Energy recovery Efficiency in Municipal Solid Waste-to-Energy plants in relation to local climate conditions

VERSION 3

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ABSTRACT

The R1 criterion included in the Waste Framework Directive (2008/98/EC) determines whether a Waste-to-Energy plant can be considered a “recovery operation” (R1, Annex II) or a “disposal operation” (D10, Annex I).

The main objective of this R1 criterion (better known as the R1 formula) is to promote the efficient use of Waste-to-Energy. It takes into account the plant’s effectiveness in recovering the energy contained in waste (which is usually very high, typically > 80%) but also the effective uses (as electricity, heat for buildings or process steam) of such available energy.

While local conditions greatly influence these external uses, they are not taken into account in the R1 formula itself. But in Article 38.1, the directive also includes a provision that local conditions can be taken into account in the calculation of the R1 formula, insofar as they influence the amounts of energy used or produced by the plant. The most influential local condition is climate, affecting plants in two ways. First, warm air temperatures decrease electricity production efficiency and, most importantly, limit the amounts of energy needed in buildings for heating. The heating demand in Scandinavia is not equivalent of that of the south of Italy or Spain.

As theoretical and statistical evidence proves that local climatic conditions affect both electricity production and heat use, the Joint Research Centre of the European Commission commissioned this study to quantify the impact of these conditions on the value of the R1 formula. Based on this quantification, the main purpose of this study is to propose a correction factor for plants located in areas where the production of electricity and use of heat is lower due to the climate, thus ensuring a level playing field within the EU and within the framework of this same R1 criterion.

After a thorough assessment of the data, results showed that the impact of warm air temperatures on electricity production could be accurately calculated and that the R1 value was much more undermined by the lack of external heat uses than by the reduction of electricity production. The key to a high R1 therefore depends on an external outlet for heat, sold either to industries or to buildings.

A synergy with industrial heat customer(s) constitutes a favourable situation in terms of energy efficiency because, in general, the industrial energy demand is regular and evenly distributed over the year. But the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

Cold climates provide a substantial and long-lasting heat demand in buildings, often met by District Heating networks, calling for a significant supply of waste heat. Temperate and warm locations imply smaller demands in District Heating networks, if they exist at all, leaving Waste-to-Energy plants with little or no use for their heat besides producing electricity.

A stark contrast exists between plants located in regions with a large heating demand in buildings, giving them a double opportunity (possible industrial heat + possible buildings’ heating), and plants in regions with weak or insignificant heating needs which have no backup plan if the only opportunity (industrial heat) is impossible.

Europe features 3 broad climatic zones (warm, temperate, cold), which in turn make District Heating exceptional, sparse or ubiquitous.

- A hot climate is clearly an impediment to the ability to create or develop District Heating networks, which will remain exceptional, implying a maximum correction factor.
- Then there are intermediate zones, where District Heating is suitable depending on the local conditions but where its presence is sparse and demands is limited both in quantities and time. However since the heating demand varies much in quantity and time, a progressive correction factor is needed to incentivise District Heating development.
- And the cold regions feature ubiquitous District Heating systems, meaning that no correction factor is applicable to these areas.

Setting the thresholds is based on District Heating presence and potential demand, which are linked to Heating Degree Days. A low threshold (HDD 2150) has been identified as the boundary between regions where District Heating is exceptional and with very weak demand and areas where it is more...
frequent and with a higher demand (through France and Italy). The high threshold (3350) separates this middle ground from colder areas where District Heating is ubiquitous (in continental and mountain climates; Northern Europe).

Furthermore, the report shows that:

- Demand for Waste Heat in District Cooling networks is insignificant, more or less equivalent all over Europe, and is far from offsetting the lack of demand for District Heating.
- The heat demand as measured by HDDs can fluctuate by up to 40% from a year to the other in the same location.
- HDD data showed as well a general and significant downward trend of heat demand on the long term: Minus 15% in 30 years (1980 - 2009) in EU average.
- Smaller-sized plants are significantly handicapped when it comes to energy efficiency compared to large ones. Size has an unquestionable influence on R1 but depends on local circumstances such as population density and dispositions related to proximity and self-sufficiency principles.

In conclusion, this study clearly shows that local conditions significantly “influence the amounts of energy that can technically be used or produced in the form of electricity, heating, cooling or processing steam” as mentioned in Article 38 of the Waste Framework Directive (2008/98/EC). Indeed, climate induces a cumulative double impact on the R1 value. A warm climate firstly means limited or virtually inexistent heat demand, while a colder climate creates an opportunity for this heat use. Climate also influences the electricity production, which directly results from thermodynamics. The warmer the outdoor ambient air, the less electricity is produced.

Consequently, in order to level the playing field as much as possible within the EU, it is necessary to set up a climate factor taking into account all the impacts resulting from the local conditions surrounding the Waste-to-Energy plant.

In accordance with the 3 options mentioned at the TAC meeting (Technical Adaptation Committee) of 1/7/2011, two formulas are proposed in this document (as Zero Correction option does not need one). The first one only addresses the climatic impact on the electricity production. The second one cumulates the two issues: impact of climate on electricity and heat. The latter formula is based on two BATs (Best Available Techniques) given in the Waste Incineration BREF, which provide information on the efficiencies of Waste-to-Energy plants respectively when supplying heat (BAT 61) or when limited to electricity export (BAT 62).

Nevertheless, this proposed factor does not fully compensate the handicap for plants in disadvantaged locations regarding heat, as the R1 formula should remain a strong incentive for plant operators to increase their heat export.

**OPTION A** (correcting only the impact on electricity production): Multiplicative factor of 1 for HDD > 3350, increasing proportionally up to 1.11 for HDD 0 (value never reached in Europe).

**OPTION B** (correcting the impact on both electricity production and heat demand): Multiplicative factor, of 1 for HDD > 3350, factor of 1.382 for HDD < 2150 and proportional to the HDD in between.

These factors are shown on Figure 0.1.

The evidence gathered in this report shows that there is an uneven playing field for Waste-to-Energy plants in respect of R1 because climatic conditions affect their electricity production and the demand for their heat. This imbalance is fully addressed in Option B as it compensates for the effect of climate on both electricity and heat, unlike option A, a minimal correction looking only at a part of the climate’s impact (electricity, but not heat) or a Zero Option that dismisses evidence of any climatic impact.
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0. EXECUTIVE SUMMARY

0.1 Purpose and scope of this paper

The Waste Framework Directive (WFD, 2008/98/EC) includes an energy efficiency criterion, often called the R1 criterion, which sets the condition for a municipal solid waste incineration facility to be considered as a Recovery operation. The R1 criterion takes into account not only the plant’s efficiency in recovering the waste’s energy, which generally is high (> 80%), but as well the effective use by third parties and the plant itself of this energy made available by the plant. It does not take into account the local conditions but the WFD also includes in Article 38.1 a provision that local conditions can be taken into account in the calculation of the R1 formula, insofar as they influence the amounts of energy used or produced by the plant.

Statistical evidence of the dependence of the R1 value to local conditions was provided by the 2nd CEWEP Energy efficiency report. Further to discussions with the Commission and the JRC (Joint Research Centre) and to the supply of a previous paper (dated 15/2/2011), this report was commissioned by the JRC (Petten) in order to study how outdoor ambient air temperature differences impact on the production and use of energy by a Waste-to-Energy plant and, consequently, on its R1 value and how that can be modelled in order to propose a correction factor which will ensure a level playing field within the EU in respect of the R1 criterion.

During the TAC (Technical Adaptation Committee) meeting on 1/7/2011, it was announced that the Commission was considering three options for a climate correction factor: one of zero correction, one only including a compensation for the climatic impact on the electricity production and one cumulating the impacts of climate on electricity and the lack of heat demand. Finally, as the CEWEP study highlighted a strong dependence on the size of the plant, this point was also discussed in the report.

0.2 Methodology

After a thorough review of the weather indicators (yearly average outdoor ambient air temperature, hour-by-hour sets of data of outdoor ambient air temperature, Heating Degree Days (the tool used to assess the heat needs), Cooling Degree Days) the statistical data corresponding to different locations in Europe (more than 20 stations) were ordered through national meteorological services in several steps in order to acquire a good understanding of the situation.

Regarding the effect of climate on electricity production, we identified a relation between outdoor ambient air temperature and electricity generation in typical state-of-the-art Waste-to-Energy plants using a condensing turbo-generator set, paired with an air condenser. And we calculated with accuracy by using hour-by-hour data the impact of warm temperatures, hereafter referred to as “handicap” since it is expressed in reference to the electricity generated by a theoretical Waste-to-Energy plant cooled all year long by air at a constant temperature of 10°C. This was necessary since yearly and even daily average data is not accurate enough for thermodynamic calculations. In order to simplify, we then searched for mathematical correlated functions requiring data which is easier to obtain than hour-by-hour data and found a way of calculating the impact of warm temperatures using yearly averages or Heating Degree Days.

With respect to heat use, we identified the links between the heat export and the production of electricity in state-of-the-art Waste-to-Energy plants when operated as CHP (Combined Heat and Power) plants. A technical distinction appeared between locations where the heat demand is so high that the design of the plant is driven by heat delivery (back pressure turbines are then used) and the other locations where heat delivery being modest or poor, the design driver is therefore electricity generation and hence condensing turbines are used. We then quantified the effect of exporting heat on the R1 value.

A correlation is visible between the observed and prospective heating demand in various regions and their HDDs (Heating Degree Days, see Section 1.2.3), the tool used to assess the heat needs. In particular, areas where heat delivery is the driver and areas were heat demand is poor or inexistent could be identified.
With respect to cooling, we listed the different kinds of District Cooling Networks and the kind of energy they use. We then assessed the District Cooling demand versus Heat demand, the share of District Cooling networks in cooling supply, the share of heat among the sources of energy used by the District Cooling networks and the location of District Cooling networks in Europe.

0.3 Results

0.3.1 Electricity generation

Regarding electricity generation, the results showed that the first findings which were put forth in our previous paper of 15/2/2011 were confirmed. Warm air temperatures over the year have a negative impact on energy efficiency, reaching a few percents of the production of the reference plant.

A climate correction factor taking into account the electricity generation ‘handicap’ is therefore needed to maintain a level playing field among European Waste-to-Energy plants.

The ‘handicap’ cannot be directly calculated from yearly average outdoor ambient air temperature since the difference with the accurate calculation, which is based on the hourly outdoor temperature, would be important. However it is possible to (indirectly) correlate the ‘handicap’ with this yearly average temperature as well as with HDDs. We found that the mathematical functions were highly correlated to the accurate calculated values.

The type of climate (oceanic or continental) appears to have a slight effect on the electrical ‘handicap’. However, when studying the impact of the heat demand, we found that the positive effects of an oceanic climate on the production of electricity are offset by the reduced demand of heat (as shown by HDDs) in these areas under oceanic influence. We therefore concluded that the overall effect of the type of climate on electricity production could be ignored since the two effects tend to compensate.

0.3.2 Heat

In spite of the equivalence factors (which compare produced heat and produced electricity to primary fuels; 1.1 and 2.6 respectively), the R1-formula is much more favourable to heat than to electricity. The R1 value of a CHP Waste-to-Energy plant selling 50% of the energy input as heat (and turning the rest into electricity) is as high as 0.858 but only 0.590 when the same CHP Waste-to-Energy plant without heat demand turns all the energy input into electricity.

The key to a high R1 depends on an external outlet for heat, sold either to industries or to buildings.

A synergy with industrial heat customer(s) constitutes a favourable situation in terms of energy efficiency because, in general, the industrial energy demand is regular and evenly distributed over the year. But the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

Cold climates provide a substantial and long-lasting heat demand in buildings, often met by District Heating networks, calling for a significant supply of waste heat. Temperate and warm locations imply smaller demands in District Heating networks, if they exist at all, leaving Waste-to-Energy plants with little or no use for their heat besides producing electricity.

An example is the average long term (30 years) HDD value for Finland, 5,774, compared to the HDD of Portugal, which is only 1,278. The JRC has developed a model which allows interpolating in Europe the HDD values of the stations on a fine grid.

Since the impact of climate conditions on heat demand and on the R1 value is much more important than it is on electricity production, a climate correction factor taking into account the heat demand is therefore also needed to maintain a level playing field among European Waste-to-Energy plants.

0.3.3 Three zones

This correction can be spread into three main zones which have been identified within the EU: First, the North Eastern European zone where climate conditions are optimal for the use of recovered energy and where no climate factor is needed. Secondly, an Intermediate zone where both the electricity production and the possibility to export heat are proportionally affected by the climate conditions. Thirdly, the South Western European zone where the electricity production is still proportionally
affected by the climate conditions. But there the ‘handicap’ on heat usage is maximal because the heat demand is inexistent or too poor to allow for a significant District Heating network. We identified limits between these three zones based on HDD values: \textbf{3350} between the North Eastern zone and the Intermediate one, \textbf{2150} between this one and the South Western one.

\section*{0.3.4 Cooling}

With respect to cooling, different facts were identified. First, it was found that the cooling demand was much lower than the heating demand. Second, it was identified that the share of District Cooling networks in cooling supply was between 1\% and 2\% of the total cooling demand. Third, it was underlined that, even when waste heat is available, the District Cooling systems designers and operators avoid to use it. This is because a District Cooling network must release in cooling towers or rivers the heat it pulls from buildings but also the additional heat used by absorption chillers when they are installed which double the heat to evacuate. Finally, it is suggested that the demand for District Cooling does not depend on the climate as it is mainly required for specific use (food preservation, computer cooling,...) and that the use of heat for cooling (absorption chillers) is better fitting the situation in cold countries where cooling develops with improved building insulation.

Having thus observed that where heat is not needed, it is not replaced by cooling needs, we concluded that cooling demand was negligible and could be ignored in a correction factor.

\section*{0.3.5 BAT 61 and BAT 62}

The Waste Incineration BREF provides efficiencies which can be achieved when using Best Available Techniques (BATs) in the case of a Waste-to-Energy plant dedicated to the export of heat (BAT 61) and in the case of a Waste-to-Energy plant not in conditions to export much heat and dedicated to electricity generation (BAT 62).

We calculated the R1 values corresponding to these efficiencies since their ratio shows the relation between the efficiency which is recognised as Best Available Technique in a plant dedicated to the export of heat and the average efficiency recognised as Best Available Technique in a plant exporting electricity only.

In fact, BAT 62 gives a range of efficiencies. As the R1 criterion must remain an incentive for the operator to increase the amount of heat exported, we compared:

- the R1 value corresponding to BAT 61 (in the worst case, i.e. a plant exporting heat and not generating electricity)
- and the average value of BAT 62 range in such a manner that only the superior half of the range recognised as BAT62 will be in a position to get the same R1 status as plants covered by BAT 61.

\section*{0.3.6 Climate annual variations and long term trend}

The statistical data collected shows huge variation from one year to the other. For instance HDDs may vary in the same location by 40\% from one year to the next one. This of course strongly affects the heat demand and also, to a lower extent, the electricity production.

HDDs have also been observed to decrease on the long term. HDDs decreased by around 15\% over the last 30 years. This means that statistically speaking, the electricity production and the heat demand are decreasing every year.

\section*{0.3.7 Size effect}

The 2\textsuperscript{nd} CEWEP energy efficiency report provides statistical evidence that small plants encounter a significant ‘handicap’ in terms of efficiency. This results from the size effect. It appears that small plants are even further handicapped by the climate in terms of R1 value. However the plants size results from their local conditions and from the requirements of the European legislation for self-sufficiency and proximity treatment of waste stated by the Waste Framework Directive in Article 16., This particular set of circumstances (warm climate + small plant) is especially unfavourable in terms of R1. A factor is suggested to take size as well into account.
0.4 Proposals

In order to partially level the playing field, the climate factor should address technical constraints impacting the R1 value of Waste-to-Energy plants, both for the reduction of electricity production and the lack of heat demand, which evolve together throughout Europe and can be simplified into an examination of a location's HDD to determine the electric handicap and the lack of heat demand.

0.4.1 Option A

However, in compliance with the statement made at the TAC meeting on 1/7/2011, a first formula is proposed to correct ONLY the impact on electricity.

\[
\begin{align*}
\text{Option A} \\
\text{Proposal for a factor } K_{\text{ClimateElec}} \text{ correcting ONLY the impact on electricity:} \\
K_{\text{ClimateElec}} &= 1 \quad \text{if } \text{HDD}_{\text{long term local}} > 3350 \\
K_{\text{ClimateElec}} &= 1.1105 - 32.97 \times 10^{-6} \times \text{HDD}_{\text{long term local}} \quad \text{if } \text{HDD}_{\text{long term local}} < 3350 \\
K_{\text{ClimateElec}} &\text{ is a multiplicative factor to be applied to the calculated R1 value.}
\end{align*}
\]

**Table 0.1: Proposal for a factor \( K_{\text{ClimateElec}} \) correcting ONLY the impact on electricity production**

Figure 0.1 shows the graph corresponding to both proposals (Option A and Option B).

0.4.2 Option B

The Waste Incineration BREF quantifies the impact that potential heat export can have on the overall efficiency of a plant. This indicates trend in the R1 value.

Indeed BAT 61 and BAT 62 provide information on efficiencies which can be achieved when using Best available Techniques. It is therefore proposed to base the maximum climate correction factor on the ratio between the efficiency requested by BAT 61 (for Waste-to-Energy plants dedicated to the export of heat, worst case) and the efficiency recognised as BAT in a plant exporting electricity only. (See above).

It is proposed that the resulting ratio, which is worth 1.382, is used as the maximum multiplicative factor used in the hot zone (HDD > 2150) and then gradually reduced to 1 as HDDs increase from 2150 to 3350, thus motivating export of heat as demand increases.

This factor **cumulates the impact of the two issues** and uses the local long term average HDD as single input. The HDDs cope well both with the ‘handicap’ on electricity production and the reduced or lack of heat demand. And reference data are available on long term periods on official database (Eurostat, JRC for interpolation).

Since the R1 criterion must remain an incentive to use waste heat from the Waste-to-Energy plants, this correction factor proposed in Option B only partially compensates the lack of heat export possibilities. It is far from bringing all South Western plants to the R1 status: less than 50% of them would comply with the R1 criterion with this factor.
Table 0.2: Proposal for a factor $K_{\text{ClimateHeat&Elec}}$ correcting the impact on BOTH electricity production AND heat demand

Figure 0.1 shows the graph corresponding to both proposals (Option A and Option B) with for approximate information the average HDDs of some Member States and regions.

Option B
Proposal for a factor $K_{\text{ClimateHeat&Elec}}$ correcting the impact on BOTH electricity production AND heat demand:

\[
K_{\text{ClimateHeat&Elec}} = 1 \text{ if } \text{HDD}_{\text{long term local}} > 3350 \\
K_{\text{ClimateHeat&Elec}} = 1.382 \text{ if } \text{HDD}_{\text{long term local}} < 2150 \\
\text{And } K_{\text{ClimateHeat&Elec}} \text{ is proportional in the interval, i.e.:} \\
K_{\text{ClimateHeat&Elec}} = -\frac{(0.382/1200)}{1} \times \text{HDD}_{\text{long term local}} + 2.0665 \\
\text{when } 2150 < \text{HDD}_{\text{long term local}} < 3350
\]

$K_{\text{Climate Heat&Elec}}$ is a multiplicative factor to be applied to the calculated R1 value.

Table 0.2: Proposal for a factor $K_{\text{ClimateHeat&Elec}}$ correcting the impact on BOTH electricity production AND heat demand

Figure 0.1: Proposed climate factors $K_{\text{Climate}}$ addressing (option A) only the electricity impact and (option B) the heat AND electricity aspects together – For approximate information, long term (30 years) HDD data in some Member States and regions according to Eurostat data – All text labels (above and below the lines) point out both options

The evidence gathered in this report shows that there is an uneven playing field for Waste-to-Energy plants in respect of R1 because climatic conditions affect their electricity production and the demand for their heat. This imbalance is fully addressed in Option B as it compensates for the effect of climate on both electricity and heat, unlike option A, a minimal correction looking only at a part of the climate’s impact (electricity, but not heat) or a Zero Option that dismisses evidence of any climatic impact.
1. INTRODUCTION

1.1 Purpose of this paper

1.1.1 The R1 formula

Directive 2008/98/EC, known as the Waste Framework Directive (WFD), includes, in its Annex II, a criterion, often referred to as the R1 criterion or the R1 formula, which sets the condition for a municipal solid waste incineration facility to be considered as a Recovery operation (R1 in the nomenclature of this Annex II) or, if not achieved, as a Disposal operation (D10 according to the nomenclature given in Annex I of this Directive).

The R1 formula is the following:

\[
\frac{Ep - (Ef + Ei)}{0.97(Ew + Ef)} \geq Threshold
\]

Where the Threshold value is 0.6 for existing plants and 0.65 for new plants (i.e. plants permitted after 31/12/2008)

Where:

- 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
- Ef means annual energy input to the system from fuels contributing to the production of steam
- Ei means annual energy imported excluding Ew and Ef
- Ew means annual energy contained in the treated waste

R1 formula assesses the overall energy efficiency of the Waste-to-Energy plants which includes the plant’s efficiency in recovering the waste’s energy as well as the effective use of this energy made available by the plant. It should be noted that the Waste-to-Energy plant’s own efficiency is generally high: more than 80% of the waste’s energy is recovered in the usable steam.

The R1 formula does not take into account the local conditions. However, local conditions impact the energy efficiency of an incinerator and Article 38.1 of the Waste Framework Directive stipulates that these local conditions can be acknowledged:

"If necessary, the application of the formula for incineration facilities referred to in Annex II, R1, shall be specified. Local climatic conditions may be taken into account, 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."

