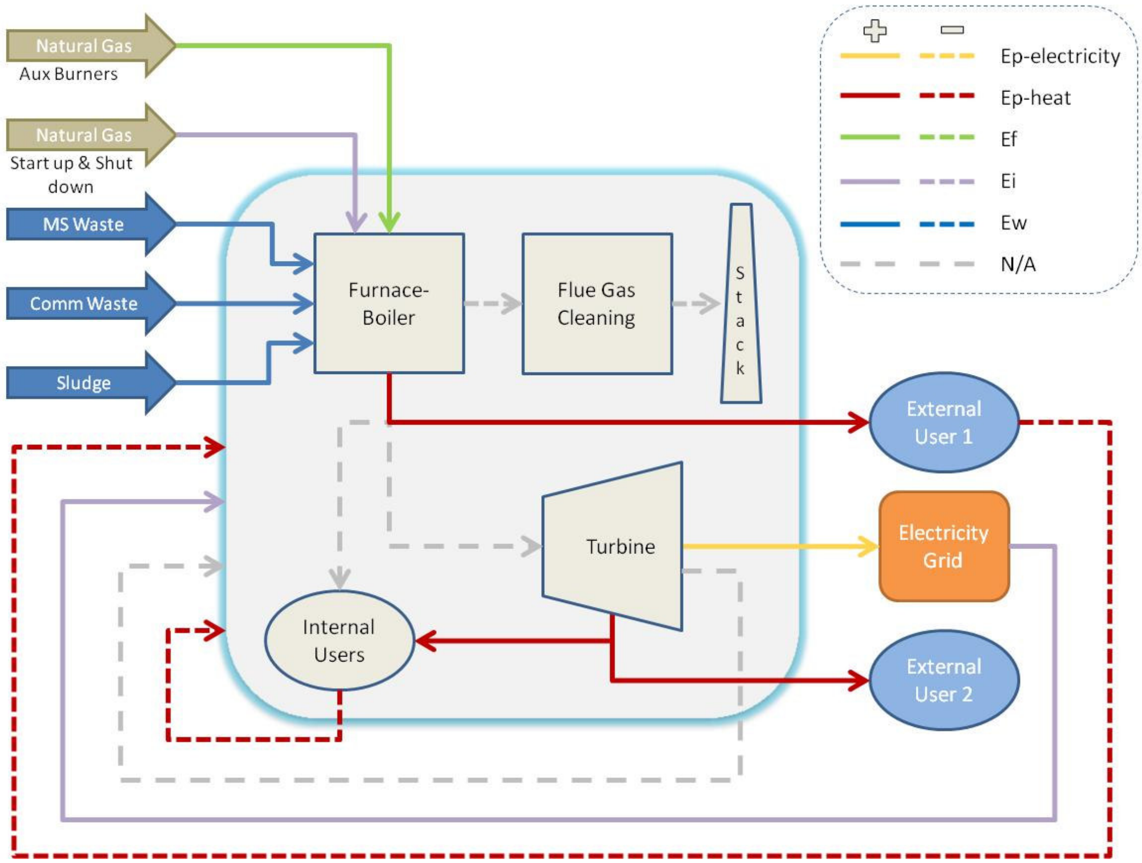
Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Gross steam for external and internal users	529.186
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.330.904
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption + Condensate return internal & external users + condensate return from turbine	259.480
Ew	All waste received	1.964.000
R1 Efficiency = 0,556		



4.2.14 Scenario 14

This scenario is identical to scenario 2. However, to stress the importance of the NCV in the formula, the NCV of the municipal solid waste was set to 10.500 kJ/kg instead of the original 9.700 kJ/kg.

Parameter	Interpretation	Value [GJ/year]
Ep-electricity	Gross electricity produced by turbine	288.000
Ep-heat	Net steam for external and internal users (calculated using difference in enthalpy)	473.715
Ep	= 2,6*Ep-electricity + 1,1*Ep-heat	1.269.886
Ef	Natural gas for auxiliary burners	8.000
Ei	Natural gas for start up and shut down + Electricity consumption	98.800
Ew	All waste received	2.076.000
R1 Efficiency = 0,575		


Natural Gas
Aux Burners
Natural Gas
Start up & Shut down
MS Waste
Comm Waste
Sludge
Furnace-Boiler
Flue Gas Cleaning
Stack
External User 1
Turbine
Electricity Grid
Internal Users
External User 2
Ep-electricity
Ep-heat
Ef
Ei
Ew
N/A