At least three different technical factors linked to the local conditions affect the R1 value:

- a) The local climate
- b) The form of the exported energy (electricity only, heat only, CHP (Combined Heat and Power))
- c) The size of the plant
1.1.2 R1 values calculated in the 2nd CEWEP energy efficiency report

The R1 dependence on the three aforementioned factors (referred to by CEWEP as geographical region, kind of energy and size) has been clearly shown in the 2nd CEWEP energy efficiency report (2004-2007) as summarised in Table 1.1.

Table 1.1: Statistical evidence of R1-value dependence to local conditions - 2nd CEWEP energy efficiency report (2004-2007) - Survey on 231 European Waste-to-Energy plants

It should be noted that the 2nd CEWEP energy efficiency report calculations were made on the basis of the draft guidance document on the R1-formula according to the consensus found during the meeting of 16/9/2010 by the working group set up by the Commission for this purpose. However, since then, in July 2011, the Commission published guidelines into which the heat consumed by the plant taken into account into Ep was drastically reduced. The R1-values calculated according to the published guidance will therefore be significantly lower (by around 10% to 15%) than the ones given in Table 1.1. In addition, it appeared that the operators of plants with low R1 value were reluctant to communicate their data. Therefore both the change in the calculation method and the limited number of low-R1 plants taken into account in the study mean that the actual R1 picture will make much more plants fall under the threshold.

The 2nd CEWEP energy efficiency report provides statistical evidence of the significant effect on the R1 value of three factors: geographical region, kind of energy and plant size.

1.1.3 Purpose and scope of the study

The question is to assess and quantify the effect of the technical factors impacting on the R1 value in order to identify the conditions for a level playing field within the EU.

Clerens Consulting was commissioned by the JRC (Petten) to collect data in order to carry out a study with ESWET on how outdoor ambient air temperature differences impact on the production and use of energy by a Waste-to-Energy plant and, consequently, on its R1 value.

During the TAC (Technical Adaptation Committee) meeting held on 1/7/2011, the Chair announced that the Commission was considering three options for a climate correction factor: 1) zero option (no climate factor) 2) wider climate correction factor compensating also a lack of demand for heat produced by the incinerator and 3) climate correction factor restricted to compensating the lower efficiency of turbines in warmer climate.

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The scope of this study therefore analyses how the R1-value depends on local conditions, in particular the impact of the climate on electricity production and on heat demand. As cooling is a possible use of heat, this opportunity has also been investigated.

1.2 Weather data indicators

A review of the commonly used weather data indicators was made first, in order to determine which kinds of data were needed.

1.2.1 Yearly average outdoor ambient air temperature

The most common source of weather information provides yearly or monthly average temperatures and sometimes daily highs and lows. While this can indicate general features about a city’s climate, more accurate information is required to assess the electricity production and the heat demand according to the location of the plant.

1.2.2 Hour-by-hour outdoor ambient air temperature sets

The same occurs with monthly and daily averages. However although the outdoor ambient air temperature usually changes a lot during a day-night period, the inertia of this temperature is such that a fairly good accuracy in the electricity production calculation can be obtained by using hourly averages.

From these hour-by-hour data, we can draw a graph showing the distribution of temperature in number of hours during the year, sometimes called ‘temperature bell’.

Such graphs can be used to compare 2 cities’ temperature profiles, as for instance shown on Figure 1.1, or the variations of profile of the same city from one year to another (see Figures 2.4 and 2.8). The shape of the ‘temperature bell’ is an indicator of the climate type. The wider the ‘temperature bell’, the more continental is the climate. Figure 1.1 shows that Porto’s climate is oceanic and that Marseille’s is already continental.

![Figure 1.1: ‘Temperature bells’ for Marseille and Porto, year 2010 - X-axis: Outdoor ambient air temperature - Y-axis: Nr of hours in the year at each temperature](image.jpg)

The hour-by-hour outdoor ambient air temperature sets of data (8760 hr per year) can be directly used for calculation and/or allow to elaborate different tools: accurate yearly average temperatures (arithmetic mean), maximum and minimum daily averages, standard deviation of the temperature distribution and other mathematic tools.
In the above example, the yearly average temperatures in 2010 are nearly the same in Marseille (14.78°C) and in Porto (15.09°C).

1.2.3 Heating Degree Days (HDDs)

Heating Degree Days (HDDs) have been used for a long time to assess the heat demand in a determined location. The HDDs measure the magnitude of the energy required for heating a building up to a temperature of comfort. Thanks to the thermal inertia of buildings, a daily temperature step is enough to characterise local heat demand.

Eurostat developed a formula\(^3\) to assess the HDDs which are published by its services\(^4\).

**European HDD Formula:**

\[(18°C - T_m) \times d\] if T_m is lower or equal to 15°C and are nil if T_m is greater than 15°C.

Where 15°C is the heating threshold and T_m is the mean (Tmin + Tmax / 2) outdoor temperature over a period of d days.

In this formula, the effective indoor temperature is 18°C. Every day the difference between 18°C and the average between Tmin and Tmax is calculated. This is the HDD of the day. However a value of 0 is taken when the mean temperature is greater than 15°C. The HDD of the year is the sum of the daily HDDs.

It should be noted that after giving the formula, the aforementioned Eurostat’s document says:

“A relatively long base period is desirable to balance out the influence of short-term changes in mean temperatures.”

The online Eurostat data represent long-term HDDs.

**Fine grid**

HDD values can be determined by interpolation for places where there are no meteorological stations.

Using a fine grid (50 km x 50 km), the JRC\(^6\) developed a meteorological model to establish the best set of weather stations for the spatial interpolation of temperature data (see Figure 1.2) at regional level (according to NUTS - Nomenclature des unités territoriales statistiques). Once this selection has been made, the actual interpolation consists of a simple average, corrected for altitude difference.

JRC’s database includes temperature data measured every day (minimum and maximum) for a 12-year period minimum from around 900 stations in Europe from where JRC can estimate the heating degree days in places between measurement stations by spatial interpolation with 1-km grid resolution\(^7\).

Eurostat provides Long term (30 year) HDD data for Member States and their region according to its own formula. JRC can provide interpolated data for any location in the EU.


\(^4\) Long term HDDs for EU Member states and their Regions are available for free on Eurostat website: http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database

\(^5\) While various calculation systems exist, the EU formula to calculate HDDs has the advantage of harmonised data for EU27 and are used by Eurostat, making it easy to compare and obtain data from all over Europe.


\(^7\) “Estimating average daytime and daily temperature profiles within Europe” by Thomas A. Huld, Marcel Suri, Ewan D. Dunlop, Fabio Micale, Environmental Modelling & Software 21 (2006) 1650e1661
1.2.4 Cooling Degree Days (CDDs)

Similarly, “Cooling Degree Days” (CDDs) may reflect the theoretical need for cooling (air conditioning ...).

Although Eurostat made an attempt to develop a CDD formula, it remains unofficial and Eurostat does not provide CDD data. It was mentioned that the parameters that could be used to devise a CDD formula representative of EU consumption patterns (less cooling than in the USA for instance) would be:

Unofficial European Formula:

\[(Tm - 25°C) \times d \text{ if } Tm \text{ is higher or equal to } 27°C \text{ and are nil if } Tm \text{ is lower than } 27°C.\]

Where 27°C is the cooling threshold and Tm is the mean \( (T_{min} + T_{max} / 2) \) outdoor temperature over a period of d days.

CDD is normally limited to 7°C per day (meaning that above Tm of 32°C, cooling is performed by a floating margin of 7°C). For example, if the Tm was of 33°C, cooling would be performed until 26°C and not 25°C.

1.3 Data acquisition

We ordered the temperature data required to elaborate the aforementioned indicators through national meteorological services by using the following methodology.

8 HDDs for EU Member States and their Region were taken from Eurostat website where they are available for free as explained earlier. But, we could not find yearly average outdoor ambient air temperatures provided by Eurostat.
A first set of cities were identified. They were selected:
- In order to represent all parts of Europe as fairly as possible
- In order to be able to make comparisons between cities with apparently similar conditions
- According to the availability of complete sets of data (8760 hours/year available or nearly) for the year chosen as reference (which was 2010 because it was the most recent one and data were available)

First orders and first calculations were made. Then complementary sets of data from other cities, other period of time and other nature (HDD, hour-by-hour) were ordered step by step as we progressed with our research in order to confirm or clarify our first findings.

Data processing had to be adapted as data was received from different sources with different presentation standards.

Eventually, temperature data was gathered for 22 locations, all of which included data for the year 2010 as well as up to 9 previous years (2001-2010) for certain cities. Although considered to be one of the warmest in the world, year 2010 was a cold year in some areas, including Europe. This is confirmed in locations where we got data for more than one year (Umeå, Marseille, Carpentras, Ostrava; in particular see Figures 2.3, 2.4, 2.5, 2.8 and 2.9).

For all locations we got hour-by-hour (except for some cases in tri-hourly values) outdoor ambient air temperature data (allowing the calculation of the specific ‘handicap’ for a plant built in such a city) from which we derived the day by day maxima and minima (which leads to HDDs).

This data base appears to be enough to acquire a fair understanding of the situation in the EU.

**Synthesis of Technical Facts – Chapter 1**

A) The scope of this study is to analyse how the R1-value depends on local conditions, in particular the impact of the climate on electricity production and on heat demand.

B) The 2nd CEWEP energy efficiency report provides statistical evidence of the significant effect on the R1 value of three factors: geographical region, form under which energy is exported and plant size.

C) Tools exist to measure the impact of climate.
   Eurostat provides Long term (30 year) HDD data for Member States and their region according to its own formula. The JRC can provide interpolated data for any location in the EU.

D) Temperature data was gathered for 22 locations, all of which included data for the year 2010 as well as up to 9 previous years (2001-2010) for certain cities

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9 Data were gathered from Belgian, Czech, French, German, Irish, Luxemburg, Spanish and Swedish Meteorological services.
2 ELECTRICITY PRODUCTION VS. OUTDOOR AMBIENT AIR TEMPERATURE

2.1 The generation of electricity in Waste-to-Energy plants

2.1.1 A reference Waste-to-Energy plant

The 2nd CEWEP energy efficiency report (see Table 1.1) has already shown the impact of the geographical location, of the kind of exported energy (electricity/heat) and of the plant size on actual Waste-to-Energy plants (i.e. plants which have each been designed to fit their own local conditions).

2.1.1.1 A standard reference plant

In this chapter we’ll focus on the impact of different climatic conditions on the amount of electricity generated by Waste-to-Energy plants: a same reference plant generating only electricity would be submitted to the various temperature patterns of the 22 sites for which temperature data were gathered. This reference plant is state-of-the-art for standard conditions, complies with the existing European legislation and implements the Best Available Techniques.

The reason for using a standard reference plant is to show that a same plant moved throughout Europe will generate different amounts of electricity according to the climate and therefore may reach the R1 threshold where the weather is cold but not in warmer locations.

In reality all plants are not the same and some local conditions may influence their design and their performances\(^{10}\). However, first it would be a tremendous work to model for every possible case. And second, the statistical analysis made by CEWEP demonstrated that even plants that exist, and were hence tailor-made for each specific location and situation, are differently impacted according to the climatic conditions.

Moreover, it is desirable that the owners and operators do their best to improve the overall efficiency of their Waste-to-Energy plants. The correction factor should therefore be based on a standard plant, and this factor should be used also for the improved plants. It would be unfair that a plant that improved its R1 value would be penalised by reducing its correction factor by the same value. It would deter other plants from investing in these environmentally-friendly improvements to end up with the same R1 value.

2.1.1.2 Condensing turbine and air condenser

If a large quantity of low-pressure steam can be exported, as it is e.g. the case with high demanding District Heating, a backpressure turbine (with its exhaust pressure at the level of the required steam pressure, typically a few bars) is installed.

When the heat demand is medium, not long-lasting or inexistent, a condensing turbine is used in order to increase the generation of electricity, and its exhaust is put under vacuum to maximise electricity production. The lower the vacuum (in bars), the higher the electricity production will be.

\(^{10}\) For instance, a few Waste-to-Energy plants with condensing turbines have the opportunity to use (river or sea) water instead of outdoor ambient air as cold source, either all year long or only during a part of the year. In some areas, the electricity can be paid up to 5 times the standard prices, hence incentivising much more important investments into relatively improved thermodynamic cycles.
In a modern Waste-to-Energy plant generating electricity, the steam parameters from the boiler are typically 40 bars, 400°C\(^{11}\).

And, as mentioned in a footnote above, water being seldom available for water cooling, in particular in Southern Europe, the cold source is most often the outdoor ambient air, forced by fans through an air condenser. The reference plant is therefore equipped with a condensing turbine and an air condenser.

Outdoor ambient air temperature variations hence have an influence on the electrical output produced by the turbo-generator set and the air condenser.

### 2.1.2 Electricity generation vs. outdoor ambient air temperature

#### 2.1.2.1 Enthalpy drop

The production of electricity by a steam turbine generator set (TG set) depends in particular upon the enthalpy drop in the turbine. The steam’s enthalpy varies according to its pressure and temperature above the saturation state\(^{12}\) and upon its pressure and moisture below. This can be read on Mollier’s enthalpy-entropy diagram (see Figure 2.1) or in the corresponding Water-Vapour tables, e.g. from the VDI\(^{13}\).

#### 2.1.2.2 Electricity generation vs. air temperature

The relation between the outdoor ambient air temperature and the electricity output of the TG set and its air condenser group is not linear. This is because enthalpy is not a linear function of pressure and, on the other hand, there is a need to limit pressure around 0.1 bar absolute (abs.), to protect the last turbine blades (as drops resulting from condensation would damage the blades). At saturation state, 0.1 bar abs. corresponds to a temperature of 45°C (condensation temperature). A typical air condenser has a difference between ambient air temperature and condensation temperature of 35°C to 40°C (the higher the air temperature, the wider the temperature difference).

Therefore, 0.1 bar abs. corresponds to an ambient air temperature of around 10°C (=45°C - 35°C). The electricity production curve with regards to ambient air temperature is therefore close to a constant value under 10°C and decreases afterwards.

When ambient air temperature is 35°C, the condensation temperature is around 75°C (=35°C + 40°C).

Figure 2.1 shows the enthalpy drop of a condensing steam turbine with ambient air temperature at 10°C (yellow bullet) and 35°C (orange bullet) on a simplified Mollier’s diagram. It takes into account the enthalpy drop difference (see the isentropic expansions on Figure 2.1) and the so-called isentropic efficiency\(^{14}\).

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\(^{11}\) Modern Waste-to-Energy plants operated in CHP mode (Combined Heat and Power) as well typically are rated at 40 bar and 400°C.

\(^{12}\) The flue gas resulting from the combustion of waste is much more corrosive and clogging than the flue gas from fossil fuels. In order to protect the boiler, the pressure and temperature of the steam in Waste-to-Energy plants are limited to lower values than the ones encountered in classical thermal power plants. This is the reason why the efficiency of Waste-to-Energy plants in generating electricity is significantly lower than the ones obtained in thermal power plants.

\(^{13}\) “VDI Wasserdampftafeln”, VDI steam tables in kcal and atmosphere by Ernst Schmidt VDI (1968) or “Properties of Water and Steam in SI-units” (1982), both at Springer Verlag Berlin Heidelberg New York R. Oldenbourg Munchen. The Mollier’s diagram is enclosed in these tables.

\(^{14}\) The isentropic efficiency results from a number of factors: Pressure drop at the admission throttle (which controls the admission pressure) – Heat radiations – Leakage losses between blades and stator/rotor – Steam friction on blades (due to roughness) – Blades twisted profiles imperfections (between the middle and the periphery – Exhaust losses (the kinetic energy of the steam at turbine outlet is lost).

The isentropic efficiency deteriorates a little as the steam pressure at turbine exhaust increases (because the angle of attack on the blades in the last section of the turbine is not optimal)
Figure 2.1: Mollier’s h,s-diagram (enthalpy-entropy) – Steam expansion in the turbine and enthalpy drop. Inlet: 40 bar, 400°C. Exhaust pressures of 0.1 bar and 0.39 bar absolute respectively correspond to outdoor ambient air temperature at 10°C and 35°C.

The lower the outdoor air temperature, the larger the enthalpy drop (see the two arrows on the left of the diagram). The larger the enthalpy drop, the more efficient the turbine is.

By calculation on the Mollier’s diagram of a number of points corresponding to different outdoor air temperature and taking into account the gear and generator efficiencies, it is possible by interpolation to draw the curve (see Figure 2.2) showing the electricity production of a condensing turbine-generator set paired with an air condenser according to the outdoor ambient air temperature, like in typical Electricity-only Waste-to-Energy plants (i.e. without steam extraction for export).
2.1.2.3 Reference situation

In this Figure 2.2, the electricity production of our reference plant is given as a ratio compared to a reference value corresponding to a (theoretical) location where the outdoor ambient air temperature would be 10°C all year long.

2.1.2.4 ‘Handicap’

This ratio is hereafter referred to as a ‘handicap’ (with ‘handicap’ = 1 - ratio). A negative handicap is to be understood as a benefit (i.e. a plant located in an area with negative handicap would be able to generate more electricity than the reference plant can do).

![Electricity generation ratio vs. elec. gen. with constant ambient air temperature at 10°C](chart)

*Figure 2.2: Impact of the ambient air temperature on the amount of electricity generated – Expressed as the ratio between the amount of electricity generated with air at a particular temperature and the amount generated with air at 10°C*

2.2 Calculating the yearly electrical production

2.2.1 Calculation table

Combining the electricity production ratio in function of the ambient air temperature (see Figure 2.2) and the outdoor ambient air temperature data over a year at a particular location gives the ratio between the local annual electricity production and the reference theoretical situation (a place at constant ambient air temperature of 10°C all over the year). From this ratio is derived the ‘handicap’ (‘handicap’ = 1 - ratio)

The curve given in Figure 2.2 not being linear in the range of temperatures encountered in Europe, it is necessary to consider short periods of time to achieve accurate calculations. The inertia of the outdoor ambient air temperatures is such that a very good accuracy can be obtained with hourly temperature values.

For comparison purpose, the same calculation of a ‘handicap’ is also made by directly using the outdoor ambient air yearly average temperature.

The impact of outdoor ambient air temperature on the electricity production of a steam condensing turbine-generator set coupled with an air condenser can be calculated with accuracy.
2.2.2 Results for a cold location: Umeå - Hölmon (Sweden)

The hour-by-hour outdoor ambient air temperatures at Hölmon, the weather station of Umeå (Sweden), are shown on Figure 2.3 for the years 2009 and 2010. The average annual temperatures were 3.86°C in 2009 and 2.03°C in 2010.

![Ambient air temperature hour by hour (Umeå)](image)

**Figure 2.3: Outdoor ambient air temperature distribution at Umeå during the years 2009 and 2010**

The annual electricity production of a condensing turbine-generator set with air condenser and fed with steam at 40 bar and 400°C, if located at Umeå station (Hölmon), is given in Table 2.1 as its ratio with the electrical output of a theoretical plant operated all year long with ambient air temperature at 10°C.

The calculation is made for the 2 years, 2009 and 2010, by using hourly data and, for the purpose of comparison, it is also made with the annual average temperatures.

<table>
<thead>
<tr>
<th>Ratio between the electricity production in this location and the electricity produced in a plant with air at 10°C all year long.</th>
<th>2009</th>
<th>2010</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hour-by-hour calculation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio</td>
<td>100.13%</td>
<td>100.21%</td>
<td>100.17%</td>
</tr>
<tr>
<td>‘Handicap’</td>
<td>- 0.13%</td>
<td>- 0.21%</td>
<td>- 0.17%</td>
</tr>
<tr>
<td><strong>Calculation on yearly average temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Temperature</td>
<td>3.86°C</td>
<td>2.03°C</td>
<td>2.95 °C</td>
</tr>
<tr>
<td>Ratio</td>
<td>100.92%</td>
<td>101.12%</td>
<td>101.02%</td>
</tr>
<tr>
<td>‘Handicap’</td>
<td>- 0.92%</td>
<td>- 1.12%</td>
<td>- 1.02%</td>
</tr>
</tbody>
</table>

**Table 2.1: ‘Handicap’ between the electricity production at Umeå - Hölmon (Sweden) and the electricity produced by a plant with ambient air at constant temperature of 10°C**

NB: A negative handicap is a benefit. It means that more elec. is produced locally than in the reference situation (at 10°C).
As it can be seen in Table 2.1, the electricity production in this location is similar to the production of a theoretical plant located in a place where temperature is 10°C all year long (with in fact a small benefit). This is because the temperature in the Umeå station (Hölmon) is below 10°C most of the year.

From this example, we can see that:

- although the average temperature differs by 1.83°C between the two years (2010 being the coldest) there is nearly no difference between the electricity productions of 2009 and 2010 when calculated on an hour-by-hour basis (benefits of -0.13% and -0.21% respectively) as well as when calculated on the yearly average value (benefits of -0.92% and -1.12%);

- however there is a difference of almost 1 percentage point (1.02% and 0.17%) between the results of the hour-by-hour calculations and the results directly using the yearly average outdoor ambient air temperature with curve in Figure 2.2.

2.2.3 Results for a 10-year period in a warm location: Marseille - Marignane (France)

Figure 2.4 shows the hour-by-hour ambient air temperature spreading at Marignane weather station (Marseille Airport) for each of the 10 years between 2001 and 2010 plus the average value (the yearly average temperatures can be seen on Figure 2.5).

![Figure 2.4: Outdoor ambient air temperature distribution at Marseille - Marignane during years 2001 to 2010 and their average](image_url)

It can be seen on Figure 2.4 that the yearly hour-by-hour ambient air temperature curves may differ significantly during the 10 year period. See for instance the curves of year 2002 (high and narrow) and of year 2005 (wide and flat). The curve corresponding to the 10 year average is much more regular (and closer to a standard normal (Gaussian) distribution) than the individual yearly curves.

As already mentioned, although year 2010 is claimed to be one of the hottest on record at world level, here it is the coldest of the series (see also Figure 2.5).
Marseille Marignane - Yearly average outdoor ambient air temperature (°C)

<table>
<thead>
<tr>
<th>Year</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>15.63</td>
</tr>
<tr>
<td>2002</td>
<td>15.81</td>
</tr>
<tr>
<td>2003</td>
<td>16.15</td>
</tr>
<tr>
<td>2004</td>
<td>15.27</td>
</tr>
<tr>
<td>2005</td>
<td>14.92</td>
</tr>
<tr>
<td>2006</td>
<td>16.29</td>
</tr>
<tr>
<td>2007</td>
<td>15.63</td>
</tr>
<tr>
<td>2008</td>
<td>15.57</td>
</tr>
<tr>
<td>2009</td>
<td>15.95</td>
</tr>
<tr>
<td>2010</td>
<td>14.78</td>
</tr>
<tr>
<td>Mean</td>
<td>15.60</td>
</tr>
</tbody>
</table>

Figure 2.5: Marseille - Marignane, yearly average outdoor ambient air temperature – Years 2001 to 2010 and 10 year average value

With the same assumptions as above (condensing turbine-generator set with air condenser and fed with steam at 40 bars and 400°C), Figure 2.6 shows the ‘handicap’ between the annual electricity production of a Waste-to-Energy plant located at Marseille Marignane station and the electrical output of a theoretical plant operated all year long with ambient air temperature at 10°C.

Calculations were made for 10 years, from 2001 to 2010, with hourly data as well as, by using the annual average temperature for comparison purpose.

As it can be seen on Figure 2.6, the electricity production ‘handicap’ vs. the reference situation (10°C all year long), calculated on hour-by-hour basis, significantly varies over the 10 years, between 4.77% (in 2010) and 6% (in 2003). Year 2010 which was the reference year for all the locations investigated in this study was the coldest of the 10 years with the smallest ‘handicap’ of the 10 years: 1.23 percentage point less than the maximum ‘handicap’ observed over the period of time. (1.23 is the difference between 6% (2003) and 4.77% (2010)).

Figure 2.6: ‘Handicap’ between the electricity production at Marseille - Marignane and the electricity produced by a plant with ambient air at constant temperature of 10°C all year long during years 2001 to 2010 and the 10 year average value – Calculated first by using the hour-by-hour temperature data and second by using the yearly temperature average
Calculations directly made with the annual average outdoor ambient air temperatures, which are also shown in Figure 2.6, give much lower values.

Figure 2.7 shows the ratio between the results of the calculations made on an hour-by-hour basis and the ones directly using annual averages. This ratio ranges from 1.47 up to 1.94 with a mean value of 1.67.

**Figure 2.7: Ratio comparing the ‘handicaps’ in electricity production when calculated with hour-by-hour outdoor ambient air temperature data and when directly calculated with the yearly average outdoor ambient air temperature – Marseille - Marignane, years 2001 to 2010 and 10 year average value**

The impact is significantly different from one year to another in the same location. It will be necessary to build the references on long term data (over 10 or even 30 years if possible).
2.2.4 Data for a 11-year period in Ostrava (Czech Republic)

As in Marseille, Figure 2.8 shows that the yearly hour-by-hour ambient air temperature curves may differ significantly during an 11 year period.

Figure 2.8: Outdoor ambient air temperature distribution at Ostrava (Czech Republic) during years 2000 to 2010 and their average

As already observed with Marseille data, year 2010 is the coldest of the series.

Figure 2.9: Outdoor ambient air temperature distribution at Ostrava (Czech Republic) during years 2000 to 2010 and their average
### 2.2.5 Results for year 2010 in 22 European cities

**‘Handicap’ values**

The following Table 2.3 gives for 22 European stations over year 2010:
- The yearly average outdoor ambient air temperature
- The Standard Deviation on outdoor ambient air temperature (hour distribution)
- The handicap in electricity production in reference to a location with air at 10°C all year long
  - calculated firstly with hour-by-hour temperature data
  - and secondly directly using only the average yearly temperature
- The Heating Degree Days calculated according to the E.U. formula

<table>
<thead>
<tr>
<th>City</th>
<th>Yearly average temperature (°C)</th>
<th>Outdoor temperature Standard Deviation (°C)</th>
<th>Handicap, accurately calc. with Hour-by-hour Temp.</th>
<th>Handicap directly calc. with Temp. YEARLY average (for the record)</th>
<th>HDD (EU formula)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Umeå Hölmon</td>
<td>2.03°C</td>
<td>11.39°C</td>
<td>- 0.21%</td>
<td>- 1.12%</td>
<td>5931</td>
</tr>
<tr>
<td>Stockholm</td>
<td>5.50°C</td>
<td>10.28°C</td>
<td>0.87%</td>
<td>- 0.71%</td>
<td>4667</td>
</tr>
<tr>
<td>Glasgow</td>
<td>7.85°C</td>
<td>6.49°C</td>
<td>0.45%</td>
<td>- 0.43%</td>
<td>3587</td>
</tr>
<tr>
<td>Ostrava</td>
<td>8.24°C</td>
<td>9.81°C</td>
<td>1.74%</td>
<td>- 0.39%</td>
<td>3707</td>
</tr>
<tr>
<td>Hamburg</td>
<td>8.26°C</td>
<td>8.74°C</td>
<td>1.40%</td>
<td>- 0.39%</td>
<td>3715</td>
</tr>
<tr>
<td>Munich</td>
<td>8.34°C</td>
<td>9.06°C</td>
<td>1.57%</td>
<td>- 0.38%</td>
<td>3677</td>
</tr>
<tr>
<td>Dublin</td>
<td>8.49°C</td>
<td>6.37°C</td>
<td>0.65%</td>
<td>- 0.35%</td>
<td>3477</td>
</tr>
<tr>
<td>Hannover</td>
<td>8.52°C</td>
<td>9.06°C</td>
<td>1.63%</td>
<td>- 0.35%</td>
<td>3622</td>
</tr>
<tr>
<td>Luxemburg</td>
<td>8.71°C</td>
<td>8.54°C</td>
<td>1.55%</td>
<td>- 0.32%</td>
<td>3465</td>
</tr>
<tr>
<td>Liverpool</td>
<td>8.91°C</td>
<td>6.80°C</td>
<td>0.93%</td>
<td>- 0.28%</td>
<td>3309</td>
</tr>
<tr>
<td>Brussels</td>
<td>9.74°C</td>
<td>7.90°C</td>
<td>1.75%</td>
<td>- 0.08%</td>
<td>3074</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>9.87°C</td>
<td>8.86°C</td>
<td>2.18%</td>
<td>- 0.04%</td>
<td>3151</td>
</tr>
<tr>
<td>London</td>
<td>10.48°C</td>
<td>7.06°C</td>
<td>1.79%</td>
<td>0.16%</td>
<td>2782</td>
</tr>
<tr>
<td>Lyon</td>
<td>11.60°C</td>
<td>8.75°C</td>
<td>3.03%</td>
<td>0.62%</td>
<td>2594</td>
</tr>
<tr>
<td>Carpentras</td>
<td>13.52°C</td>
<td>9.15°C</td>
<td>4.37%</td>
<td>1.66%</td>
<td>2127</td>
</tr>
<tr>
<td>Granada</td>
<td>14.64°C</td>
<td>8.86°C</td>
<td>4.97%</td>
<td>2.42%</td>
<td>1818</td>
</tr>
<tr>
<td>Marseille Marignane</td>
<td>14.78°C</td>
<td>8.17°C</td>
<td>4.77%</td>
<td>2.52%</td>
<td>1782</td>
</tr>
<tr>
<td>Porto</td>
<td>15.09°C</td>
<td>6.13°C</td>
<td>3.90%</td>
<td>2.76%</td>
<td>1222</td>
</tr>
<tr>
<td>Roma</td>
<td>15.74°C</td>
<td>7.17°C</td>
<td>5.02%</td>
<td>4.35%</td>
<td>1385</td>
</tr>
<tr>
<td>Lisboa</td>
<td>17.02°C</td>
<td>5.67°C</td>
<td>5.54%</td>
<td>4.35%</td>
<td>874</td>
</tr>
<tr>
<td>Trapani (Sicily)</td>
<td>18.76°C</td>
<td>6.28°C</td>
<td>7.17%</td>
<td>6.01%</td>
<td>697</td>
</tr>
<tr>
<td>Sevilla</td>
<td>19.57°C</td>
<td>7.92°C</td>
<td>8.5%</td>
<td>6.84%</td>
<td>670</td>
</tr>
</tbody>
</table>

Table 2.3: Yearly average outdoor ambient air temperature - Standard Deviation on outdoor ambient air temperature (hour distribution) - Handicap in electricity production (in reference to a location with air at 10°C all year long), calculated first accurately with hour-by-hour temperature data and second directly using only the average yearly temperature - Heating Degree Days

The results presented in this Table 2.3 and in Figure 2.10 confirm that the direct calculation of the handicap with the average yearly outdoor ambient air temperature gives a much lower result than when accurately calculated on an hour-by-hour basis. However, generally speaking, the yearly average outdoor ambient air temperature and the accurately calculated ‘handicap’ (respectively in blue ref. the left Y-axis and in pink ref. the right Y-axis on Figure 2.10) show a similar trend.
There is a significant difference in the results when the calculation is done with accuracy by using hour-by-hour temperature data, compared to when it is directly done with temperature data averaged on longer periods of time.

2.3 Simplified formulas

Since it is not always possible to get hour-by-hour values, we therefore investigated a formula which would give the accurate ‘handicap’ value using more widely available data, such as outdoor ambient air yearly averages and HDDs.

The main objective of this exercise was to find an indirect link between the accurate ‘handicap’ and the yearly outdoor ambient air temperature or HDDs, which is different from trying to calculate the ‘handicap’ by directly using this yearly average temperature with the TG set efficiency curve (Figure 2.2).

2.3.1 Linear function $f_1(Y_T)$

A first linear function $f_1$ was identified:

$$f_1(Y_T) = \frac{(0.5 \times Y_T - 2.71)}{100}$$

Where $Y_T$ is the local Yearly average outdoor ambient air Temperature and $f_1(Y_T)$ expresses in % the ‘handicap’ in electricity production reduction.

As it can be seen in Figure 2.11, this function $f_1$ (in pale green) works well. The correlation coefficient with the accurate values of the ‘handicap’ is 0.958. However the accurate ‘handicaps’ of some cities are slightly overestimated by function $f_1$. The ends of the temperature range (Umeå and Stockholm at one end and Seville at the other one) are more difficult to approximate.
Electricity generation handicap vs. Functions of outdoor ambient air temperature

Figure 2.11: Yearly average outdoor ambient air temperature for European cities (in blue, in °C, left Y-axis) - ‘Handicap’ in electricity production calculated with hour-by-hour temperature data (in pink, in%, right Y-axis) - Function f1(Yearly Temp) as an attempt to derive the accurate ‘handicap’ from the yearly temperature (in pale green, in%, right Y-axis)

2.3.2 Function of second degree f2(YT)

A function of second degree, f2 was then selected:

\[ f2(YT) = \frac{0.022 YT^2}{100} \]

Where YT is the local Yearly average outdoor ambient air temperature and f2(YT) expresses in % the ‘handicap’ in electricity production reduction.

As shown in Figure 2.12, this function f2 (in green) works better at the ends of the temperature range. The correlation coefficient with the accurate values of the ‘handicap’ is 0.981. However the accurate ‘handicaps’ of some intermediate cities are slightly overestimated by function f2.

Figure 2.12: Yearly average outdoor ambient air temperature for European cities (in blue, in °C, left Y axis) – ‘Handicap’ in electricity production calculated with hour-by-hour temperature data (in pink, in%, right Y axis) – Function f2(Yearly Temp) as an attempt to derive the accurate ‘handicap’ from the yearly temperature (in pale green, in%, right Y-axis)
2.3.3 Function of 2 variables \( f_3(YT,SD) \)

After thorough analysis, it appears that these cities where the ‘handicap’ value is slightly lower than that given by functions \( f_1 \) and \( f_2 \), are these cities where the ‘temperature bell’ is narrower, in fact the cities experiencing an influence from the ocean. This can be seen in Table 2.3 for instance between Marseille and Porto (see also Figure 1.1): The yearly average temperature at Porto (15.09°C) is slightly higher than in Marseille (14.78°C) but the electricity generation ‘handicap’ is lower in Porto (3.90%) than in Marseille (4.77%). British Isles appear to be among the best locations to generate electricity.

The explanation lays in the Standard deviations: 6.13°C in Porto and 8.17°C in Marseille. In fact, the ‘temperature bell’ is wider in continental climates and narrower in oceanic ones: (Glasgow, Dublin, Liverpool, London, Porto and Lisbon in our selection of cities). Mathematically this can be calculated by using the Standard Deviation of the hour-by-hour temperature distribution. See the curve in pale blue on Figure 2.13.

We thus identified a more detailed function \( f_3 \) with 2 variables:

\[
f_3(YT,SD) = \frac{[(0.022 YT^2) - 0.3 \times (9 - SD)]}{100}
\]

Where \( YT \) is the local Yearly average outdoor ambient air temperature, \( SD \) is the Standard Deviation of the hour-by-hour temperature distribution and \( f_3(YT, SD) \) expresses in % the ‘handicap’ in electricity production reduction.

As shown in Figure 2.13, this function \( f_3 \) (in yellow) perfectly matches the accurate values of the ‘handicap’ (in pink). The correlation coefficient with the accurate values of the ‘handicap’ is 0.995.

![Electricity generation handicap vs. Functions of outdoor ambient air temperature](image)

Figure 2.13: Yearly average outdoor ambient air temperature for European cities (in blue, in °C, left Y-axis) - Standard deviation of hour-by-hour temperature distribution (in pale blue, in °C, left Y axis) - ‘Handicap’ in electricity production calculated accurately with hour-by-hour temperature data (in pink) and functions \( f_1 \), \( f_2 \) and \( f_3 \) (in pale green, green and yellow respectively, in %, right Y-axis). See text for the definitions of the functions

However, to calculate the Standard Deviation, the hour-by-hour temperature data are required (and as seen before, on a long period of time, 10 or even 30 years whenever possible). This might be difficult to collect.

On the other hand, the differences between the accurate calculations based on hour-by-hour temperature data and the different functions \( f \) occur for cold areas (Umeå and Stockholm) which are not relevant for the discussion on the ‘handicap’ and the city of Seville which is reported by meteorologist expert as very specific and probably the hottest on the European continent. The average temperature in Granada (14.64 °C), located 250 km at east of Seville, is just less than the one of Marseille (14.78°C). See table 2.3.
Simpler functions may therefore be alright.

### 2.3.4 Linear function of HDD $f_4(\text{HDD})$

Another formula was therefore experimented, based on the HDDs values, these data being usually easier to get than the hour-by-hour ones.

Figure 2.14 shows the same curves as the previous Figures with, in addition, the HDD values (in green and divided by 250 in order to match the scale on the left Y-axis) and the curve of function $f_4$ (in brown, in%, right Y-axis):

$$f_4(\text{HDD}) = \frac{(7.26 - 1.57 \times \text{HDD}/1000)}{100}$$

Where HDD is the local Heating Degree Days value according to the EU formula and $f_4(\text{HDD})$ expresses in % the ‘handicap’ in electricity production reduction.

![Electricity generation handicap vs. Functions of outdoor ambient air temperature](image)

**Figure 2.14:** Same curves as in previous Figure plus the local HDD value (divided by 250; refers to the left Y-axis) and function $f_4(\text{HDD})$ (in brown; referring to the right Y-axis).

*See text for the definition of function $f_4$*

This function $f_4$ (in brown) does not match better the accurate ‘handicap’ curve (in pink) than functions $f_2$ and $f_3$ but is nearly as accurate as function $f_1$ (not represented again in Figure 2.14 for the sake of clarity; see Figure 2.13). Its correlation coefficient is 0.938 if the cold cities values (Umeå and Stockholm) are excluded.

However, if we exclude the extreme values of Umeå and Seville, it is noteworthy that the differences between the curve of function $f_4$ and the accurate ‘handicap’ curve mainly occur in these cities with oceanic climate. In these cities the ‘handicap’ on electricity production is slightly smaller than predicted by $f_4$ but on the other hand, the HDD is smaller.

If we consider again the cities of Porto and Marseille which nearly have the same yearly average temperature, Table 2.3 shows that the heat demand is lower in Porto (HDD 1222) than in Marseille (HDD 1782).

Comparing the plots of the accurate ‘handicap’ (in pink) and of the $f_4$ curve (in brown), it is clear that the main differences occur for the cities with oceanic influence: Glasgow, Dublin, Liverpool, London, Porto.

In summary, when comparing two cities with the same yearly average temperature, the one with the narrower ‘temperature bell’ will face:

- Less electricity production reduction because the number of hours at high temperatures is lower (less electricity drop during hot hours, on the right side of the ‘bell’ in our Figures showing the ‘temperature bells’).
- Less heat demand because the number of hours at low temperature is lower (left side of the 'bell')

The reduced heat demand in oceanic climates will compensate the smaller ‘handicap’ reduction on electricity generation.

It is therefore probably useless to use a function such as f3 which tries to take into consideration the influence of oceanic/continental climate because the effects on electricity are offset by the effects on heat. A simple linear function will do.

Function (f4) is almost as precise as function (f1) in quantifying the impact on electricity production. But it uses HDD as single variable which is widely available data.

2.4 Electricity demand

We assumed in this study that exporting the electricity generated by the plant is always possible and therefore that this is not an issue.

2.5 Conclusions on electricity generation vs. temperatures

Summarising the above data and facts, it appears that:

1 It is not possible to take into consideration all possible plant specificities. And, as it is desirable that the owners and operators do their best to improve the overall efficiency of their plants, it would be counterproductive to penalise with a reduced climate factor those plants which benefit from improvement in respect of the standard situation. This quantification of the impact can therefore be assumed by using a same state-of-the-art standard plant moved to different locations in Europe.

2 The outdoor ambient air temperature has a clear effect on the electricity production of a steam condensing turbine-generator set coupled with an air condenser which is the typical situation for state-of-the-art Waste-to-Energy plants with moderate or inexistent heat demand.

3 This impact can be calculated with accuracy by using hour-by-hour data.

4 The effect is very small when the outdoor ambient air temperature is under 10°C. Above 10°C, the effect is significant and it reduces production. It is possible to calculate the electricity production ‘handicap’ due to the local outdoor ambient air temperature by comparison with a reference situation (where the air temperature is 10°C all year long).

5 The effect is significantly different from one year to another in the same location. It will be necessary to build the references on long term data (over 10 or even 30 years if possible).

6 There is a significant difference in the results when the calculation is done with accuracy by using hour-by-hour temperature data, and when it is directly done with temperature data averaged on longer periods of time because the electricity production curve is not linear and the temperature changes during a day-night period are usually important. The ratio between hour-by-hour calculations of the ‘handicap’ and calculations directly based on the yearly average temperature is not a constant. For Marseille’s 10 year period the difference ranges from 1.47 to 1.94 with a mean value of 1.67.

7 However it is possible to find a function (see functions f1 and f2 in the text) of the yearly average outdoor air temperature giving a pretty good correlation coefficient (0.958 and 0.981 respectively) with the accurately calculated ‘handicap’. (These functions give an indirect relation between the handicap and the yearly average outdoor air temperature).
When comparing two cities with the same yearly average outdoor ambient air temperature, the 'handicap' is slightly smaller in cities with narrower 'temperature bell' distributions. The width of the 'bell' is related to the oceanic (narrow 'bell') or continental (wide 'bell') climate in the cities. Mathematically, the width of the 'bell' corresponds to its standard deviation. A function (see function f3 in the text) has been identified which takes into consideration the two variables (the yearly average outdoor ambient air temperature and the standard deviation) and perfectly matches the accurately calculated 'handicap'. Its correlation coefficient is 0.995.

However, the hour-by-hour temperature data is required for the calculation of the standard deviation but they are not always easy (or possible) to get. And the deviations corrected by the use of the standard deviations correspond to the oceanic climate.

Another function (f4) was identified which uses HDD as single variable (as defined by the EU formula). Even if smaller than the one of the previous functions, its correlation coefficient (0.938) is still correct if we except cities with very high HDD (Umeå and Stockholm) which anyway are not relevant for climate correction factor. The differences between the two curves (f4 vs. accurate handicap) mainly occur in cities with oceanic climate. In these cities the handicap on electricity production is slightly reduced but on the other hand, the HDD is smaller.

The reduced heat demand in oceanic climates will compensate the smaller 'handicap' reduction on electricity generation. It is therefore probably not necessary to take into consideration the influence of oceanic/continental climate.

Although, one of the warmest at world level, year 2010 was a very cold year in Europe; this is confirmed in the locations where we got statistics on long term: 2010 was the coldest of two years (2009-2010) in Umeå (Sweden), the coldest of 10 years (2001-2011) in Marseille and Carpentras in France (which are not very far from each other), the coldest of 11 years (2000-2011) in Ostrava (Czech Republic).

In Marseille-Marignane, the 2010 'handicap' is 0.46% less than the 10-year average value.

A climate correction factor based on these findings is proposed in Sections 7.3.2 and 7.4. See also Section 5.4.1

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**Synthesis of Technical Facts – Chapter 2**

_E) The outdoor ambient air temperature has a clear effect on the electricity production of state-of-the-art Waste-to-Energy plants with moderate or inexistent heat demand. The warmer the air, the lower the electrical efficiency._

_F) This effect on electrical efficiency can be calculated with accuracy in a function by using hour-by-hour air temperature values._

_G) With the data gathered for this study, the impact numbers in a few percents._

_H) Another function (f4) was identified which uses HDD as single variable. It is almost as precise in quantifying the impact on electricity production as using hour-by-hour data and uses widely available data._
3. HEAT USE/DEMAND

When possible, it is valuable to export heat or process steam from a Waste-to-Energy plant as it usually improves the overall energy efficiency of the plant. However when it is feasible, the amounts which can be exported depend on a number of factors and affect the design of the plant.