4.3 DISCUSSION

4.3.1 Overview

Scenario		1	2	3	4	5	6	7
R1		**0,651**	**0,608**	**0,539**	**0,611**	**0,987**	**0,993**	**0,291**
Ep-electricity	GJ	288.000	288.000	205.200	288.000	0	0	288.000
Ep-heat	GJ	473.715	473.715	473.715	529.186	1.812.798	1.928.624	473.715
Ep	GJ	1.269.886	1.269.886	1.054.606	1.330.904	1.994.078	2.121.487	1.269.886
Ef	GJ	8.000	8.000	8.000	8.000	8.000	8.000	614.000
Ei	GJ	16.000	98.800	16.000	154.271	98.800	214.626	98.800
Ew	GJ	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	1.358.000

		8	9	10	11	12	13	14
R1		**0,420**	**0,539**	**0,596**	**0,553**	**0,484**	**0,556**	**0,575**
Ep-electricity	GJ	288.000	288.000	288.000	288.000	205.200	288.000	288.000
Ep-heat	GJ	473.715	473.715	473.715	473.715	473.715	529.186	473.715
Ep	GJ	1.269.886	1.269.886	1.269.886	1.269.886	1.054.606	1.330.904	1.269.886
Ef	GJ	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Ei	GJ	704.800	231.280	121.209	204.009	121.209	259.480	98.800
Ew	GJ	1.358.000	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	2.076.000

4.3.2 Discussion

As can be seen in the table above, for the same installation, the R1 efficiency can vary from 0,29 to 0,99 by giving a different meaning to the E-parameters.

In scenario 1, the gross produced electricity and net heat flows were taken into account. When compared to scenario 2 (own electricity consumption in Ei), one sees that the R1efficiency goes down from 0,651 to 0,608. If only the net electricity production is used in Ep (scenario 3), the R1 efficiency drops further to 0,539.

If the gross electricity production and gross heat production are used and the own consumption of electricity and returning heat flows are considered in Ei (scenario 4), the R1 efficiency is 0,611.

In scenario 5 and 6, the plant only delivers steam (e.g. turbine in third party). This leads to a R1 efficiency of 0,987 if the net exchanged heat flow is considered. If the gross heat flow is used with the return heat in Ei, the R1 reaches a slightly higher value of 0,993.

Scenario 7 and 8 are the same as scenario 2, but only considering the municipal waste in the Ew parameter. All other waste is considered as Ef (scenario 7) or Ei (scenario 8) leading to R1 efficiencies of 0,291 (scenario 7) and 0,420 (scenario 8).

Scenario 9 is the same as scenario 2 using the gross electricity production and net heat production, with the exception that the electricity consumption of the plant is multiplied by 2,6. As could be expected, the R1 efficiency of this scenario of 0,539 is exact the same as for scenario 3 where the net electricity consumption is considered.

Scenarios 10 to 13 are in accordance with scenarios 1 to 4, but also consider the temperature of the condensate return (46°C) to the steam production. Using the gross produced electricity and net heat flows (scenario 10), this leads to a R1 of 0,596. With the own electricity consumption in Ei (scenario 11) it becomes 0,553. Considering the net electricity production (scenario 12), the R1 efficiency drops to 0,484. By using gross electricity and heat production and putting the electricity consumption and heat return flow in Ei (scenario 13), R1 becomes 0,556.

The 14th and last considered scenario is identical to scenario 2, but uses a NCV of 10.500 kJ/kg instead of the original 9.700 kJ/kg. The R1 is only 0,575 instead of 0,608 in scenario 2.

4.4 CONCLUSION

It is very important that the boundary conditions and the E-parameters are defined clearly in a non ambiguous way in order to obtain a R1 value that is comparable for different installations. Correctly defining the NCV is also of major importance as it influences the formula as proven by scenario 14. Underestimating the NCV increases the R1 energy efficiency factor.

SECTION 5 SUGGESTIONS

5.1 BOUNDARY LIMITS

The boundary limits must be chosen very carefully. There are various possible interpretations concerning energy flows to third parties. Three possible solutions and some of their consequences are described below.