3.1 Links between exported heat and electricity production

3.1.1 Back pressure turbine

The technical design of a CHP (Combined-Heat-and-Power) Waste-to-Energy plant should be optimised according to the conditions of the project and in particular according to the form of the exported energy.

When there is a very high and long-lasting heat (or process steam) demand, priority is normally given to heat (which in general generates a higher profit) and the turbine exhaust pressure is defined according to the district heating network (or process) temperatures (feed temperature plus heat exchanger pinch). With such back pressure turbines it is possible (and recommended as it is the objective) to use (temporarily or, better, permanently) up to 100% of the steam flow for heating. The higher heat export ability largely compensates the electricity generation reduction resulting from the higher exhaust pressure.

3.1.2 Condensing turbine

For plants where the heat demand is smaller (in quantity or in time duration), in order to generate as much electricity as possible, a condensing turbine is preferred. With air condensers, its exhaust pressure will be 0.1 bar absolute when outdoor air temperature is 10°C (see section 2.1.4). In such case, the steam needed for heat (or process steam) export is extracted at the required pressure from a bleed in the turbine. The low pressure stages of the turbine, located after the steam extraction, need to be cooled by a minimum steam flow, typically 15% to 20% of the nominal steam flow (i.e. the flow which goes through when there is no steam extraction). The instantaneous heat export is therefore limited to roughly 50% of the energy input15.

Back pressure turbines are typically installed in the Waste-to-Energy plants in Nordic and Eastern countries. Condensing turbines are typically used in the Waste-to-Energy plants in the rest of Europe. As extraction bleeds cannot be added later to a turbine, most often the owners and the operators of Waste-to-Energy plants exporting only electricity require CHP-ready plants, i.e. turbine with bleeds ready to export heat if demand is identified.

3.1.3 Interaction between exported heat and electricity production

Let us consider a good state-of-the-art Combined-Heat-and-Power Waste-to-Energy plant rated at 250,000 t/year of waste located in Eastern Central Europe (average yearly temperature 7°C) with a fair heat demand (however not sufficient for opting for a back pressure turbine) but leading to designing the plant with a technical capacity to export heat in a range between 0% and 50% of the waste’s energy input and a steam bleed at 4 bar.

The relationship at design steady nominal load between the fraction of the energy input exported as heat and the electricity production is given in Table 3.1.

---

15 One turbine manufacturer can offer turbines specially designed to allow a higher flow rate, e.g. 60%, but only for large capacities.
Table 3.1: Technical relationship at design steady nominal load between the fraction of the energy input which is exported as heat and the electricity production for a large plant (250,000 tonnes of waste per annum, t/y) in rounded figures

‘State-of-the-art’ refers to CHP Waste-to-Energy plants as typically designed in 2011 by the suppliers after a tendering competition where the performances of the plant, and in particular their energy efficiencies, are carefully appraised by competent consultants. It should also be noted that the time to set up such a project is very long (10 years) and that the plants designed in 2011 will not be started before 5 to 8 years. We should also keep in mind that the performances of older plants were lower.

3.2 The R1 value of a CHP Waste-to-Energy plant according to the ratio of exported heat

The following Table 3.2 provides typical values for the secondary parameters of the R1 formula.

<table>
<thead>
<tr>
<th>Assumptions for the secondary parameters of the R1 formula</th>
<th>Value (in% of Ew)</th>
<th>Equivalence factor</th>
<th>With equivalence factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ep heat used by the plant</td>
<td>1%</td>
<td>1.1</td>
<td>0.011</td>
</tr>
<tr>
<td>Ei elec (imported electricity)</td>
<td>0.25%</td>
<td>2.6</td>
<td>0.0065</td>
</tr>
<tr>
<td>Ei other energies (energy inputs not contributing to steam production)</td>
<td>1%</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Ef (other energy inputs, contributing to steam production)</td>
<td>0.5%</td>
<td>1</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Table 3.2: Assumptions for the secondary parameters of the R1 formula (rounded figures)

The efficiencies given in Table 3.1 are technical manufacturer’s design values as obtained in nominal steady conditions. In day to day operation, the plants are not continuously operated in these conditions. They face load variations and partial load operation periods (e.g. according to the delivery of waste), equipment fouling and ageing, bad weather conditions (wind, storms,…), incidents on customers networks…. The “operation factor” (defined as the ratio between the effective operational yearly average value and the performances at design nominal steady conditions) is typically around 0.916.

Assuming the values given in Table 3.2 for the secondary parameters of the R1 formula, the values of the R1 formula corresponding to the efficiencies of Table 3.1 and calculated according to the Commission guidelines dated 30/6/2011 are given in Table 3.3.

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16 The figures given in Table 3.2 and the “operation factor” were provided by SVDU, the French Association of Waste-to-Energy plants operators.
Thermal exported (in% of Ew) | Electricity gross production (in% of Ew) | "Instantaneous R1 value" at design steady nominal conditions (at 10°C all year) | Annual R1 value (with operation factor 0.9) (at 10°C all year) | Annual R1 value compared to 0.65
---|---|---|---|---
0% | 25% | 0.656 | 0.590 | -0.060
5% | 24% | 0.686 | 0.617 | -0.033
10% | 23% | 0.715 | 0.644 | 0.006
15% | 22% | 0.745 | 0.671 | 0.021
20% | 21% | 0.775 | 0.697 | 0.047
25% | 20% | 0.805 | 0.724 | 0.074
30% | 19% | 0.834 | 0.751 | 0.101
35% | 18% | 0.864 | 0.778 | 0.128
40% | 17% | 0.894 | 0.805 | 0.155
45% | 16% | 0.924 | 0.831 | 0.181
50% | 15% | 0.953 | 0.858 | 0.208

Table 3.3: State of the Art CHP Waste-to-Energy plant – R1 value at design steady nominal load with the assumptions of Table 3.2 – R1 value in operation (with the ‘operation factor’ – R1 value compared to 0.65

Table 3.3 shows that, for a given plant, the R1 value technically drops very significantly with decreasing heat export possibilities: the same new state-of-the-art CHP Waste-to-Energy plant barely passes the R1 value of 0.590 if it runs continuously without exporting heat but reaches 0.858 if all year long it can export 50% of the energy input (50% of Ew).

The same Waste-to-Energy plant reaches a much higher R1 value when it exports heat than when it generates electricity. The higher the heat export, the higher the R1 value. The R1 value of a plant depends mainly on its ability to export heat.

Thus, the R1 formula appears to be a strong incentive in favour of CHP Waste-to-Energy plants exporting heat, which actually is a good thing. However, the thresholds of the R1 formula were set on the basis of the 1st CEWEP Energy efficiency report of Waste-to-Energy plants which were mainly located in an area where the heat demand is significant. The results in Table 3.3 show how difficult it can be to reach the R1 thresholds in areas where the heat demand is low or inexistent.

In Scandinavia, most Waste-to-Energy plants export much more than 50% of the energy input as heat in such a manner that some plants can reach R1 values up to circa 1.3 and that their average R1 value is around 1\[17\].

If the objective were to fully counterbalance the effect of heat export (between e.g. the average Scandinavian plants and plants without heat demand), a factor of around 1.695 ( = 1/0.590) would be requested. This is certainly excessive since the R1 formula should remain an incentive for operators to increase the amount of energy produced and exported as heat.

A guidance to identify a fair factor can be found in the Waste Incineration BREF.

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17 The 2nd CEWEP energy efficiency report, which as already said (see Section 1.1.2) overestimates the R1 values by 10 to 15%, gives a maximum R1 value of 1.41 and an average value of 1.1 for the 31 plants included in its ‘North Europe’ zone (see Table 1.1). However, as already said, these R1 values are overestimated by 10-15% due to the change in the guidelines.
3.3 Energy efficiency BATs according to the WI-BREF

The Waste Incineration BREF (WI-BREF, published in August 2006) includes two BATs (Best Available Techniques) addressing the energy efficiency in its Section 5.2 which is the one dedicated to the Municipal Solid Waste-to-Energy plants:

BAT 61. "the location of new installations so that the use of CHP and/or the heat and/or steam utilisation can be maximised, so as to generally exceed an overall total energy export level of 1.9 MWh/tonne of MSW (…), based on an average NCV of 2.9 MWh/tonne”

BAT 62. "in situations where less than 1.9 MWh/tonne of MSW (based on an average NCV of 2.9 MWh/tonne) can be exported, the greater of:

a. the generation of an annual average of 0.4 – 0.65 MWh electricity/tonne of MSW (based on an average NCV of 2.9 MWh/tonne (…) processed (...))".

This section assesses the R1 values of Waste-to-Energy plants complying with BAT 61 and BAT 62, which are shown in Figure 3.0 and Table 3.4.

The calculation is made according to the aforementioned Commission guidelines dated 30/6/2011 and by using the values given in Table 3.2 (Ef, Ei, Ep self heat consumption) except Ei elec for plants complying with BAT 61 and only generating heat since their electrical consumption is lesser.

3.3.1 BAT 61

The Waste-to-Energy plants complying with BAT 61 are dedicated to heat export and may be operated in CHP mode or export all the produced energy as heat or steam.

As shown on Figure 3.0 (see the rectangle on the left), different R1 values correspond to the same single threshold given by BAT 61 (1.9 MWh/t), depending on whether the plant imports the electricity it needs (heat-only plant), only produces the amount of electricity it needs or produces more and exports the surplus.

The first option achieves the lowest R1 value, the third option the highest one.

3.3.2 BAT62

The fact that BAT 62 provides a range of electricity production for plants without sufficient heat demand recognises that, even when using the best available technology, the electricity production is site specific and that the highest efficiency cannot be obtained anywhere because of the variety of the local conditions.

Figure 3.0 shows (see the rectangle on the right) the R1 values corresponding to the ends of the range given by BAT 62 (0.4 to 0.65 MWh/t) as well as the R1 value corresponding to the average value of that range, i.e. 0.525 MWh/t (= (0.65 + 0.4)/2).

3.3.3 R1 values corresponding to BAT 61 and BAT 62

The results show that the energy export value given in BAT 61 corresponds to the R1 threshold for new plants (0.65) in the worst case (i.e. when generating only heat) and can be significantly higher when the plant generates electricity but, on the other hand,

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18 BAT 62 includes provisions for heat export as far as possible but indicates that the electrical output can then be reduced accordingly; it also includes a condition b) which is to provide the electricity required for the whole site but it in practice this request is always less stringent than condition a).

19 A plant exporting only heat uses less electricity for self consumption than a plant generating a significant amount of electricity because there is no air condenser or it is small or only partially used, the steam being normally condensed in the heat exchanger. The consumption of the air condenser fans (which are important consumers), if any, is therefore significantly reduced. Secondly, the pressure in the boiler is much lower, typically between 15 and 30 bars, and therefore the feed pumps require less energy.
that the whole range of values given in BAT 62 leads to a R1 value below the two R1 thresholds (0.6 for existing plants and 0.65 for new ones).

**Figure 3.0: R1 values corresponding to BAT 61 and BAT 62 of the Waste Incineration BREF-8/2006**

### 3.3.4 Ratio between BAT 61 and BAT 62

In order to give the plants without heat demand a chance to reach the R1 thresholds, it looks fair to propose a factor based on the ratio between the R1 values corresponding to what can be achieved by plants recognised as Best Available Techniques when dedicated to heat export (BAT 61) and when heat demand is inexistent or poor (BAT 62).

Considering that the R1 criterion must remain an incentive for operators to increase the overall efficiency of their plants and, in particular, to increase the heat export, the ratio used for a climate factor must not aim at fully compensating the effect of a lack of heat demand but should aim at making the R1 condition workable in warmer areas.

For this reason, we propose not to take into consideration the R1 value corresponding to the lower end of the BAT 62 range but the one corresponding to the average of that range (R1 = 0.472 with 0.525 MWh/t). And in respect of BAT 61, we propose to take into account the R1 value corresponding to the most pessimistic situation (plant exporting only heat; R1 = 0.65).

On this basis the ratio between R1 values associated to BAT 61 and BAT 62 is **1.382**, which is the most conservative one as shown on Figure 3.0.

The figures used for this calculation are given in Table 3.4.

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20 As aforementioned, for instance a CHP plant complying with BAT 61 and generating electricity for self use, will get a R1 value of 0.782 and therefore the ratio would be 1.657 (= 0.782/0.472) instead of 1.382.
### Table 3.4: R1 value according to BAT 61 and BAT 62 of the Waste Incineration BREF - Ratio between the R1 value of BAT 61 and R1 values of BAT 62

<table>
<thead>
<tr>
<th></th>
<th>BAT 61</th>
<th>BAT 62 Average of the range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy input (MWh/t)</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Heat export (MWh/t)</td>
<td>1.9</td>
<td>0</td>
</tr>
<tr>
<td>Electricity production (MWh/t)</td>
<td>0</td>
<td>0.525</td>
</tr>
<tr>
<td>Imported electricity (MWh/t)</td>
<td>0.09</td>
<td>See table 3.2</td>
</tr>
<tr>
<td>Other (Ef, Ei non elec, Ep self heat)</td>
<td>See table 3.2</td>
<td>See table 3.2</td>
</tr>
<tr>
<td>R1 value</td>
<td>0.652</td>
<td>0.472</td>
</tr>
<tr>
<td>Ratio between the R1 value of BAT 61 and the R1 value of BAT 62 average</td>
<td>1</td>
<td><strong>1.382</strong></td>
</tr>
</tbody>
</table>

The energy efficiencies provided by the Waste Incineration BREF give much higher R1 values for plants using Best Available Techniques dedicated to heat than for plants using BATs not in conditions to export heat and dedicated to electricity generation. The ratio between these R1 values was assessed (worst case) to be worth 1.382. This seems the right value for a factor that still incentivises efficiency improvement measures.

### 3.4 Outlets for Heat from Waste-to-Energy plants

The main outlets for heat are:
- Industries (often as “Process Steam”), with different steam parameters according to the process;
- Buildings, for space heating and hot water preparation (usually low temperatures and pressures).

Industrial consumers in general need to be directly connected to the Waste-to-Energy plant because they use medium or high pressure steam. On the other hand, District Heating networks, which seek to serve a wider area, usually carry hot water, suitable for buildings’ needs but which is rarely used by industry.

#### 3.4.1 Heat/steam to industry

Industrial heat demand can be found in most European regions.

A good synergy is established when one or several industrial heat consumer(s) are located near a Waste-to-Energy plant, whose heat can be used to supply their demand. This synergy should be applied wherever possible as it increases the R1 value and boosts resource- and energy-efficiency. However several factors limit the development and durability of such synergies.

The synergy’s realisation first depends upon the existence of industrial heat demands to be fulfilled in the area near a Waste-to-Energy plant. Where a new Waste-to-Energy plant is to be built, an area with industrial heat demand is sought. Where an existing Waste-to-Energy plant has waste heat, the newly developed industries must be implemented in the vicinity.

Then, the technical possibility to supply waste heat with the required steam parameters in the industrial process must exist. Since heat cannot travel very far, the technical possibility also depends on the distance between the supplier and the consumer. Such a
synergy must finally appear desirable for the industrial partner, especially for instance if an existing industry already invested in its own heat supply facility. The permit to build the new plant (either the Waste-to-Energy plant or the industrial one) and to link the new plant to the existing one must then obtain public’s and authorities’ acceptance, which often is a challenge.

Another challenge is the duration of the industrial customer’s heat demand. Indeed the varying economic cycles may have a tremendous impact on energy consumption: the volatility of industrial energy consumption was shown during the recent economical downturn years, indicated by a decrease in fossil fuel consumption and greenhouse gas emissions in Europe. While many industries can recover, those that closed down mean a permanently lost opportunity for waste heat use.

This is therefore a lingering issue for the Waste-to-Energy plant, since such facilities are designed to operate for decades. Even when a Waste-to-Energy plant operator manages to sign a relatively long term contract with the client industry, the latter cannot commit himself over the very long loans payback periods which are necessary for the Waste-to-Energy plant to reach an acceptable gate fee (typically 15 to 25 years for the initial investments).

This problem is of the utmost importance for new Waste-to-Energy projects’ financing because the banks consider that such contracts do not secure the energy sales and the expected revenues.

All things considered, a synergy with industrial heat customer(s) constitutes a favourable situation in terms of energy efficiency because, in general, the industrial energy demand is regular and evenly distributed over the year. But the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

Exporting heat to industrial customer(s) constitutes a favourable situation in terms of energy efficiency, but the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

3.4.2 District heating - Different kinds of networks

The District Heating networks can be classified according to the fluid used and to their temperature range.

The fluid can be steam, super-heated water or hot water. With steam, the temperature typically ranges between 200°C and 300°C, the pressure between 10 and 30 bars and the feedback is condensate. If super-heated water is used, the outgoing temperature is typically around 180°C and the feedback at 90°C. When hot water is used the temperatures are typically 110°C (outgoing) and 60°C (feedback). Very low temperature networks are also used with hot water outgoing at around 55°C and feedback at 25°C.

Some famous historical networks using steam are still in operation, such as in New York or Paris. However new networks do not use steam for safety reasons.

As with steam, the high temperature difference (ΔT) achieved with super-heated water, typically 90°C (= 180°C - 90°C), leads to smaller pipes diameters. However such systems are rarely implemented in new networks for the same reasons, which are that

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21 For instance the Paris heating network operated by CPCU, which provides steam to industry and heat to dwellings, is designed for a minimum pressure of 5 bars at the remote ends of the network. Steam is fed to the network at a velocity of 30 m/s (i.e. more than 100 km/h) by 11 sources, including the 3 Waste-to-Energy plants of Paris SYCTOM, at 20 bar and 240°C (super-heated steam).
the measures required to guarantee safety are complex and overall more expensive than with low temperature networks.

The most common situation today is to use hot water. The temperature difference is smaller, typically $\Delta T = 50^\circ C$ ($= 110^\circ C - 60^\circ C$) but still leads to 'reasonable' pipes diameters.

Very low temperature networks are essentially found in the Nordic countries (Sweden, Denmark, Finland), where climatic conditions are favourable and strong political efforts were made to develop district networks. The temperature difference is smaller, with typical $\Delta T$ of $30^\circ C$ ($= 55^\circ C - 25^\circ C$) which leads to larger pipes diameter but the use of such temperature ranges in the network allows to recover more heat (at low temperature) from the heat generator, e.g. from the Waste-to-Energy plant. The large and long lasting heat demand encountered in these areas can balance the extra investment costs caused by larger pipe diameters as well as the cost of additional pieces of equipment which will even improve the plant efficiency\textsuperscript{22}.

### 3.4.3 District Heating network feasibility

The construction cost of a District Heating network depends on a number of factors, including:

- The density of population (piping cost would be excessive in areas with low density of habitations, e.g. rural areas). Also networks in larger cities are more energy-efficient, since they use larger pipes; they also are more cost-effective since they sell more of the produced heat to less losses
- The ground quality (building a network for instance in the rock or in mountains is usually much more difficult and expensive than in a plain)
- The occupation of the ground (it is easier to install a piping network in an empty field than in an already built dense district)

The construction and operation costs of a District Heating network should be covered by the heat sale revenues. On the other hand, the network needs to sell the heat at an acceptable price in order to get and maintain a market, which means that a substantial amount of heat must be sold by piping length unit and during a period of time long enough each year but also long-lasting over years.

### 3.4.4 District Heating – European overview

District Heating networks are numerous and often large in North Eastern Europe but scarce or inexistent in the South Western part of Europe. When existing there, it is often to provide heat to a hospital or an industry and sometimes a few residential buildings or a small block of housings which were all built at the same time. In industrial sites, waste heat is usually already available so that there is no need for Waste-to-Energy plants supply.

Figure 3.1 below shows the final energy demand as heat from District Heating networks in the EU 27 Member States in 2003 according to the EU-financed Ecoheatcool project\textsuperscript{23}.

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\textsuperscript{22} The large and long-lasting heat demand also makes it cost-effective in theses areas to install additional devices such as heat pumps and flue gas condensation systems which lead to enhanced overall efficiency.

\textsuperscript{23} From EcoHeatCool, Work Package 4, p.11. See http://www.euroheat.org/Files/Filer/ecoheatcool/index.htm

The heat demand from District Heating networks is given by country. These values have been divided by the number of inhabitants in 2003, which is also given in this report.
Although not directly comparable to the previous Figure, because it shows the final energy demand in the EU 27 Member States as heat from District Heating networks but also from Combined Heat and Power, Figure 3.2 below shows the figures derived from a European Commission report aiming at determining the development of the EU Energy system up to 2030. The study assumes in particular that national targets under the Renewable Energy directive 2009/28/EC and the Greenhouse Gas Effort sharing decision 2009/406/EC will be achieved in 2020.

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The study determines the development of the EU energy system, firstly under current trends and policies (Baseline scenario) and, secondly, including in addition the policies adopted between April and December 2009 (Reference scenario). The latest, which is presented here, assumes that national targets under the Renewables directive 2009/28/EC and the GHG Effort sharing decision 2009/406/EC are achieved in 2020. The study provides the amounts of energy country by country (in ktoe) and the populations assessment for 2030. We present here the values per inhabitant derived from this data.
It emerges from the above two Figures that, even with the necessarily optimistic projections currently encountered in this kind of reports, the heat demand and its future potential are much lower in the South Western part of EU than in its North Eastern part.

District Heating networks can be a major outlet for heat from waste. However climate greatly influences the existence of District Heating networks and their energy demands, hence affecting the possibilities for a plant to export heat. This can be clearly seen at the European level: the District Heating demand per capita is much higher in cold areas than in warm areas.

3.4.5 Waste-to-Energy plants operated in CHP mode in some EU countries

The limited possibility to build and operate a District Heating network connected to Waste-to-Energy plants in warmer areas is illustrated by statistics (2009 data from CEWEP website, if not otherwise specified):

- Sweden: around 31 Waste-to-Energy plants, with an average capacity of 150,000 t/y; 100% CHP Waste-to-Energy plants
- Denmark: around 31 Waste-to-Energy plants, with an average capacity of 120,000 t/y; 100% CHP Waste-to-Energy plants
- The Netherlands: 12 Waste-to-Energy plants, with an average capacity of 620,000 t/y; 100% CHP Waste-to-Energy plants (2011 data)
- Germany: 71 Waste-to-Energy plants, with an average capacity of 250,000 t/y; 71.8% (= 51/71) of CHP Waste-to-Energy plants
- France: 130 Waste-to-Energy plants with an average capacity of 100,000 t/y; 27.7% (= 36/130) of CHP Waste-to-Energy plants
- Italy: 50 Waste-to-Energy plants with an average capacity of 100,000 t/y; 11 (22%) CHP Waste-to-Energy plants: All CHP are among the 29 plants in Northern Italy (none in the 24 plants in Central and Southern Italy). (2010 data, Federambiente)
- Spain: 10 Waste-to-Energy plants with an average capacity of 220,000 t/y; 1 CHP Waste-to-Energy plant; 10% of CHP Waste-to-Energy plants
- Portugal: 3 Waste-to-Energy plants with an average capacity of 350,000 t/y; 0 (0%) CHP Waste-to-Energy plants (all generating electricity only).

3.4.6 Collective heat supply in South Western countries

According to EcoHeatCool25: “No district heat deliveries have been identified in the IEA Energy Balances for Cyprus, Malta, Spain, and Turkey. But a few systems have recently started in Spain (as in Barcelona) and 13 geothermal systems have been identified from other sources in Turkey”. Some minor heat deliveries were identified in Ireland (0,1PJ) and Greece (1.0 PJ) (...). These 6 countries are not further considered in the following three chapters of this report.”

3.4.6.1 Spain

Since then, some networks have been built in Spain but they are biomass fired and very small: most of them are below one 1MWth – ranging from 50 kWth to max 6 MWth; the “Registro del Observatorio” published a list with 40 heating networks in operation in 2011 cumulating an overall capacity of 36.7 MWth plus 6 in project.

A District Heating network with a capacity of 20 MWth has been recently constructed in Barcelona, which uses the energy from waste.

The development of these networks is most often due to high level of subsidies.

Altogether, according to the data we found, the capacity of the District Heating networks in Spain is less than 100 MWhth.

3.4.6.2 Portugal

According to EcoHeatCool26 in 2003, “only one minor district heating system (Lisbon-Parque das Nações) with annual heat sales of 0.1 PJ [i.e. 28 GWhth] have been identified”. Indeed, the capacity of this District Heating Network is only 20 MWth.27 According to Avaler, the Portuguese Waste-to-Energy association, this network has been implemented in a newly developed area for the Expo ‘98 (1998 Lisbon World Exposition). It was financed by a mix of private financing with public financing programmes, namely from EU.

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26 EcoHeatCool Work Package 1 p. 13
27 The capacity of the heat exchanger (20 MWth) is given in “Production de froid à partir de chaleur” by Energie-Cités/Ademe, 1998
3.4.6.3 Greece

According to EuroHeat & Power\(^{28}\) there are 5 District Heating networks in Greece. The four largest ones are located in the Macedonian regions, the coldest of Greece. These regions’ HDDs can be as high as 2500, comparable to Île de France or Cornwall in the UK, while the warmer Greek regions are under 1000 HDDs. In total, the installed capacity is 445 MW\(_{th}\).

3.4.6.4 Italy

According to Euroheat & Power in 2011, there are 55 District Heating networks in Italy. According to AIRU\(^{29}\), the Italian District Heating association, the trend shows a significant increase of the overall capacity\(^{30}\) in the last 20 years. But with a total supply of around 6400 GWh\(_{th}\), the absolute values remain moderate.

The map provided by AIRU clearly shows that the District Heating networks are located in the Northern regions of Italy (see regions in green in Figure 3.3) and that there are none in Central and South Italy. As it can be seen on Figures 3.4 and 3.5, most of the heat delivery is made in the 6 most Northern regions: Piedmont, Lombardy, the two alpines regions, Veneto and in Emilia Romagna.

![Map of Italian regions including District Heating networks - Source AIRU](image)

Figure 3.3: Italian regions including District Heating networks - Source AIRU

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\(^{29}\) See http://www.lsta.lt/files/events/EHP_Venecijoje/6_PontaAIRU.pdf

\(^{30}\) We could not find an accurate value of the District Heating capacity installed in Italy. According to AIRU data, it seems to be 3500 MW\(_{th}\) in 2007.
3.4.6.5 France

French District Heating networks energy source

There were 427 District Heating networks in France in 2008. Their total capacity was 17,119 MWth. In 2008 they delivered 24,430 GWhth serving 2,078,169 equivalent households through 3,201 km of piping. More information on the French cooling networks can be found in the national survey made by SNCU (French association for heating and cooling networks) for year 2008\(^\text{31}\).

\(^{31}\) See : ‘Enquête nationale de branche sur les réseaux de chaleur et de froid’, SNCU: http://www.viaseva.org/Ressources/Base-documentaire/Statistiques-reseaux-de-chaleur
Figure 3.6 shows that renewable and surplus energy amount to 29% of the total. Table 3.5 and Figure 3.7 show 21% of the total comes from the energy of Waste-to-Energy plants.

Figure 3.6: District Heating network energy type in France in 2008 (expressed in produced energy) - “EnR&R” means ‘Renewable and Surplus energy’ and ‘cogé’ ‘CHP’

Table 3.5: District Heating network energy type in France in 2008 (expressed in produced energy) - “EnR&R” means ‘Renewable and Surplus energy’ - “UIOM” means ‘Waste-to-Energy plant’
Figure 3.7: District Heating network energy type in France in 2008 (expressed in produced energy) - “UIOM” means ‘Waste-to-Energy plant’

Figure 3.8 below shows the location of the District Heating networks installed in France. It can be observed that:

- The density of District Heating networks is clearly higher in the Northern and the Eastern parts than in the Southern and the Western parts of the country (where the rare networks feed a few industries)
- Most of the networks are located in the highly populated conglomerations in the North-Eastern part of the country, such as Paris (120 networks), Lyon region (Rhône-Alpes Region, 50 networks), Lille and most often in the large social housings built around these conglomerations; or in cities re-built after destruction during the 2nd World War (Le Havre, Brest...)

Unfortunately the yellow spots on this map being just labels, their sizes are related to the number of letters in the networks’ names, not to their capacity or demand in heat, which would have emphasized the gradation from top right to bottom left.

Figure 3.8: Location of the 427 District Heating networks in France.

However, the following map\(^{32}\) (Figure 3.6) shows the gradation of the District heating networks heat sales at the regional level. If we put apart Auvergne and Limousin regions which are located in the mountains and which encounter a very low density of population, we clearly can distinguish two series of regions. On the North Eastern side are regions with relatively high heat sales. On the West and Southern sides are Regions with much lower heat sales. Ile de France, the region of Paris, achieves the highest heat sales rate because of the density of population which is much higher than in the country. A similar

A trend can be observed in the Rhône-Alpes region where the cities of Lyon and Grenoble are located.

NB: The red line shows the limit between the two series of regions. It follows the borders of the administrative regions except in Provence-Alpes-Côte d’Azur which includes a part on the Mediterranean coast as well as a part in the Alps. See also Section 3.5.3.

Figure 3.9: District Heating networks sales by Region in France in 2008 (kWh/inhab).

The more detailed data we gathered for Southern European countries show that District Heating systems may exist in warm locations but the demand decreases until becoming inexistent as the climate warms up. This confirms the findings made previously at the European level: the District Heating demand per capita is much higher in cold areas than in warm areas.

3.5 Heating Degree Days (HDD)

3.5.1 Countries HDDs

As explained above (see Section 1.2.3), the HDDs, which are derived from measurements of outside ambient air temperature, reflect the demand for energy needed to heat home or business buildings. They are widely used by building sector professionals
as well as by energy suppliers to assess energy needs for heating. They are the most representative energy consumption indicator for space heating, exemplified by their selection by Eurostat\(^33\).

The annual HDD values between 1980 and 2009 are available on Eurostat website\(^34\) for the 27 EU Member States, their Regions and some non EU States. Long term averages are more representative as significant differences can be observed between the years. See Chapter 5.

Table 3.6 and Figure 3.10 show the long term (30 years) average HDDs for the 27 EU Member States. Finland with 5774 has the highest HDD of the EU, Portugal with 1278 the lowest of continental EU. The average EU-27 HDD value is 3219.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>AVERAGE HDD 1980-2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>5774</td>
</tr>
<tr>
<td>Sweden</td>
<td>5387</td>
</tr>
<tr>
<td>Estonia</td>
<td>4393</td>
</tr>
<tr>
<td>Latvia</td>
<td>4220</td>
</tr>
<tr>
<td>Lithuania</td>
<td>4048</td>
</tr>
<tr>
<td>Poland</td>
<td>3574</td>
</tr>
<tr>
<td>Austria</td>
<td>3540</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>3533</td>
</tr>
<tr>
<td>Denmark</td>
<td>3438</td>
</tr>
<tr>
<td>Slovakia</td>
<td>3416</td>
</tr>
<tr>
<td>EU-27</td>
<td>3219</td>
</tr>
<tr>
<td>Germany</td>
<td>3199</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>3164</td>
</tr>
<tr>
<td>Romania</td>
<td>3092</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3081</td>
</tr>
<tr>
<td>Slovenia</td>
<td>3024</td>
</tr>
<tr>
<td>Hungary</td>
<td>2886</td>
</tr>
<tr>
<td>Ireland</td>
<td>2871</td>
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<tr>
<td>Netherlands</td>
<td>2854</td>
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<tr>
<td>Belgium</td>
<td>2830</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>2654</td>
</tr>
<tr>
<td>France</td>
<td>2459</td>
</tr>
<tr>
<td>Italy</td>
<td>1949</td>
</tr>
<tr>
<td>Spain</td>
<td>1831</td>
</tr>
<tr>
<td>Greece</td>
<td>1642</td>
</tr>
<tr>
<td>Portugal</td>
<td>1278</td>
</tr>
<tr>
<td>Cyprus</td>
<td>762</td>
</tr>
<tr>
<td>Malta</td>
<td>543</td>
</tr>
</tbody>
</table>

Table 3.6: 30-year average HDDs (from 1980 to 2009) for the 27 EU Member States and the EU-27 average – Data from Eurostat website and according to the EU HDD formula

\(^{33}\) Metadata information for HDDs mention: “Consumption of energy depends strongly on weather conditions. If the temperature decreases below a certain value, "heating threshold", more energy is consumed due to increased need for space heating. Taking this into account, Eurostat launched a project aiming at the development and implementation of a common method for the climatic correction of final energy consumption for space heating purposes in the 27 Member States of the European Union. Temperature corrected energy consumption data help interpreting energy consumption trends.”


\(^{34}\) See: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_esdgr_a&lang=en
We have reported these long term (30 years) EU HDD values on the map of Europe showing one of the most widely used climate classification systems, the Köppen–Geiger classification system\textsuperscript{35}. (See Figure 3.11)

The limit between on one hand the Continental warm summer zone (Dfb, in medium blue) and on the other hand the Maritime Oceanic (Cfb, in medium green) and the Mediterranean zones matches well with the District heating heat demands as shown in Figures 3.1 and 3.2.

\textsuperscript{35} Köppen Geiger map and details available at:
http://www.wmo.int/pages/themes/climate/understanding_climate.php
http://upload.wikimedia.org/wikipedia/commons/b/bf/Europe_Koppen_Map.png
http://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification
3.5.2 HDDs by Regions

The representativeness of the HDDs by country depends on the size of the countries. There are obviously significant variations between the regions of a same large country especially for Germany, France, the UK, Italy, Spain, but also Sweden.

Fortunately, as said above, Eurostat also provides data for the Regions of the EU Member States and these statistical data are also available on the same period of 30 years, from 1980 up to 2009. Table 3.7 below shows regional long term data for 3 Member states located in South-Western Europe.

<table>
<thead>
<tr>
<th>COUNTRY/Region</th>
<th>HDD_{30y}</th>
<th>COUNTRY/Region</th>
<th>HDD_{30y}</th>
<th>COUNTRY/Region</th>
<th>HDD_{30y}</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPAIN</td>
<td>1831</td>
<td>ITALY</td>
<td>1949</td>
<td>France</td>
<td>2459</td>
</tr>
<tr>
<td>Castilla y León</td>
<td>2392</td>
<td>Provincia Autonoma Bolzano/Bozen</td>
<td>4055</td>
<td>Auvergne</td>
<td>3006</td>
</tr>
<tr>
<td>La Rioja</td>
<td>2225</td>
<td>Provincia Autonoma Trento</td>
<td>3485</td>
<td>Franche-Comté</td>
<td>2950</td>
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<tr>
<td>Aragón</td>
<td>2132</td>
<td>Valle d'Aosta/Vallée d'Aoste</td>
<td>3109</td>
<td>Lorraine</td>
<td>2923</td>
</tr>
<tr>
<td>Comunidad Foral de Navarra</td>
<td>2002</td>
<td>Friuli-Venezia Giulia</td>
<td>2444</td>
<td>Rhône-Alpes</td>
<td>2771</td>
</tr>
<tr>
<td>Castilla-la Mancha</td>
<td>1981</td>
<td>Lombardia</td>
<td>2436</td>
<td>Champagne-Ardenne</td>
<td>2763</td>
</tr>
<tr>
<td>Comunidad de Madrid</td>
<td>1960</td>
<td>Veneto</td>
<td>2387</td>
<td>Alsace</td>
<td>2756</td>
</tr>
</tbody>
</table>
3.5.3 Three zones with respect to heat demand

The information presented in Sections 3.4 and 3.5 unambiguously shows that:

- The heat demand is such in the North Eastern part of Europe that the Waste-to-Energy plants are designed with the primary objective to satisfy the demand. These plants do not appear to necessitate a correction related to the climate conditions.

- The heat demand is most often not high enough in the South Eastern part of Europe to build a District Heating network or, if one exists, its heat sales are usually drastically limited to a few medium or large consumers (hospital, industry for process steam) but not to many households.

- In between, the heat demand is decreasing with HDDs and the R1 value is strongly affected.

The challenge is then to set limits between the three identified zones.

3.5.3.1 Upper HDD threshold

When comparing, on one hand, the distribution of heat effective sales in the Member states in 2003 (see Fig 3.1), the projection of heat sales by CHP and District Heating networks in 2030 (see Fig. 3.2) and, on the other hand, the climate classification map of Europe (see Figure 3.11) with the Member states long term (30 years) average HDD values (given in Table 3.6), it appears that a limit between the regions where priority is given to heat and regions where condensing turbines are commonly used can be found below the HDD of Denmark (3438) and above the one of Germany (3199).

We therefore propose to set an upper threshold between the North Eastern zone and the intermediate zone at a medium HDD\textsubscript{30year} value of 3350, which also matches with the Köppen-Geiger classification between continental and oceanic climates (see Figure 3.11).
3.5.3.2 Lower HDD threshold

The limit must be situated between regions where the sales of the District Heating networks are tiny or inexistent and regions where it is still possible to export a more significant amount of heat to a District Heating network at affordable cost (see Figures 3.1, 3.2, 3.3 and 3.9). Looking at the regional long term (30 years) average HDD values in South Western countries (given in Table 3.7), the District heating situation in France shows this limit to be between 2457 (Centre region, the region with the lowest HDD value on the East of the red line) and 2252, (Bretagne region, the region with the highest HDD value on the South West of the red line) as Figures 3.9 and 3.12a show. On this basis, the threshold between the intermediate zone and the South Western zone would be set up at a HDD30year value of 2300, which is a little less than the average between 2457 and 2252.

**Figure 3.12 a and b: Lower HDD threshold 1) (red line) first assessment based on the French regional heat demands 2) (blue line) final assessment taking into account the political will in Emilia Romagna - See Figures 3.3 and 3.9**

Such a threshold matches well with the Italian regions’ heat sales and HDD values (see Figures 3.3, 3.4, 3.5 and Table 3.7) for Piedmont, Lombardy and the two alpine regions. We therefore drew the red line on the map (Figure 3.12b) at HDD 2300. While this threshold would work well in France and most of Italy, Emilia Romagna however shows that there is still an opportunity to sell some collective heat with an HDD as low as 2177 when good conditions are encountered (such as strong political will and subsidies, cities in mostly flat terrains, industrial estate...). This is therefore taken into consideration as shown by the blue line (in Figure 3.3), passing south of Emilia Romagna.

Taking this into account, we propose to set a lower HDD threshold between the intermediate and the South Western zones at a HDD30year value of 2150. (This limit is also shown by the blue line in Figures 3.3 and 3.9).

Figure 3.13 shows limits between the 3 identified zones by using the long term (30 years) HDD data provided by Eurostat for the administrative EU regions. However this is only approximate information because, as already said, the HDDs to be considered for a climate factor are the ones corresponding to the location of the Waste-to-Energy plants and not the average regional values since wide ranges can be encountered in certain regions as already mentioned.

36 Provence-Alpes-Cotes d’Azur region is not homogeneous, as said above.
3.6 Conclusions on Heating

The main findings about heating are the following.

1. The technical design of a CHP (Combined Heat & Power) Waste-to-Energy plant should be optimised according to the conditions of the project. When the heat demand is really high, back pressure turbines are used and up to 100% of the steam flow can be used for heating.

2. When the heat demand is lower, the optimal design is different: Condensing turbines are used in order to increase the electricity production and the heat export is limited to roughly 50% of the energy input due to technical reasons.

3. In spite of the equivalence factors, a same CHP Waste-to-Energy plant reaches a much higher R1 value when it exports heat than when it generates electricity. The higher the heat export, the higher the R1 value.

4. A synergy with industrial heat customer(s) constitutes a favourable situation in terms of energy efficiency because, in general, the industrial energy demand is regular and evenly distributed over the year. But the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

5. Building and operating a District Heating network requires sufficient heat sales to balance the costs.

6. In terms of heat demand, three main zones have been identified within EU: North Eastern Europe, Intermediate, South Western Europe.
In the North Eastern zone, high heat demands lead to design the Waste-to-Energy plants with priority given to heat export. It seems that no correction is needed in this zone. Based on District Heating networks heat sales in 2003 and on the prospective of heat demand from Combined Heat and Power & District heating published by the Commission for year 2030, we propose that this zone includes locations where the HDD$_{30\text{year}}$ value is 3350 or above.

There are few opportunities to build new District Heating networks in areas where the potential sales of the District Heating networks are tiny or inexistent. Based on the correlation between the regional heat sales statistics in France and Italy, on one hand, and the regions’ average HDD on the other, we propose that the South Western zone includes locations where the HDD$_{30\text{year}}$ value is 2150 or below. Maximal correction should apply to plants located in this zone.

A state-of-the-art large CHP Waste-to-Energy plant (as designed in 2011, i.e. started in 2014-2020) can hardly reach a R1 value of 0.65 if it cannot export heat. With electricity only and assuming an operation factor of 0.9, it would reach 0.590 when the same plant in the same conditions reaches a R1 value of 0,858 if exporting all year long 50% of the energy as heat.

The Waste Incineration BREF provides BAT energy efficiencies for Waste-to-Energy plants exporting heat alone or in CHP mode (BAT 61), on one hand, and exporting electricity (BAT 62) on the other. The ratio between the R1 values of BAT 61 (worst case) and average BAT 62 is 1.382. This seems the right value for a factor between heat only and electricity-only Waste-to-Energy plants.

A climate correction factor based on these findings is proposed in Sections 7.3.3 and 7.4. See also Section 5.4.2.

Cross impacts of climatic zones on possible heat supply outlets

Supplying heat to industrial consumer(s) is very favourable for a project’s economics and its R1 value. This should be incentivised, possibly with dedicated policies, especially for new plants.

However, the uncertainties lingering over the contract’s duration are seen in banks’ reluctance to finance such projects and, while such synergies can be established throughout Europe, industrial outlets are not found near every existing Waste-to-Energy plant or where new ones need to be located (according to the EU proximity and self-sufficiency principles and conditional to acceptance by the public and of permitting authorities).

If the extra possibility of supplying heat to buildings exists, it is a complementary lifeline because it ensures heat exports both in terms of revenue and of long-term stability, thus maintaining the R1 value above the threshold.

In regions where buildings’ heating demand is weak, opportunities to supply industries with heat exist but are not widespread. Plus the absence of District Heating networks or their very limited demand further limit a plant’s R1 value.

A stark contrast exists between plants located in regions with a large heating demand in buildings, giving them a double opportunity (possible industrial heat + possible buildings’ heating), and plants located in regions with weak or insignificant heating needs which have no backup plan if the only opportunity (industrial heat) is impossible.

This structural imbalance, caused by climate, must be compensated by a factor linked to the plant’s local climate. This compensation must not fully offset the handicap affecting plants in hot regions, but must be sufficient to enable them, through reasonable effort, to meet the R1 criteria, even when they are located in regions with limited or insignificant heating demand.
Synthesis of Technical Facts – Chapter 3

I) The R1 value of a same Waste-to-Energy plant depends mainly on its ability to export heat. The higher the heat export, the higher the R1 value.