1. The boundary limits are set at the end use of the energy flow. Even if the electricity is produced by a third party, this amount should be accounted for in the Ep-factor instead of the thermal flow sent to that third party. Similarly, the heat destroyed by a third party cannot be seen as commercial use and must be disregarded. This solution leads to complicated administrative and legal issues for the installation, as the R1 efficiency is strongly affected by third parties.
2. The boundary limits are set conform the permit of the plant. If the permit states that the plant is a steam producer and exports this steam, the Ep is calculated for this steam flow, even if it is turned into electricity by a third party. This interpretation could have as a consequence that installations that currently operate their own turbine will refuse to continue doing so as this could be a major disadvantage if the turbine efficiency is lower than the average of 38%. It could be more interesting for them to sell the turbine to an electricity producer or even create a new company.
3. The boundary limits are set from chute to stack and therefore not considering the electricity produced. This interpretation eliminates the difference between installations with or without an own turbine to produce electricity.

5.2 NET CALORIFIC VALUE

As the calculation method of the net calorific value has an important role in the formula, all installations should calculate it in the same way. The WFD states that the formula shall be applied in accordance with the reference document on the Best Available Techniques for Waste incineration. Therefore, it could make sense to use the calculation formula for NCV as provided in the BREF waste incineration (part 2.4.2.1).

Some plants have developed detailed calculation models, adapted to their own specific situation, using different assumptions compared to the BREF. It could be interesting to compare these models to the results obtained using the BREF formula.

Also, certain analysis methods have been formulated (e.g. CMA methodology by VITO) and could of course be used as well.

5.3 ENERGY LOSSES THROUGH TRANSPORT

Transport of energy (steam/hot water) to external parties and within the installation results in energy losses which are inevitable. In many cases, these losses are not measured and can only be calculated or estimated.

One interpretation is that they should be accounted for as a commercial use as well, as they are necessary and actually part of the commercial application. This however could result in creative solutions to export energy for a commercial application while in reality destroying it through the (large) transport losses.

On the other hand, one could stimulate more efficient transport of energy by not considering the energy losses as a commercial use. The difficulty of this interpretation is the determination of the energy losses in a clear and unambiguous way. A possible result is also that installation won't be keen to export energy over long distances.

5.4 MEASURING PROTOCOL

In order to determine the different thermal flows which are considered in the Ep-factor as well as the necessary values for the NCV calculation, it is advisable to require a measurement of these flows in a standardized fashion (place of measurement, way and number of measurement,…). As an example, the measuring protocol used by the Netherlands for granting subsidies could be used.

5.5 DEFINITION COMMERCIAL USE

It is important to have a clear and non ambiguous definition of "commercial use". A check list could be made listing the most common applications that use heat in a commercial way.

One possibility for interpretation could be to take into account all parts of the installations necessary to comply with the European legislation concerning emissions. Therefore, all electricity and heat sent to the flue gas cleaning system is to be seen as a commercial use.

Any heat users with the purpose to reduce emissions even further or to achieve zero-water-discharge could also be included in the list of commercial use.

5.6 DEFINITION OF MUNICIPAL SOLID WASTE AND FIELD OF APPLICATION OF THE FORMULA

The formula is applicable to incineration facilities dedicated to the processing of municipal solid waste. It is not clear how the term "dedicated to" should be interpreted. Does this term mean that the facility is mainly incinerating municipal solid waste? Or does it mean that the facility is suitable for incinerating municipal solid waste, but that it might as well incinerate other waste streams? From a technical point of view the type of waste stream has little relevance for the energy recovered. It is the net calorific value that is more important. So the field of application might be broader than only municipal solid waste. A wider application would also resolve the question what is to be understood by solid municipal waste, a term which has not been defined and may be interpreted in different ways by Member States.

We should also avoid that other wastes, like RDF, are regarded as auxiliary fuels (included in Ef) or as other sources of energy (included in Ei) as this would not make much sense from a technical point of view.

5.7 ENERGY LEVEL OF RECOVERED HEAT

The actual formula does not take into account the level of recovered thermal energy. Using exergy would overcome this.

One could consider introducing a factor based on the temperature difference between the temperature level of the recovered heat and ambient temperature.