J) The energy efficiencies provided by the Waste Incineration BREF give much higher R1 values for plants using Best Available Techniques dedicated to heat than for plants dedicated to electricity (which can hardly reach the R1 criterion). The ratio between these R1 values was assessed (worst case) to be worth 1.382. This seems the right value for a factor.

K) Exporting heat to industrial customer(s) constitutes a favourable situation in terms of energy efficiency, but the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

L) District Heating networks can be a major outlet for heat from waste. However Climate greatly influences the existence of District Heating networks and their energy demands, hence affecting the possibilities for a plant to export heat.

M) A stark contrast exists between plants located in regions with a large heating demand in buildings, giving them a double opportunity (possible industrial heat + possible buildings’ heating), and plants in regions with weak or insignificant heating needs which have no backup plan if the only opportunity (industrial heat) is impossible.

N) 3 different zones exist in Europe where District Heating is ubiquitous, sparse or virtually inexistent. They can be delimited by using HDD values.

O) These 3 zones indicate the likelihood that District Heating constitutes an outlet for the heat from Waste-to-Energy plants. It is proposed that, depending on the climate, a proportional or maximum correction factor compensates the lack of heat sales possibilities.
4. COOLING

4.1 Cooling with heat

4.1.1 Techniques

Besides the heat demand, there is an increasing need/demand for cooling in the EU. In most cases, the building-bound cooling systems are the dominant solution and the main energy source is electricity.

However District Cooling is developing. The cooling techniques use 'Free cooling' (the cold source is a river, a lake, the ocean), conventional Compression or Absorption chillers. The industrial compression chillers have a much higher efficiency than the individual cooling units but they use electricity as primary energy. On the contrary, the absorption chillers use the heat to generate cooling, therefore constituting a potential market for the surplus heat available in Waste-to-Energy plants.

The absorption chillers can be integrated into the central plant generating the heat, for instance a Waste-to-Energy plant. In such a case a District Cooling network will distribute the cooling fluid - usually chilled water - through an underground network to sub-stations where heat exchangers will cool the customers' secondary cold circuit fluid.

Alternatively, heat can be distributed to the buildings or to local stations where local absorption chillers will turn the heat into cold.

The first option (central production of cooling) has a better energy efficiency (single large industrial unit) but requires a specific distribution network with pipes of much larger diameters than the District Heating network because District Cooling networks typically operate with considerably lower temperature differences ($\Delta T$ of $6\text{–}10^\circ$C) than the most common District Heating networks ($\Delta T$ of $40\text{–}50^\circ$C).

The major benefit of the second option (production in local sub-stations) is to use the same single main piping network for heating and cooling. Such double distribution can simultaneously be achieved on one hand for space heating and sanitary water and, on the other hand, for air conditioning by a local heat exchanger and a local chiller. The drawback is that absorption chillers are needed in every sub-station, requiring space.

4.1.2 Coefficient of performance (COP)

The COP (Coefficient of Performance) is the ratio of cooling or heating energy to energy consumption. A refrigerator with a COP of 2 moves 2 Watts of heat for every Watt of electricity consumed.

When using heat in an absorption chiller, the typical COP (coefficient of performance) is between 0.6 and 0.8. This means that 1 kWh of heat is needed to generate between 0.6 and 0.8 kWh of cold. With compression chillers, the COP is typically around 3 to 4, which means that only 1 kWh of electricity is needed to generate 3 to 4 kWh of cold.

Compression chillers use electricity instead of heat but need 4 to 5 times less energy than absorption chillers, which can already be seen as a benefit.

4.1.3 The amount of heat to release

The other aspect is the amount of heat to evacuate. A District Cooling network can be seen as a heat extractor. This means that the heat extracted from inside a building has to be released somewhere in the loop. In addition, the energy used to produce the cold must also be evacuated. This additional energy amounts to 25% to 33%\(^{37}\) of the

\[ 25\% = 1/4 \text{ and } 33\% = 1/3. \text{ (It refers to the COP values).} \]
extracted heat with compression chillers but to 125% to 166%\textsuperscript{38} of it when using absorption chillers.

Altogether, the total amount of heat to release is typically double\textsuperscript{39} when using heat as primary energy (absorption chillers) than when using electricity (compression chillers).

4.1.4 The water demand to cool the system

The cold reservoir used to release the heat can be a river or cooling towers, most often located on the roofs of the buildings to cool.

When it is a river, doubling the heat to release by using absorption chillers means doubling the thermal load to the river (which generally is limited).

When cooling towers are used, the required flow of cooling water is not only doubled but nearly multiplied by 4. The reason is that a much lower temperature is required when using absorption chillers (30-35°C) than compression chillers (40-45°C)\textsuperscript{40}. It leads to much larger pipes and cooling towers.

4.1.5 Geographical suitability

Water is abundant in Northern Europe. It is scarce in Southern Europe where its consumption must be minimised.

The possibility to increase the temperature in the rivers is very limited in Southern Europe. The absolute temperature of these cold reservoirs is much lower in Northern Europe.

The heat to evacuate from District Cooling networks is most often released downtown on the top of the building to cool and multiplying the size of the cooling towers by a factor around 4 is not really popular.

For all these reasons, District Cooling operators avoid as much as they can to use heat as primary source of cooling in warm areas where they prefer to use electricity or the so-called 'free cooling'. See below the sections on the Paris and Singapore District Cooling networks which illustrate this finding.

Using absorption chillers (using steam/heat) instead of compression chillers (using electricity) to produce cold leads to doubling the amount of heat to be evacuated and to nearly multiply by four the size of cooling towers when these devices are used. This is compatible with the conditions encountered in the north of Europe but it is the main reason why the district cooling operators avoid as much as possible to use heat to generate cold in warm countries.

4.2 Cooling demand vs. Heating demand

Key figures for cooling are not as well documented as for heating because most of the corresponding energy consumption is embedded in the total electricity usage for buildings.

\textsuperscript{38} 125% = 1/0.8 and 166% = 1/0.6. (This refers as well to the COP values).

\textsuperscript{39} In total, where a network using a compression chiller needs to release 1.25 (= (4+1)/4) to 1.33 kWh (= (3+1)/3) of heat per kWh of cold, a network using an absorption chiller will have to evacuate between 2.25 kWh (= (0.8+1)/0.8) and 2.7 kWh (= (0.6+1)/0.6).

\textsuperscript{40} Information provided by Mr. Franck Benassis and Mr. P. Poeuf, District Cooling experts, Climespace.
4.2.1 Cooling needs

However, some information can be found in the EU-financed Ecoheatcool project\textsuperscript{41} from 2005-2006, carried out by Euroheat & Power, which analysed District Heating and Cooling networks in the EU and their growth perspectives. Table 4.1 puts into perspective some data.

<table>
<thead>
<tr>
<th>Ecoheatcool project</th>
<th>Heating (PJ\textsubscript{h})</th>
<th>Cooling (PJ\textsubscript{c})</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU32\textsuperscript{42} Residential and Service sectors\textsuperscript{43} <strong>total net heat demand</strong> in 2003 compared to the <strong>cooling total potential demand</strong> (very optimistic assumption that 100% of all useful space would be air conditioned)</td>
<td>12,067\textsuperscript{44}</td>
<td>4921\textsuperscript{45}</td>
</tr>
<tr>
<td>EU32 <strong>Actual District Heating demand</strong> in 2003 compared to <strong>Actual District Cooling demand</strong> in the same year</td>
<td>2400\textsuperscript{46}</td>
<td>1% - 2%\textsuperscript{47} i.e. 7 - 11</td>
</tr>
<tr>
<td>EU32 District Heating demand in 2003 (same as line before) compared to District Cooling Potential supposing that its market shares may go from 1-2% of the existing cooling demand to 25% of the total potential demand, i.e. being multiplied by more than 60</td>
<td>2400</td>
<td>594\textsuperscript{48}</td>
</tr>
</tbody>
</table>

**Table 4.1: Existing and potential heating and cooling needs and potential cooling needs**

At this stage we can assume that heat and cold are equivalent (i.e. 1PJ\textsubscript{th} equivalent to 1 PJ\textsubscript{c}). We have seen above that this assumption is not very far from the truth for cold made from heat but that much less electrical energy is in fact required when compression chillers are used.

**Teachings from Table 4.1:**

- The effective heat demand in 2003 was nearly 3 times higher (12,067 vs. 4921) than the most optimistic potential Cooling demand assuming that 100\% of all useful space in the EU-32 would be air conditioned.
- The effective District Cooling demand in 2003 was more than 200 times weaker (7-11 vs. 2400) than the effective District Heating demand in EU32.
- Even with the dramatically optimistic supposed growth from 1-2\% to 25\% (7-11 to 594), District Cooling demand would still remain 4 times lower (2400 vs. 590) than the existing District Heating demand.

\textsuperscript{41} See: http://www.euroheat.org/Files/Filer/ecoheatcool/index.htm

\textsuperscript{42} ‘EU 32’ is a short cut by Ecoheatcool for what is defined in the reports as EU15 + NMS10 + ACC4 + EFTA3, where EU15 were the 15 EU members in 2003, NMS10, the 10 new member states who joined in 2004, ACC4 the 4 states in accession status at that time (Bulgaria and Romania who joined in 2007, plus Croatia and Turkey) and EFTA3, 3 European Free Trade Association countries (Iceland, Norway and Switzerland).

\textsuperscript{43} We have only taken the data for heating in Residential and Services because the Industry needs are not related to climate and above all because the EcoHeatCool data for cooling include Residential and Services demand.

\textsuperscript{44} See: Ecoheatcool Work Package 1, p.48, table 4. Total during 2003 for Residential and Service: 12,067 (= 9229 + 2838) for the 32 states (‘EU 32’).

\textsuperscript{45} See: Ecoheatcool Work Package 2, p. 4, 5\textsuperscript{th} paragraph and p.36, table 5. Total for Residential and Service: 4921 PJ (= 1367 TWh \times 3.6).

\textsuperscript{46} See: Ecoheatcool Work Package 4, p.44, figure 23. Total District heating generated heat in 2003 for the 32 states : 2.4 EJ = 2400 PJ.

\textsuperscript{47} See: Ecoheatcool Work Package 2, p.31, figure 17 and text below. Market share cooling 1-2\% of the total cooling market or 2 to 3 TWh\textsubscript{c}, which multiplied by 3.6 gives (rounded) 7 to 11 PJ\textsubscript{c}.

\textsuperscript{48} See: Ecoheatcool Work Package 5, p.22, in text. 165 TWh\textsubscript{c} \times 3.6 = 594 PJ\textsubscript{c}.
The recorded District Cooling demand in EU in 2003 was around 200 times less than the District Heating demand. Even under very optimistic assumptions (multiplication by 60) the District Cooling demand would remain 4 times lower than the District Heating demand in Europe.

4.2.2 District Heating and Cooling Demand Figures

The figures from Euroheat & Power, District Heating and Cooling Statistics, 2007\(^{49}\) given in Table 4.2 compare the major District Cooling markets to the District Heating sales.

NB: the following table only shows the markets with reported cooling data in 2007. Three other countries with District Cooling installed capacity were mentioned: Slovenia with a capacity of 0.967 MWth, Denmark (1.5 MWth), Italy with an installed capacity of 145, similar to the one of Germany (185) and Finland (121). Since 2007, the EU installed capacity increased a little (in particular, a District Cooling network has been started in Barcelona\(^{50}\).) This figure of 6,873 TJ in Table 4.2 corresponds to the lower end of the range given in Table 4.1: 7 to 11 PJ.

<table>
<thead>
<tr>
<th>EU Country</th>
<th>District Heating Demand (TJ)</th>
<th>District Cooling Demand (TJ)</th>
<th>Heating/Cooling Ratio</th>
<th>Installed Capacity (MWth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>80,078</td>
<td>3,380</td>
<td>24</td>
<td>620</td>
</tr>
<tr>
<td>Sweden</td>
<td>169,200</td>
<td>2,304</td>
<td>73</td>
<td>*missing</td>
</tr>
<tr>
<td>Germany</td>
<td>267,171</td>
<td>731</td>
<td>365</td>
<td>185</td>
</tr>
<tr>
<td>Finland</td>
<td>108,360</td>
<td>200</td>
<td>540</td>
<td>121</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>144,773</td>
<td>108</td>
<td>1340</td>
<td>30</td>
</tr>
<tr>
<td>Hungary</td>
<td>44,835</td>
<td>28</td>
<td>1597</td>
<td>8</td>
</tr>
<tr>
<td>Austria</td>
<td>60,828</td>
<td>25</td>
<td>2433</td>
<td>15</td>
</tr>
<tr>
<td>Poland</td>
<td>425,000</td>
<td>97</td>
<td>4381</td>
<td>97</td>
</tr>
<tr>
<td>Total for these 8 countries</td>
<td>1,300,245</td>
<td>6,873</td>
<td><strong>189</strong></td>
<td>1,076</td>
</tr>
</tbody>
</table>

Table 4.2: District Heating and Cooling networks demands in the 8 EU countries with reported cooling demand

Teaching:
In the eight countries having reported the cooling demand, the District Heating demand in 2007 was at least 24 times higher than the District Cooling demand and up to 4381 times higher, with an average of 189 times.

Figure 4.1 below shows that District Cooling networks are not less developed in the North Eastern part of Europe than in the South West. The long lasting cooling demand is related to activities such as food preservation, computer cooling etc. which are not related to climate conditions. But the main reason is the insulation of the buildings which has been strongly developed in North Eastern areas and which makes cooling a necessity in these buildings\(^{51}\) (which therefore is inversely related to the climate conditions).


\(^{50}\) Recently installed together with the District Heating network of 20 MWth, the District Cooling network of Barcelona has a cooling capacity of 29 MW from which 20 MW are provided by electrically driven chillers and 9 MW by absorption chillers using the steam from a Waste-to-Energy plant (which generates in total 80 MWth).

\(^{51}\) According to Mr. Poeuf, District Cooling expert of Climespace, the impact is even reinforced by the fact that the sun is lower in the northern sky, which warms insulated houses faster in the North than in the South.
The long-lasting cooling demand for industrial use (food preservation, computer cooling ...) is the same everywhere. The reduction of heat demand thanks to better insulation in the Northern part of Europe induces a growing cooling demand. The cooling demand is therefore not as much dependent on climate conditions as heat demand.

4.2.3 Cooling demand and Waste-to-Energy plants

Because of public reluctance, Waste-to-Energy plants, in particular new ones, are rarely located in places where the demand for cooling (and/or heating) is high (high population density areas). As said above, cold is more difficult to transport on long distances than heat, because the ΔT is much smaller in cold networks than in heat distribution. Higher initial capital expenditure, coupled with much smaller demand for Cooling than for Heating networks, prevent the development of large District Cooling networks.

Although it requires more space and is more expensive, the local production of cold from heat distributed by a District Heating network can be of interest when a District Heating network already exists with a significant demand leading the Waste-to-Energy operator not to focus primarily on electricity production. Indeed the cooling demand related to climate conditions is much shorter in time (around 3 months per year) than the heating demand period (6 to 8 months). This makes the expenditures of a District Cooling network using heat more difficult to amortize when there is no parallel demand for heat.
District Cooling networks are often more expensive than District Heating ones. When a District Heating network exists, costs can be reduced by installing local chillers using the distributed heat. Moreover, the cooling season is shorter than the heating season: the network can hardly be amortized when cooling is not supported by a parallel heat demand.

4.2.4 Additional considerations

While heating is a vital need and all buildings are equipped with heaters, cooling, except in specific applications such as food preservation, is not as crucial and is often a comfort feature. In return for indoor air conditioning, outdoor air or natural water resources are heated, which is questionable for the Environment.

4.3 Heat share in District Cooling network energy supply

The next important question is to identify the share of the energy used in District Cooling networks which effectively comes from surplus heat. The following examples show that this share is often very small.

4.3.1 Case study – The French cooling networks energy sources

With 620 MW in 2008, France is the 1st European country in terms of installed capacity, before Sweden. There are 13 District Cooling networks in France serving 80,000 equivalent households (894 GWh as final energy) through 130 km of piping located in some Paris districts (including la Défense), Bordeaux, Grenoble, Lyon, Montpellier...52

More information on the French District Cooling networks can be found in the national survey53 made by SNCU (French association for heating and cooling networks) for year 2008.

Figure 4.2 shows that renewable and surplus energy amount to 3% of the total. Table 4.3 and Figure 4.3 show that this corresponds to the energy from Waste-to-Energy plants.

![Figure 4.2: District Cooling network energy type (expressed in produced energy) - “EnR&R” means ‘Renewable and Surplus energy’](http://www.viaseva.org/Ressources/Base-documentaire/Statistiques-reseaux-de-chaleur)

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53 See ‘Enquête nationale de branche sur les réseaux de chaleur et de froid’, SNCU: http://www.viaseva.org/Ressources/Base-documentaire/Statistiques-reseaux-de-chaleur
Table 4.3: District Cooling network detailed energy type (expressed in produced energy); “UIOM” means ‘Waste-to-Energy plant’ and “EnR&R” means ‘Renewable and Surplus energy’

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Produced energy (GWh)</th>
<th>Natural gas</th>
<th>Coal</th>
<th>Biogas</th>
<th>WTE</th>
<th>EnR&amp;R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Units</td>
<td>Quantity (GWh)</td>
<td>Part (%)</td>
<td>Units</td>
<td>Quantity (GWh)</td>
<td>Part (%)</td>
</tr>
<tr>
<td>Charbon</td>
<td>6 tonn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel bound &amp; CH4</td>
<td>6 tonn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel domestic</td>
<td>0 MWh</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gas natural</td>
<td>18 236 MWh</td>
<td>15</td>
<td>13</td>
<td>15</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Biomasse</td>
<td>0 tonn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel to atm. renewable</td>
<td>0 MWh</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Fuel to comp</td>
<td>0 MWh</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Chaleur industrielle</td>
<td>0 MWh</td>
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</tr>
<tr>
<td>UIOM</td>
<td>28 430 MWh</td>
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<td>Géothermie</td>
<td>0 MWh</td>
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<td>0</td>
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</tr>
<tr>
<td>Géothermie</td>
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</tr>
<tr>
<td>Chaudière électrique</td>
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<td>0</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Pompe à chaleur</td>
<td>0 MWh</td>
<td>0</td>
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</tr>
<tr>
<td>Fuel compressors</td>
<td>255 390 MWh</td>
<td>250</td>
<td>250</td>
<td>250</td>
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<td>250</td>
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<tr>
<td>Cogénération extre</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Absorption heat</td>
<td>7 524 MWh</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Autre réseau</td>
<td>77 MWh</td>
<td>7</td>
<td>7</td>
<td>7</td>
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<td><strong>Total</strong></td>
<td><strong>726 MWh</strong></td>
<td><strong>70</strong></td>
<td><strong>68</strong></td>
<td><strong>70</strong></td>
<td><strong>68</strong></td>
<td><strong>70</strong></td>
</tr>
</tbody>
</table>


Figure 4.3: District Cooling network detailed energy type (expressed in produced energy); “UIOM” means ‘Waste-to-Energy plant’

4.3.2 Case study – The Paris District Cooling network (Climespace)

The Paris District Chilled water network54 is developing at a rate of approximately 20 MW worth of new customers per year. In 2009 the District Cooling network’s total power was 290 MW with 475 customers connected meaning the equivalent of 5 million m² of office space. The District transport network is 70 km long, amounting to 140 km of tubes running along sewers or technical galleries, and buried pipes. It includes 3 cold storage units with a capacity of 140 MWh (2 ice storage units, 1 chilled water storage). And it is fed by 7 chilled water production plants:
- 4 production plants cooled by air cooling towers
- 3 production plants cooled by the Seine river

Although Paris hosts a large District Heating network fed with steam (see footnote to Section 3.4.2 about CPCU District Heating network), the cooling network does not use this steam. The main reason is the amount of heat to evacuate. The COP of this network


R1_Climate_Factor_Report_v3.doc, 22/03/2012 11:31:00 65/86
with the Seine River is around 4 and, as said above, using compression chillers would lead to multiply by 2 or 3 the amount of heat to evacuate.

4.3.3 World, Case study – Singapore

In Europe, the District Cooling networks represent 1% or 2% of the cooling market.

Elsewhere in the world, the District Cooling networks mainly develop in highly urbanised areas, with hot climates and a high standard of living such as in the United Arab Emirates or Japan. Most often, a cooling network is built with a new part of the city.

As an example, “the largest and most ambitious district cooling project ever undertaken”, according to ABB55, is in operation in Singapore’s Marina bay. Hailed as the ‘multi-billion dollar city within a city’, Marina Bay, which is built on reclaimed land at the southern tip of the island-state, is a 360-hectare extension to Singapore’s existing business district and downtown area. To date, phases 1 (operation started in May 2006) and 2 (operation started in August 2010) of the District Cooling network are in operation, providing 1.1 million m² of commercial space with cool air via two chilled water production plants and a 5-km piping network. The system currently has an installed capacity of 157 MWr out of 330 MWr planned for the two plants. The ultimate potential of the system is 900 MWr serving 8 million m² of commercial space.

The project demonstrates the sustainable benefits of district-scale chilled water production and distribution in lieu of building-scale facilities. As ABB says this “network sets a new international energy efficiency benchmark for cooling commercial buildings.”

However, one must keep in mind that Singapore has a hot and humid equatorial climate, in which daytime temperatures are rarely below 30°C, which is not common in the EU.

Another interesting observation in the context of this study is that, although Singapore holds 4 huge Waste-to-Energy plants, among the biggest in the world (total capacity 2.4 million tons of waste a year, generating 2 million MWh a year as electricity), the District Cooling network of SDC (Singapore District Cooling PTE Ltd) at Marina Bay is made with water chillers, brine chillers and cooling towers and does not use waste heat neither from a Waste-to-Energy plant nor from any other origin.

These 2 examples (Paris and Singapore District Cooling networks) illustrate that the potential use of waste heat for cooling is very limited in warm and hot areas.