A possibility is to multiply the enthalpy with the following factor:

Exergy factor = F – (T/Tref)

In which

- F is a factor to be determined, in any case F > 1
- T is the temperature of the hot water/steam and
- Tref is the reference temperature (ambient temperature)

Using this formula on the scenarios above leads to the following results with **F=2**:

Scenario		**1***	**2***	**3***	**4***	**5***	**6***	**7***
R1		**0,907**	**0,864**	**0,794**	**0,869**	**2,003**	**2,012**	**0,547**
Ep-electricity	GJ	288.000	288.000	205.200	288.000	0	0	288.000
Ep-heat	GJ	918.221	918.221	918.221	1.019.918	3.579524	3.760.817	918.221
Ep	GJ	1.758.843	1.758.843	1.543.563	1.870.710	3.937476	4.136.899	1.758.843
Ef	GJ	8.000	8.000	8.000	8.000	8.000	8.000	614.000
Ei	GJ	16.000	98.800	16.000	200.497	98.800	280.093	98.800
Ew	GJ	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	1.358.000

		8*	**9***	**10***	**11***	**12***	**13***	**14***
R1		**0,789**	**0,794**	**0,821**	**0,778**	**0,708**	**0,783**	**0,817**
Ep-electricity	GJ	288.000	288.000	288.000	288.000	205.200	288.000	288.000
Ep-heat	GJ	918.221	918.221	918.221	918.221	918.221	1.019.918	918.221
Ep	GJ	1.758.843	1.758.843	1.758.843	1.758.843	1.543.563	1.870.710	1.758.843
Ef	GJ	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Ei	GJ	704.800	231.280	180.675	263.475	180.675	365.172	98.800
Ew	GJ	1.358.000	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	2.076.000

Using this formula on the scenarios above leads to the following results with **F=1,5**:

Scenario		**1****	**2****	**3****	**4****	**5****	**6****	**7****
R1		**0,771**	**0,727**	**0,658**	**0,731**	**1,481**	**1,488**	**0,411**
Ep-electricity	GJ	288.000	288.000	205.200	288.000	0	0	288.000
Ep-heat	GJ	681.363	681.363	681.363	755.325	2.673.125	2.796.505	681.363
Ep	GJ	1.498.300	1.498.300	1.283.020	1.579.657	2.940.437	3.076.155	1.498.300
Ef	GJ	8.000	8.000	8.000	8.000	8.000	8.000	614.000
Ei	GJ	16.000	98.800	16.000	172.762	98.800	222.180	98.800
Ew	GJ	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	1.358.000

		8**	9**	10**	11**	12**	13**	14**
R1		**0,593**	**0,658**	**0,712**	**0,669**	**0,600**	**0,673**	**0,688**
Ep-electricity	GJ	288.000	288.000	288.000	288.000	205.200	288.000	288.000
Ep-heat	GJ	681.363	681.363	681.363	681.363	681.363	755.325	681.363
Ep	GJ	1.498.300	1.498.300	1.498.300	1.498.300	1.283.020	1.579.657	1.498.300
Ef	GJ	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Ei	GJ	704.800	231.280	128.070	210.870	128.070	284.832	98.800
Ew	GJ	1.358.000	1.964.000	1.964.000	1.964.000	1.964.000	1.964.000	2.076.000

If compared to the original results, it is clear that using the suggested exergy factor for this test case benefits the R1 efficiency factor. The F factor should be determined by a committee.

5.8 FUEL FOR START UP AND SHUT DOWN

In theory, it is easy to make a distinction between fuel used for steam production and fuel not used for steam production. In reality however, it is not easy to determine when exactly the fuel starts contributing to the production of steam during start up and when it stops contributing during shut down. The most correct approach is to measure the fuel used before and after connection to the steam circuit. Another solution could be to use a fixed percentage of the total amount of fuel used during start up and shut down to estimate the amount contributing to steam production based on experience.

Compared to scenario 2 (efficiency of 0,608), if all the natural gas is seen as Ef, the result is 0,603. If the natural gas for start up and shut down is disregarded compared to scenario 2, the efficiency factor becomes 0,616.

5.9 TIME FRAME

The formula could be reviewed every year, together with the yearly reporting to the government. The values on which the calculation is based should be the average of minimum one year.

For new installations, the design values can be used and checked after the first year of operation.

The validity of the R1 status must be set. This validity should bear in mind sudden unexpected changes and the time necessary to resolve these.

5.10 ENERGY CONTENT OF RECOVERED MATERIALS

In analogy with carbon footprint calculations, one could also consider the amount of avoided energy included in recovered products. This could be incorporated in the formula by using a correction factor.

5.11 VERIFICATION OF R1

The R1 formula can be calculated based on data provided by the installations. However, it is also useful to appoint a third independent party for the verification and check of the provided information and final calculation of the R1 formula.

SECTION 6 ANNEXES