4.4 Conclusions on cooling

In conclusion, in the EU:

1 District Cooling networks can use heat as primary source of energy (with absorption chillers in lieu of electricity with compression chillers). This is a possible market for surplus heat.

2 The recorded District Cooling demand in EU in 2003 was around 200 times less than the District Heating demand. Even under very optimistic assumptions (multiplication by 60) the District Cooling demand would remain 4 times lower than the District Heat demand in EU.

3 In Europe, the District Cooling networks represent 1% or 2% of the cooling market.

4 The long-lasting cooling demand for industrial use (food preservation, computer cooling ...) is the same everywhere. The reduction of heat demand thanks to better

---

55 http://m.abb.com/cawp/seip202/b68e72f3c6c68658c12578f80030a78.aspx
insulation in the Northern part of Europe induces a growing cooling demand. The cooling demand is therefore not as much dependent on climate conditions as the heat demand.

5 District Cooling networks are often more expensive than District Heating ones. When a District Heating network exists, costs can be reduced by installing local chillers using the distributed heat.

6 The cooling demand which is related to climate conditions is much shorter in time (around 3 months per year) than the heating demand period (6 to 8 months). The network can hardly be amortized when cooling is not supported by a parallel heat demand.

7 Using absorption chillers instead of compression chillers to produce cold leads to doubling the amount of heat to be evacuated and to nearly multiply by four the size of cooling towers when these devices are used. This is compatible with the conditions encountered in the north of Europe but it is the main reason why the District Cooling operators avoid as much as possible to use heat to generate cold in warm countries.

8 Indeed, heat is a very small part of the District Cooling networks’ energy source: 3% in France, the 1st European country in terms of DC installed capacity; 0% in Singapore.

9 It seems to be technically and financially easier to provide cooling from a network in places where there are good conditions for District Heating.

10 While heating is a vital need and all buildings are equipped with heaters, cooling, except in specific applications such as food preservation, is not as crucial and is very often a comfort feature. In return for indoor air conditioning, outdoor air or natural water resources are heated, which is questionable for the Environment.

11 In conclusion, the demand for heat by District Cooling networks which can be met by heat supplied by Waste-to-Energy plants is very small and not clearly related to climate conditions. Cooling does not appear to be a more significant opportunity of exporting surplus heat in warm climates than in cold climates.

Synthesis of Technical Facts – Chapter 4

P) District Cooling networks can use heat as primary source of energy in lieu of electricity. However:

Q) The existing District Cooling market as well as the maximum potential market are much lower than the recorded effective District Heating market.

R) The share of District Cooling networks is not more than 1% or 2% of the total cooling market.

S) The cooling demand is not as dependent on climate conditions as the heat demand.

T) Using heat as primary source of energy requires evacuating more energy and increasing the water consumption. Therefore, in warm areas, the District Cooling operators avoid to use heat as primary source of energy even when surplus heat is available.

U) In conclusion, cooling does not appear to be a more significant opportunity for exporting surplus heat from Waste-to-Energy plants in warm climates than in cold climates. Cooling can be neglected in the elaboration of a climate factor.
5. HDD variations with time and location

5.1 HDDs variation with time

As shown in Figure 5.1, the HDD value may significantly change from year to another: The ratio between min and Max HDDs in Marseille-Marignane is 1.392 (=1782/1280) over the 10 years 2001-2010).

For this reason, sound references must be based on long term average values.

Year 2010 was chosen for the acquisition of our data because it was the most recent, but this year appears to be the coldest of the decade, i.e. the year for which the ‘handicap’ on electricity production was the smallest and the heat demand was the highest. With respect to electricity, this must be taken into account by adequately correcting the functions identified with 2010 figures (see functions identified in Section 2.3).

Heating Degree Days can vary by 40% from one year to another. This impacts heat export and electricity production. HDDs of year 2010 were the lowest of the decade. 2010 data used in this study correspond to minimal impacts on electricity production and heat demand.

Feedback from the field

When finalising this report, we received the heat demand data for 3 Waste-to-Energy plants delivering heat to a District heating network for years 2010 and 2011. See Table 5.1.

This set of data is really interesting by two aspects:

- First if, as already said, year 2010 was a cold one in Europe, 2011 has been a hot one at least in the locations of these 3 plants: The HDDs variations between only these 2 years are respectively -41% (near Paris), -29.6% (in Lyon) and -42.6% (in Côte d’Azur)

- Second, it confirms that the heat demand variation is nearly strictly proportional to the annual HDD variation
Table 5.1: Variation of HDD value (French formula) and heat sales for 3 Waste-to-Energy plants in 2010 & 2011

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrières sur Seine</td>
<td>2 551</td>
<td>1 809</td>
<td>-41,0%</td>
<td>51 617 MWh</td>
<td>38 090 MWh</td>
<td>-35,5%</td>
</tr>
<tr>
<td>Lyon</td>
<td>2 513</td>
<td>1 939</td>
<td>-29,6%</td>
<td>92 337 MWh</td>
<td>71 624 MWh</td>
<td>-28,9%</td>
</tr>
<tr>
<td>Toulon</td>
<td>1 489</td>
<td>1 045</td>
<td>-42,6%</td>
<td>16 119 MWh</td>
<td>11 530 MWh</td>
<td>-39,8%</td>
</tr>
</tbody>
</table>

5.2 Climate evolution

Although not observed in the sets of local data we collected on only 10 years period, the trend to a warmer climate (Climate change) can be seen in Figures 5.2 and 5.3 which show the average HDDs in the PACA region and in the EU-27 over 30 years (Eurostat data, 1980-2009\textsuperscript{56}).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{hdd_paca.png}
\caption{HDDs over 30 years (1980-2009) in region PACA, Provence-Alpes-Côte d'Azur}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{hdd_eu27.png}
\caption{HDDs over 30 years (1980 - 2009) in EU27}
\end{figure}

\textsuperscript{56} Unfortunately, Eurostat does not provide data for year 2010.
## 5.3 Local HDDs inside a same region

Inside a same administrative region, the HDDs may significantly differ, for instance when the region contains mountains and coastal areas.

As an example, the HDD value for the Provence - Alpes - Cote d’Azur region was 2163 in 2009 (see Figure 5.2) but the HDD value of Marseille Marignane, which is the capital of this region, was only 1491 for the same year 2009 (see Figure 5.1). This reflects the fact that Marseille is a port city, while parts of the region reach an altitude of 4000 meters.
The HDDs to be taken into consideration must actually correspond to the local climate in the area of the plant. This does not mean that a local station must be systematically used but the above example makes it clear that the average value of a region cannot be taken without checking. If necessary, e.g. in uneven areas, the interpolation tool of JRC might be used (see section 1.2.3).

HDDs may vary a lot inside a same region. It is local HDDs which must be taken into account.

5.4 Conclusions on HDDs variation with time and location

The teachings from Tables 5.1, 5.2 and Figures 5.1, 5.2 and 5.3 are the following:

1. The average EU-27 HDD value over 30 years ranges from 1 to 1.268 (= 3664/2889), which is less than the range observed in the investigated region (HDD value ranging in PACA region from 1 to 1.334 = 2690/2017), which itself is less than the local HDD range in a particular station such as Marseille-Marignane over only 10 years (in Marseille HDD values range from 1 to 1.392 = 1782/1280) or even over only two years, in Carrière sur Seine (1 to 1.41) or Toulon (1 to 1.426); see Table 5.1. Statistically speaking, it is not surprising that the local HDD ranges are wider than the averages over large zones.

2. Independently from the ‘erratic’ yearly variations, Figures 5.2 and 5.3 clearly show a long term trend to a decrease of the HDDs which illustrate the famous climate change due to Greenhouse Gas emissions. At EU-27 level (see Figure 5.3 and Table 5.1), the average HDD drop over 30 years is 15.94 degrees days per year, i.e. 0.5% a year (=15.94/3219). At PACA Region level (see Figure 5.2 and Table 5.1), the average HDD drop over 30 years is 13.26 degrees days per year, i.e. 0.58% a year (=13.26/2299).

3. HDDs may significantly vary a lot over time in a same location; even among two successive years (more than 40% between 2010 and 2011 in 2 different locations; see Table 5.1)

The aforementioned points have a double impact on the R1 value:

1. The large HDDs variation range leads to significant changes in the potential overall efficiency of the Waste-to-Energy plants from one year to another. As seen in Figure 5.1 and Table 5.1, the HDDs, and consequently the heat demand, varies over only 10 years in a range from 1 to 1.392 and even locally (Toulon) over two successive years from 1 to 1.426.

2. The move towards a warmer climate will on long term decrease the HDDs at a rate of around 16°C/year and therefore reduce the heat demand, at a rate of 0.5% to 0.58% a year or more, as well as the electricity production; which consequently will significantly deteriorate the R1 value.

The R1 formula as given in the 2008 Waste Framework Directive was developed following an impact assessment made by the Commission which was based on the 1st CEWEP Energy efficiency report. This report used operational data from European Waste-to-Energy plants over the 2001-2004 period, (essentially from 2004 and 2003), i.e. 8 to 9 years ago.

On the other hand, the R1 formula is to be used for at least 20 more years. We should at least consider the coming 12 years in a prospective.

Considering that the local conditions have changed since were gathered the data on which the R1 formula was built and that the R1 criterion must remain fair in the future, we propose to take into consideration the effect of HDDs evolution over 20 years (= 8 years in past + 12 years into future). As the proposed climate factor is elaborated differently for electricity alone and heat & electricity together, we discuss separately below the impact of HDD variations in these two options.
5.4.1 Impact on electricity production

The calculations made in Chapter 2 refer to year 2010 which was the coldest of the last decade in all the sites from where we got long term data and which, according to general information found on the internet, appears to have been the coldest of the period in EU 27, even if 2010 was one of the warmest at world level. This must be accounted by a complementary correction to the ‘handicap’ functions f identified in Section 2.3. In order to face the range of potential variations, we propose to take into account the gap between the ‘handicap’ found in Marseille during the coldest year, 2010, and the hottest of the decade (2003) which was 1.23% (see section 2.2.3).

Similarly, the long term climate change has an effect on the reduction of electricity production which also needs to be taken into account. Based on a decrease of HDD over 20 years of 0.58% per year in Marseille Region, an impact of 0.42% can be assessed by using function f4.

In total, the impact on electricity production of the yearly variations of HDDs and of the long term trend will be 1.65% (= 1.23% + 0.42%) in Marseille. We propose to use this reference point to adjust the correction factor. See Section 7.3.2.

5.4.2 Impact on heat demand

In respect of heat demand, our calculations and our assessment on the impact are not based on a particular year and therefore no additional correction is required on the fact that 2010 was the coldest year of the decade in Europe.

However, if the assessment were to be made differently, this effect should be compensated in order to avoid that a plant with a fair energy recovery ratio during years with average HDD values fails to reach the R1 threshold that years when there is a lack of heat demand. As seen in Section 3.2, the absence of heat export leads to a significant deterioration of the R1 value. And as seen in this Chapter, the heat demand varies from one year to another in a range of up to 1 to 1.42.

The long term climate change has a significant effect to reduce the heat demand and as well should be taken into account if the assessment on the impact was made differently. Based on a decrease of HDD of 0.5% a year (EU value, which is lower than for instance the Marseille’s one: 0.58% per year) over 20 years, in such a case, the correction should be 10%.

5.4.3 Impact on cooling demand

The long term temperature increase will certainly have an effect on cooling demand. But as seen in Chapter 4, compared to the heat demand, the cooling demand is small, a very small part of it (1% to 2%) is supplied by District Cooling networks and a very small part of the energy used by these networks is heat. The impact on R1 will therefore remain too small to be taken into account in this study.

Synthesis of Technical Facts – Chapter 5

V) Heating Degree Days can vary by 40% from one year to another. HDDs may vary a lot inside a same region. HDDs to consider are the local ones on long term averages. HDDs of year 2010 (reference year for this study) were the lowest of the decade.

W) 30 year data show a long term decrease trend of HDD values: 0.5% per year. Statistically it’s every year more and more difficult to comply with the R1 criteria.
6 Plant size, local conditions and related R1 value

6.1 Small plants ‘handicap’
Small plants encounter a significant ‘handicap’ in terms of efficiency because of the size effect. For instance, additional exchangers which improve the steam cycle are hardly affordable in small plants. Suppliers do not offer small tailor-made turbines because they would be too expensive. Therefore, standard small turbines must be used which do not provide the highest performance as they are not specially designed for the particular plant. The Waste Incineration BREF also mentions, p. 293, that larger plants get an economy of scale in terms of energy consumption per unit of waste treated.

In addition, being often located in sparsely populated places (see below), small plants also often have no or restricted possibilities to export heat as it is not economically feasible to build District Heating networks in such areas.

6.2 Principles of self-sufficiency and proximity
Confirming the requirements of the previous European legislation, the Waste Framework Directive (2008/98/EC, 19/11/2008), requires in its Article 16 ‘Principles of self-sufficiency and proximity’, that Member States take appropriate measures “to establish an integrated and adequate network of waste disposal installations and of installations for the recovery of mixed municipal waste collected from private households, including where such collection also covers such waste from other producers, taking into account best available techniques.”

It also states (in Article 16.2) that “The network shall be designed to enable the Community as a whole to become self-sufficient in waste disposal as well as in the recovery of waste referred to in paragraph 1, and to enable Member States to move towards that aim individually, taking into account geographical circumstances or the need for specialised installations for certain types of waste.”

In order to comply with EU legislation, waste should therefore be treated as closely as possible to the point at which it is generated, thus aiming to achieve responsible self-sufficiency at a regional/or sub regional level.

Consequently, the size of a Waste-to-Energy plant technically results from the local conditions, as in particular it is related to number of people generating waste in the area. Indeed, the principles of self-sufficiency and proximity induce small plants in remote or low population density areas.

Synthesis of Technical Facts – Chapter 6

X) Because of the size effect on costs, small plants cannot achieve the same energy efficiencies as large plants and consequently reach much lower R1 values.

Y) The size of a Waste-to-Energy plant technically results from the local conditions: By application of the principles of self-sufficiency and proximity (EU legislation), only small plants can be built in low population density areas.

Z) It should be necessary to take into account the technical effect of size on R1 value, for instance by application to their R1 value of a multiplicative factor.
6.3 Uneven population distribution

As it can be seen from Figure 6.1\textsuperscript{57}, the density of population in EU varies from a few thousand people per square km\textsuperscript{2} down to about 10 to 50.

![Population density grid](http://ec.europa.eu/dgs/jrc/index.cfm?id=2820&dt_code=HLN&obj_id=217&lang=en)

\textbf{Figure 6.1 Population densities as measured by the JRC’s EU population density grid, in 2000}

6.4 Quantification of the size effect on the R1 value

This size effect has been highlighted in the 2\textsuperscript{nd} CEWEP energy efficiency report which has been already mentioned (See Section 1.1.2 and Table 1.1).

The following Table 6.1 and Figure 6.2 quantify the relation observed in this CEWEP survey between the plant size (3 plots obtained by dividing the total amount of waste incinerated for each size group by the number of units of this group) and the percentage of plants of the group with an R1 value above 0.6 as well as the R1 value.

The last version of the R1 guidance document published in July 2011 removed 2 steam flows from Ep. This drastically reduced the R1 values of the Waste-to-Energy plants (by around 10\% to 15\%) in comparison to what was agreed by the working group set up by the Commission for this purpose during the meeting of 16/9/2010. As the R1 values of the 2\textsuperscript{nd} CEWEP energy efficiency report were calculated according to the conclusions of the WG meeting, they now appear to be overestimated. In addition, it appeared that the operators of plants with low R1 value were reluctant to communicate their data, which is a second reason for overestimate.

\textsuperscript{57} Onsite: http://ec.europa.eu/dgs/jrc/index.cfm?id=2820\&dt_code=HLN\&obj_id=217\&lang=en
<table>
<thead>
<tr>
<th>Size ranges (Mg/y)</th>
<th>Number of plants</th>
<th>Total throughput (Mg/y)</th>
<th>Average capacity (Mg/y)</th>
<th>Average R1 value (overestimated by 10-15%)</th>
<th>Percentage of plants with R1 &gt; 0.6 (overestimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100 000</td>
<td>92</td>
<td>5 340 000</td>
<td>58 043</td>
<td>0.68</td>
<td>54.3%</td>
</tr>
<tr>
<td>100 000 - 250 000</td>
<td>77</td>
<td>12 770 000</td>
<td>165 844</td>
<td>0.77</td>
<td>77.9%</td>
</tr>
<tr>
<td>&gt; 250 000</td>
<td>62</td>
<td>27 410 000</td>
<td>442 097</td>
<td>0.85</td>
<td>95.2%</td>
</tr>
</tbody>
</table>

Table 6.1: Size effect according to the 2nd CEWEP energy efficiency report

6.5 Conclusions on plant size

It appears that small plants are even further handicapped by the climate in terms of R1 value. However, the plants size results from their local conditions and from the requirements of the European legislation for self-sufficiency and proximity treatment of waste stated by the Waste Framework Directive in Article 16. This particular set of circumstances (warm climate + small plant) is especially unfavourable in terms of R1. A factor is suggested to take size as well into account by application of a multiplicative factor to their R1 value. Table 6.1 shows that the R1 ratio between large and small plants is of 1.25 (= 0.85/0.68). But we propose to limit this factor to 1.15 to incentivise efficiency gains.

The proposed $K_{size}$ factor is as follows.

**Proposed $K_{size}$ factor addressing the size aspect:**

$K_{size} = 1$ if plant capacity $\geq 250,000$ t/a

$K_{size} = 1.15$ if plant capacity $\leq 50,000$ t/a

$K_{size}$ proportional in between

$K_{size}$ being also a multiplicative factor applies to the R1 calculated value multiplied by $K_{climate}$

Table 6.2: Proposed $K_{size}$ factor addressing the plant size aspect
7. CONCLUSIONS - PROPOSAL for CORRECTION CLIMATE FACTORS

7.1 General conclusions

This study clearly shows that the overall efficiency of Waste-to-Energy plants as it is assessed by the R1 criterion is significantly impacted by local conditions including climate.

In particular, the processing of numerous statistical data made for this study shows with no doubt that the local climatic conditions significantly "influence the amounts of energy that can technically be used or produced in the form of electricity, heating cooling or processing steam" as mentioned in Article 38 of the WFD (Waste Framework Directive, 2008/98/EC).

Indeed, climate induces a cumulative double impact on the R1 value:

- One on heat export possibility, triggered by a high and long-lasting heat demand for space heating purposes in cold countries. This demand is limited or virtually inexistent in warm locations

- One on electricity production, which directly results from thermodynamics. The warmer the outdoor ambient air is, the less electricity is produced

It is therefore necessary to identify the conditions for a level playing field within the EU.

7.2 Main teachings of the study - Technical aspects

1. The actual recovery efficiency of state-of-the-art Waste-to-Energy boilers (ratio between the energy in the steam and the energy in the waste) is high (> 80%) and it is not very much dependent upon the climate.

2. The R1 formula takes into account not only the plant’s efficiency in recovering the waste’s energy but as well the effective use by third parties and the plant itself of this energy made available by the plant.

3. Waste-to-Energy plants can provide heat and/or electricity. While usually all exportable electricity is easily put on the grid, the heat is only exported under the condition that there is an established nearby demand for it.

4. The design of a Waste-to-Energy plant depends upon the way the energy recovered from the waste will be used (heat and/or electricity). The plant is then optimised to export as much energy as possible in its location.

5. Nevertheless, the 2nd CEWEP Energy Efficiency report has shown that even though plants are in principle optimised for their specific locations, they still have different R1 values; this is most often due to the local climatic conditions since plants exporting heat and electricity generally have higher R1 values than those exporting only electricity, and this report showed that those located in colder areas have a higher R1 than those in warmer areas.

6. The main driver for the thermodynamical design is the heat export potential: whenever possible, priority is given to heat export for economical reasons.

7. Only when there is a very high and long lasting heat demand and at low energy levels (low temperature networks), some equipments which improve the actual efficiency of the plant, such as heat pumps and flue gas condensers, can be justified. Such plants generally reach very high R1 values.

8. When the heat demand is not very high, condensing turbines are used. With condensing turbines, the instantaneous heat export is limited to roughly 50% of the energy input (for technical purposes).
It is not possible to take into consideration all possible plant specificities. And, as it is desirable that the owners and operators do their best to improve the overall efficiency of their plants, it would be counterproductive to penalise with a reduced climate factor those plants which benefit from improvement in respect of the standard situation. This quantification of the impact can therefore be assumed by using a same state-of-the-art standard plant moved to different locations in Europe.

Where no heat demand exists, electricity is still produced and Waste-to-Energy plants typically use air condensers as cold source, which establishes a dependency of energy production towards the outdoor ambient air temperature. This is the first expression of the climate’s impact, where high outdoor ambient air temperatures decrease the efficiency of electricity production in Waste-to-Energy plants.

For a representative assessment of the climate’s impact on thermodynamics, a standard reference plant should therefore be defined and the correction for all plants should be based on it. This plant will be submitted to different weather patterns existing in Europe to compare their impact.

Thermodynamics drives the efficiency of the turbine-generator set and air condenser system; a curve has been calculated giving the ‘handicap’ in electricity production in function of the temperature of the outdoor ambient air (vs. a theoretical Waste-to-Energy plant using all year long ambient air at 10°C).

Temperature data (hour-by-hour and sometimes daily max and min) have been collected through national meteorological services and processed.

Accurate calculations made with hour-by-hour temperature data over a year – and for some locations over 10 years – show that in continental Europe the ‘handicap’ on electricity production numbers in a few percents in reference to a location where the ambient air would be at 10°C all year long. However most South Western locations are far from suffering such a high ‘handicap’.

For thermodynamic reasons the average yearly temperature cannot be directly used for these calculations as it would lead to significantly underestimating the ‘handicap’.

A sensitivity of the ‘handicap’ to the type of climate (oceanic/continental as shown by the width of the ‘temperature bells’) has been observed but it is offset by the reverse impact from heat demand.

However functions with good correlation coefficients were identified which, indirectly, gives the electricity production ‘handicap’ in function of the yearly average outdoor ambient air temperature (and, for one of them, of the standard deviation but this requires the complete set of hour-by-hour data, which is not always available). We did not find Eurostat/JRC data on long term yearly outdoor ambient air temperature, and therefore also developed a linear function using the local Heating Degree Days.

Eurostat has developed a formula to calculate HDDs (Heating Degree Days) which is used by Eurostat to determine the final energy consumption for space heating purposes depending on weather conditions. Eurostat website provides long term (30 years) HDDs for Member States and their regions. And the JRC has developed an interpolation tool.

The impact of heat export on the R1 value is much more important than the impact related to a reduction of the production of electricity. In spite of the equivalence factors (which compare produced heat and produced electricity to primary fuels), a same CHP Waste-to-Energy plant reaches a much higher R1 value when it exports heat than when it generates only electricity. A state-of-the-art large CHP Waste-to-Energy plant reaches a R1 value of 0.590 when the same plant in the same conditions reaches a R1 value of 0.858 if exporting all year long 50% of the energy as heat.

The Waste Incineration BREF provides BAT energy efficiencies for Waste-to-Energy plants dedicated to heat export (BAT 61) and to electricity export (BAT 62). The ratio between the R1 values of BAT 61 (in the worst case) and average BAT 62 is 1.382.
This shows the imbalance between heat only and electricity only Waste-to-Energy plants.

21 A synergy with industrial heat customer(s) constitutes a favourable situation in terms of energy efficiency because, in general, the industrial energy demand is regular and evenly distributed over the year. But the Location and Technical challenges, along with lingering contractual uncertainties, sum-up to limit the reproducibility of such a synergy.

22 A stark contrast exists between plants located in regions with a large heating demand in buildings, giving them a double opportunity (possible industrial heat + possible buildings’ heating), while plants in regions with weak or insignificant heating needs have no backup plan if the only opportunity (industrial heat) is impossible.

23 In terms of heat export, the impact on efficiency technically starts with the change in design due to heat demand being not high enough to give priority to heat export and where instead condensing turbines are used. A HDD threshold (3350) has been identified corresponding to the conditions where this change occurs.

24 Similarly, another HDD threshold (2150) has been identified corresponding to the conditions where District Heating networks are scarce (rare) and, if existing, with poor demand or essentially feeding industry with process steam.

25 An interesting finding is that the effect of the climate type (oceanic/continental) on heat demand is opposed to its effect on electricity production in cities with the same yearly average temperature. The narrower the ‘temperature bell’ (oceanic climate), the lesser the handicap on electricity production will be, but also the lesser the heat demand. In other words the smaller climate type effect on electricity production is offset by a lower heat demand.

26 A substantiated enquiry was made about cooling as it is a potential output for heat and as it was suggested that lower heating needs could be replaced or at least substantially offset by cooling needs.

27 The findings were that the cooling market is much smaller than the heating market; and, thanks to insulation and specific needs (food, computer cooling, etc), not so much related to the climate. Other findings were that District Cooling share is around 1% or 2% of the total cooling market and cannot develop very significantly in the foreseeable future; and that when a District Cooling network is developed, waste heat is rarely used because it leads to much higher amounts of heat to evacuate.

28 The HDD value may significantly change from a year to another, e.g. in the location where investigated (Marseille) by a ratio from 1 to 1.392 in only 10 years and even by a ratio above 1 to 1.4 over only 2 years in Toulon and Carrière. Year 2010 which was used for our calculations, as the most recent, was the coldest of the 10 last years, i.e. 2010 was the year for which the ‘handicap’ on electricity production was the smallest of the decade. The climate formula must take this into account by adequately correcting the functions identified with 2010 figures. 2010 was as well and for the same reason the year with the highest heat demand.

29 A clear trend of HDDs to decrease over the long term was observed (which confirms the climate change). At EU-27 level, the average HDD drop over 30 years is 0.5% a year. In the investigated region (PACA), this drop is 0.58% a year. This must also be taken into account in a correction formula as it leads to less electricity produced and less heat exported.

30 A clear relation between plant size and R1 value was identified, related in particular to the economy of scale in Waste-to-Energy plants.
7.3 Proposed correction formulas

This study clearly shows that, due to technical constraints, there is an uneven playing field at EU level in respect of the R1 criterion and that, in spite of the equivalence factors, the R1-formula is much more favourable to heat than to electricity. Therefore, the evidence gathered invalidates TAC option 1 (Zero Option) in the perspective of levelling the playing field. The same can be concluded regarding TAC option 3 (electricity only), an option too narrow because it neglects the large impact on heat that we documented.

However, in order to assess the options mentioned at the TAC meeting on 1/7/2011, we propose below two formulas corresponding to the options mentioned there with the aim to improve the playing field over the EU:

- **Option A:** factor taking *only* into account the electricity production reduction due to warm climate
- **Option B:** factor taking into account the impact of climate on heat demand as well as its effect on electricity production

These formulas do not pretend to establish a perfectly level playing field:

- First because although climate clearly appears as the main factor influencing the potential R1 value of a Waste-to-Energy plant, miscellaneous other factors can have an effect on it. And taking all of them into account would be very complicated
- Second, because the R1 criterion must remain an incentive for operators to increase the overall efficiency of their plants and, in particular, to increase the heat export. The climate factor must not aim at fully compensate the effect of lack of heat demand but should aim at making the R1 condition workable in warmer areas
- Third, because the R1 formula is not an expression of efficiency in physics\(^{58}\), it cannot be used to create a precise ranking order of plants across Europe

In respects of the impacts, three main zones have been identified.

1. In the first one (North-Eastern Europe), the high and long lasting heat demand is a driver to design plants with back pressure turbines. The high amount of heat exported, combined with a still fair electricity production produce the optimal conditions to reach a very high R1 value. No correction is needed because of climate.

2. In the second one (Intermediate), a smaller heat demand leads to use condensing turbines, the production of which is reduced when instantaneous temperature increase. In order to ensure a fairer playing field, a correction factor is needed to cope with the electricity production reduction due to temperature, but also and mainly to compensate the smaller heat demand since its effect on the R1 value is much more important. We consider that this factor should be proportional to the reduction in heat demand and electricity production. The starting point for this zone has been assessed to correspond to HDD 3350.

3. In the third one (South-Western Europe), the heat demand is too low to develop significant District Heating networks except when by chance there is an industrial demand not already satisfied by other waste heat providers. We consider that a correction factor is needed to take into account the lack of heat demand. However, it can be the same for the whole zone since the effect on the R1 value will be the same in all of it. The starting point for this area has been assessed to correspond to HDD 2150.

The decrease in electricity production due to temperature increase is proportional to the temperature in the Intermediate and Southwestern zones. In **option A** (factor taking only electricity into account), we propose not to set a low threshold for the electricity correction (the highest correction being therefore reached in a theoretical place where HDD = 0).

\(^{58}\) The aforementioned Commission guidelines dated 30/6/2011 say p. 5, 1st paragraph: “The “R1-formula” is not strictly speaking an expression of efficiency in physics...”
However in **option B** (factor taking into account electricity and heat), in order to simplify, we propose to set a common threshold for heat and electricity since the heat demand much more impacts the R1 value than the electricity reduction. And, as explained above, since the effect is the same all over the zone, this correction factor should be the same maximum value corresponding to the low identified threshold.

Generally speaking, the climate correction factor should be based:

- **On local data.** This does not mean that the temperature statistics must be taken at the exact plant site but that they must be representative of the situation at the plant location. Sometimes, the country or region data will be accurate enough, sometimes not, e.g. in regions which include mountain and coastal zones. If necessary NUTS, the interpolation model of JRC can provide HDD data in intermediate areas (See Section 1.2.3).
- **On long term statistics** as the temperature data (yearly average, HDDs etc.) are not the same every year in the same place.
- **On official data** whenever possible. Official and mutually recognised data should be preferred. Eurostat data is probably the best option at regional level.

### 7.3.1. Climate Factor to apply to the calculated R1 value

The handicaps which have been assessed for reduction of the electricity production and poor or inexistent heat demand refer to the energy produced and used by the plant, i.e. to Ep. Whatever the climate factor, it should therefore apply to Ep as a whole (neither to only the electrical part of Ep, nor to only its heat part, nor separately to each of them).

Although there is no justification that the climate factor should also multiply Ef and Ei at the numerator of the R1-formula (which in most cases, according to figures given in Table 3.2, would reduce the R1 value by around 1.5%, see Table 3.2), it would be simpler for users if the climate factor applies to the overall value of the calculated R1.

We therefore propose that the following factors multiply the calculated R1 value. (An exception could be made for plants importing the electricity they need since in this specific case, the value of Ei is much higher; for them the factor should apply to Ep only).

As mentioned above, since the R1 values are not an expression of efficiency in physics, they must not be used to create a precise ranking order of plants across Europe. Therefore one needs to assess the climate factor if it has an impact on passing or not passing the threshold but it should not be necessarily applied to plants already passing the threshold.

### 7.3.2 Electricity

In order to establish a level playing field at EU level, the climate factor for electricity must compensate the differences due to climate over the 2 affected zones (Intermediate and South-Western Europe), i.e. in areas where HDD < 3350. For this electricity correction, a function (f3) was identified which gives the handicap in 2010 with great accuracy. However it requires the standard deviation and therefore the complete set of hour-by-hour data over a number of years (10 to 30 if possible). Moreover, in this formula, the standard deviation is used to take into account the climate type (oceanic/continental). But as mentioned above, the effects of the climate type on electricity are opposite to its effect on heat demand and offset by them. Therefore, the accuracy provided by the use of the standard deviation does not seem to be required.

A linear function is therefore preferred as it is much simpler. Function f1 could do if yearly average outdoor ambient air temperatures were available. However, because we could not find this data provided by Eurostat and since the area threshold is expressed in HDD, we have chosen here to use a factor based on HDDs as it was shown that a good correlation could be found (see function f4 in section 2.3.4) with this variable, which can be provided by Eurostat and the JRC.
Determining the linear function

As no correction is made above HDD 3350, the value of the climate factor should be 1 at or above this threshold.

In order to define the linear function, a second point is needed. This second point should be near the middle of the HDD range of the zone (HDD 3350 to 0) and should not be influenced by short terms variations. Marseille station is roughly half way between HDD 0 and HDD 3350 and on top of it we have values over a 10 year period (see Section 2.2.3) allowing us to offset the fact that 2010 was the coldest of the decade.

Adjustments

Initial value: According to Table 2.3, the ‘handicap’ in 2010 in Marseille was 4.77% in reference to a theoretical place where the ambient air temperature is 10°C all year long.

First correction: The starting point for correction being 3350 HDD, Table 2.3 shows that the theoretical handicap for cities with HDD around 3350 is between 1% and 1.5%. In order to get a value of 1 at HDD 3350, we propose to deduce 1.25% to the calculated theoretical ‘handicap’.

Second correction: The ‘handicap’ of 4.77% was calculated with year 2010 data, which was the coldest of the last decade. This must be accounted as well as the long term trend to warmer climate. As mentioned in section 5.4.1, we propose for that to raise the ‘handicap’ by 1.65%.

Altogether the corrected ‘handicap’ value is 5.17% (= 4.77% - 1.25% + 1.65%) and therefore the climate factor for Marseille is 1.0517.

From these two points (1 and 1.0517), the equation of the linear function can be derived: The Y-intercept is 1.1105 and the slope is -32.97 \times 10^{-6}.

And therefore the proposal for a correction factor is the following.

<table>
<thead>
<tr>
<th>Option A</th>
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</thead>
<tbody>
<tr>
<td>Proposal for a factor $K_{\text{ClimateElec}}$ correcting ONLY the impact on electricity:</td>
</tr>
<tr>
<td>$K_{\text{ClimateElec}} = 1$ if $\text{HDD}_{\text{long term local}} &gt; 3350$</td>
</tr>
<tr>
<td>$K_{\text{ClimateElec}} = 1.1105 - 32.97 \times 10^{-6} \times \text{HDD}<em>{\text{long term local}}$ if $\text{HDD}</em>{\text{long term local}} &lt; 3350$</td>
</tr>
<tr>
<td>$K_{\text{ClimateElec}}$ is a multiplicative factor to be applied to the calculated R1 value.</td>
</tr>
</tbody>
</table>

Table 7.1: Proposal for a factor $K_{\text{ClimateElec}}$ correcting ONLY the impact on electricity production

Figure 7.1 shows the graph corresponding to both proposals (Option A and Option B).

7.3.3 Heat

The climate correction factor for the heat aspect should:

- Not aim at totally offsetting the handicap of plants generating electricity versus the ones exporting heat because the R1 formula must remain an incentive to increase the use of recovered heat.
- Aim at partially counterbalancing the handicap of plants located in areas where District Heating networks can hardly be constructed and operated or where the demand is poor. The factor must have a ceiling corresponding to situations where the heat demand does not justify the construction of significant District Heating networks. This limit is assessed to correspond to HDD 2150.
- Be progressive. Correction to start at places where heat demand does not justify giving priority to heat supply and where technically condensing turbines have to be preferred: HDD 3350.

- Offset the effects of an unusually warm year (in term of HDDs), when the heat demand is reduced (ratio 1 to 1.4 as shown by HDD yearly variations).

- Take into account the effect of climate change since the data used to elaborate the R1 formula were collected 8 to 10 years ago and since the formula need to be used at least 12 more years. This induces a supplementary correction of 10% (see Section 5.4.2).

As an option taking only into account the effect of reduced heat demand was not envisaged at the TAC meeting on 1/7/2011, we did not develop a specific proposal for that. The proposal below copes with both the electrical and the heat effects and is based on BATs provided by the WI-BREF. If for some reason, this proposal was not accepted, it would be necessary to build a formula in particular combining all the impacts mentioned above about reduced electricity production and heat demand.

### 7.3.4 Cooling

District cooling must be encouraged as such. However, the demand which can be met from heat supplied by Waste-to-Energy plants being very small, not clearly related to climate conditions, and District Cooling needs being rarely satisfied with surplus heat, it is proposed not to take cooling in consideration for the R1 climate factor.

### 7.3.5 Heat and electricity together

The reduced or inexistent heat demand impacts much more the ability of the plant to produce or provide energy for use than the electricity production handicap. And as said above, the sensitivity of the electricity production to the climate type (oceanic/continental) is offset by the reverse effect of the type of climate on heat demand (much less heat demand in oceanic climate).

In order to make it simple, we therefore propose to use a single formula taking into account at the same time the main impacts due to poor or inexistent heat demand and the less sensitive electricity production reduction. As we exposed that heat has a larger impact on R1 than electricity, this formula will be built on the basis of the heat impact (see Section 7.3.3):

- It should not aim at totally offsetting the handicap of plants generating electricity
- The factor should have a ceiling (at 2150 HDD) corresponding to situations where the heat demand does not justify the construction of significant District heating networks
- Be progressive to incentivise District Heating development. Correction to start at places where heat demand does not justify giving priority to heat supply: HDD 3350

At this stage, the alternative is either to combine the numerous impacts identified in order to build a global climate factor addressing all of them together or to refer to the findings of the Waste-Incineration BREF as summarised in its BATs 61 and 62. Indeed, the second option is simpler and also has the advantage of being a technical document from the Commission reflecting a consensus among industry and Member States experts.

We therefore propose to use the relation given by BAT 61 and BAT 62 between Waste-to-Energy plants dedicated to heat export and Waste-to-Energy plants without sufficient heat demand. The proposed maximum climate factor will then be 1.382 (see Section 3.3).
7.4 Proposed overall climate factor

<table>
<thead>
<tr>
<th>Proposed climate factor</th>
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</thead>
<tbody>
<tr>
<td><strong>Option B</strong></td>
</tr>
<tr>
<td><strong>Proposal for a factor</strong> $K_{\text{ClimateHeat&amp;Elec}}$ correcting the impact on BOTH electricity production AND heat demand:**</td>
</tr>
<tr>
<td>$K_{\text{ClimateHeat&amp;Elec}} = 1$ if $HDD_{\text{long term local}} &gt; 3350$</td>
</tr>
<tr>
<td>$K_{\text{ClimateHeat&amp;Elec}} = 1.382$ if $HDD_{\text{long term local}} &lt; 2150$</td>
</tr>
<tr>
<td>And $K_{\text{ClimateHeat&amp;Elec}}$ is proportional in the interval, i.e.:</td>
</tr>
<tr>
<td>$K_{\text{ClimateHeat&amp;Elec}} = - (0.382/1200) \times HDD_{\text{long term local}} + 2.0665$ when $2150 &lt; HDD_{\text{long term local}} &lt; 3350$</td>
</tr>
<tr>
<td>$K_{\text{Climate Heat&amp;Elec}}$ is a multiplicative factor to be applied to the calculated R1 value.</td>
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</table>

Table 7.2: Proposal for a factor $K_{\text{ClimateHeat&Elec}}$ correcting the impact on BOTH electricity production AND heat demand

Figure 7.1 shows the proposed climate factor:

- Taking only into account the impact of climate on electricity production (Option A)
- Taking into account the heat and electricity impacts together (Option B).

For information, it also displays the long term (30 year average) HDD values for some Member states and some regions. But as already mentioned, the HDDs to be taken into consideration are the local ones.

![Proposed climate factor graph](image)

Figure 7.1: Proposed climate factors $K_{\text{Climate}}$ addressing (option A) only the electricity impact and (option B) the heat AND electricity aspects together - For approximate information, long term (30 years) HDD data in some Member States and (in italics) regions according to Eurostat data - All text labels (above and below the lines) point out both options.
The evidence gathered in this report shows that there is an uneven playing field for Waste-to-Energy plants’ R1 because climatic conditions affect their electricity production and the demand for their heat. This imbalance is fully addressed in Option B as it (partially) compensates for the effect of climate on both electricity and heat. To level the playing field, the evidence gathered in this study invalidates option A, a minimal correction looking only at a part of the climate’s impact (electricity, but not heat) and the Zero Option, which dismisses evidence of any climatic impact.
Synthesis of technical facts – Chapter 7, Overall study

a) Tools exist to measure the impact of climate. Long term (30 year) HDDs (Heating Degree days) according to Eurostat formula can be provided by the JRC by interpolation on a fine grid.

b) The outdoor ambient air temperature has a clear effect on the electricity production of the waste-to-Energy plants used in areas where the heat demand is moderate or inexistent. The warmer the air, the lower the electrical efficiency. This impact on electrical efficiency can be quantified and expressed as a function of HDDs. It is smaller than the impact from lack of heat.

c) The same Waste-to-Energy plant reaches a much higher R1 value when it exports heat than when it generates electricity. The higher the heat export, the higher the R1 value. The R1 value of a plant depends mainly on its ability to export heat.

d) The energy efficiencies provided by the Waste Incineration BREF gives much higher R1 values for plants using Best Available Techniques dedicated to heat than for plants dedicated to electricity. The ratio between these R1 values was assessed (worst case) to be worth 1.382.

e) Exporting heat to industrial customer(s) constitutes a favourable situation in terms of efficiency, but cannot be done everywhere and cannot provide the long term contracts requested for project financing.

f) District Heating networks can be a major outlet for heat from waste. However, Climate greatly influences the existence and demand of Heating networks.

g) Plants located in regions with a large heating demand in buildings, have a double opportunity (possible industrial heat + possible buildings’ heating), while plants in regions with weak or insignificant heating needs have no backup plan if the only opportunity (industrial heat) is impossible.

h) 3 different zones exist in Europe where District Heating is ubiquitous, sparse or virtually inexistent. They could be delimited by using HDD values. In the North Eastern zone, heat demand is high and electricity production is not affected. In South Western zone heat demand for heating is more or less inexistent and electricity production is the most affected. In the intermediate zone, the impacts are proportional to HDDs.

i) Cooling network demand is much smaller than Heating demand. Moreover, operators avoid using heat to cool in warm region because of technical problems. Heat for cooling demand does not offset the lack of heat demand.

j) HDD values can vary by 40% from one year to the other and over 30 years it statistically decreased by 0.5% a year. Every year, the R1 criterion is more difficult to reach.

k) The plant size is a consequence of location, population density and EU law (Proximity and self sufficiency principles). Small plants reach lower R1 values which should as well be compensated.

l) According to Commission request, two climate factor formulas are proposed: One for electricity only (Option A). One for electricity and heat together (Option B) which is based on the Waste Incineration BREF statements.

m) This correction factor does not fully compensate the lack of heat export possibilities since the R1 criterion must remain an incentive to use waste heat from the Waste-to-Energy plants.

n) The factor proposed in Option B is far from bringing all South Western plants to the R1 status: less than 50% of them would comply with the R1 criterion with this factor.
Final conclusions

The evidence gathered in this report shows that there is an uneven playing field for Waste-to-Energy plants’ R1 because climatic conditions affect their electricity production and the demand for their heat. This imbalance is fully addressed in the climate factor proposed in Option B as it (partially) compensates for the effect of climate on both electricity and heat. To level the playing field, the evidence gathered in this study invalidates option A, a minimal correction looking only at a part of the climate’s impact (electricity, but not heat) and the Zero Option, which dismisses evidence of any climatic impact.

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It appears that small plants are even further handicapped by the climate in terms of R1 value. However the plants size results from their local conditions and from the requirements of the European legislation for self-sufficiency and proximity treatment of waste stated by the Waste Framework Directive in Article 16. This particular set of circumstances (warm climate + small plant) is especially unfavourable in terms of R1. A factor is suggested to take size as well into account.