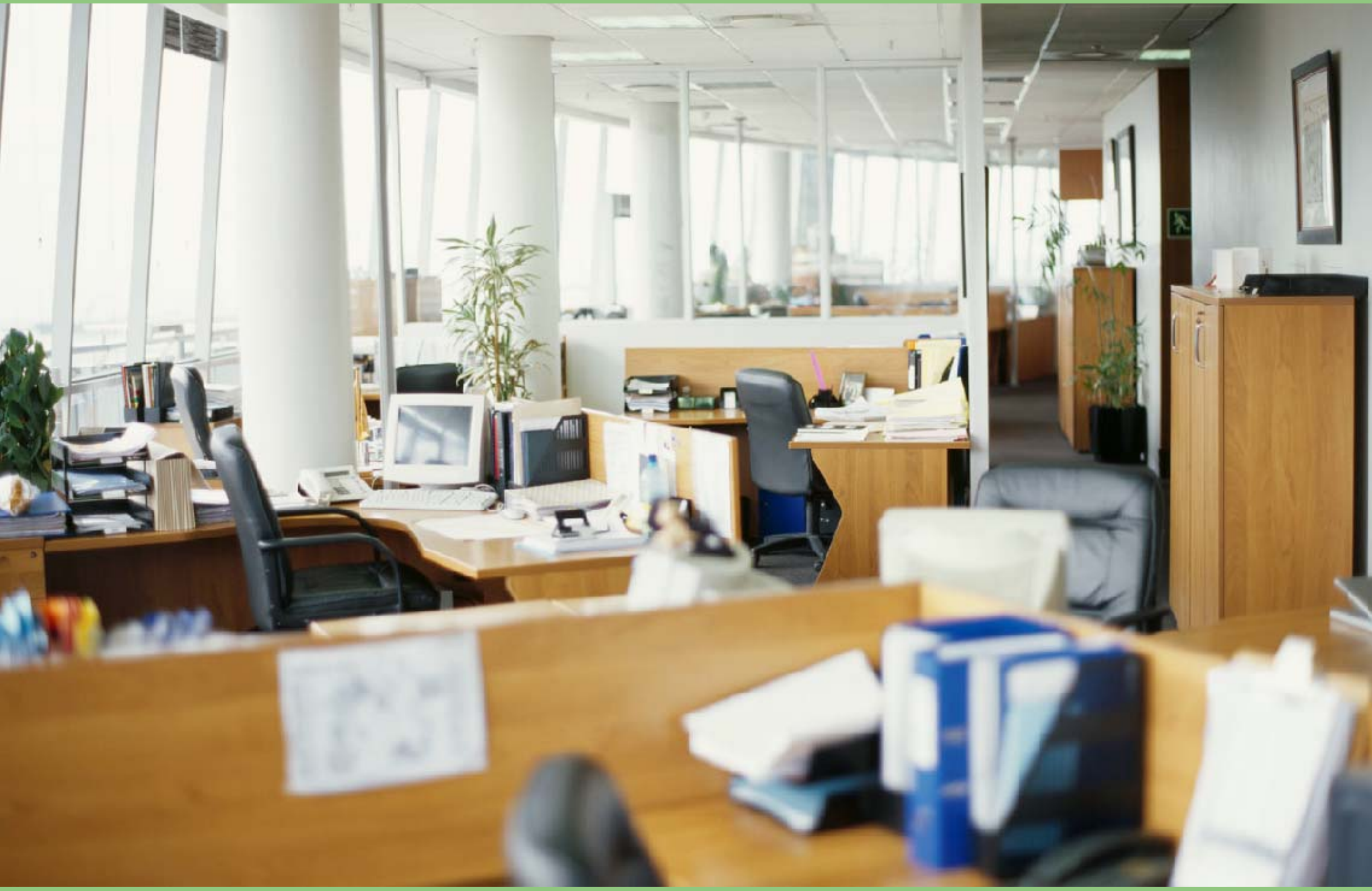
RENEWABLE SMART COOLING FOR URBAN EUROPE

WORK PACKAGE 2



ENVIRONMENTAL FACTORS FROM A COOLING PERSPECTIVE

PEF, RES and CO_2

Co-funded by the Intelligent Energy Europe Programme of the European Union

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Report prepared by:

RESCUE – RENEWABLE SMART COOLING FOR URBAN EUROPE

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CONTENT

1. PREFACE

This report has been elaborated in the RESCUE (Renewable Smart Cooling in Urban Europe) project. This IEE (Intelligent Energy Europe) co-funded project is scheduled from June 2012 to November 2014.

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- Helsinki Energy (www.helen.fi)
- AGFW (www.agfw.de)
- Euroheat and Power (www.euroheat.org)
- ICLEI Europe (www.iclei-europe.org)
- Regional Energy Agency of Liguria (www.areliguria.it)

If you would like to know more about RESCUE project please visit our website www.rescue-project.eu.

2. PROJECT DESCRIPTION

Cooling energy demand within Europe, especially in urban regions, is rising significantly, mainly caused by building design, internal heat loads, heat island effects, and comfort reasons. If served conventionally using small scale and distributed electric driven compressor chillers this would result in a significant rise in primary energy consumption, greenhouse gas emissions and peak electricity demand.

The RESCUE project focuses on the key challenges for further development and implementation of District Cooling (DC) using low and zero carbon emitting sources, thereby enabling local communities to reap the environmental and economic benefits of this mature technology. Although DC allows the application of high efficient industrial chillers or absorption chillers driven by waste heat it is estimated that DC market share today is about 1-2 % in the service sector (which is about 3 TWh) but less than 1 % of the total present existing European cooling market including residential. The main steps to extend the use of smart, energy efficient and renewable DC Systems are:

1. Dissemination of essential background information.

2. Decision making based on (pre-) feasibility studies exploring cooling options.

3. Implementation, monitoring and optimization.

The RESCUE project focuses on steps 1 and 2 within the project duration addressing main actors and target groups, i.e. Local Authorities (LA), utility companies, building owners, and the financing sector. The main objectives of the project are therefore:

- Promote DC as a high potential, sustainable energy solution.

- Increase familiarity and reliability of information available to decision makers and LA about the DC business.

- Improve networking activities and experience exchange.

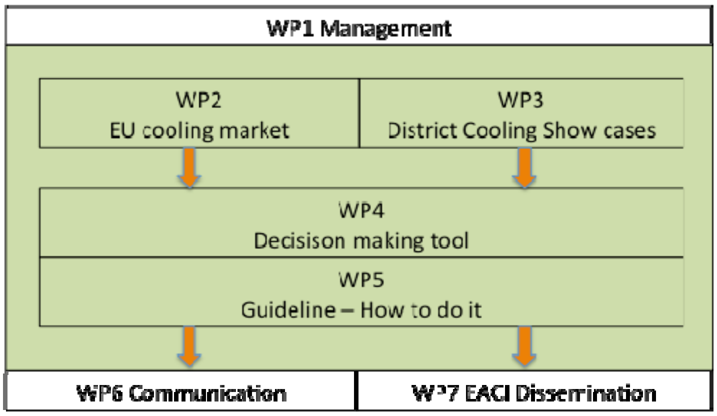
A key action of the project is to provide a number of target cities with a decision-making support package assisting LA to account for DC in their planning policies and to guide them when looking for cooling options fitting best to their Sustainable Energy Action Plan (SEAP). Key outputs and main deliverables of the project, available to the public, are:

- An impact calculator which shows the key figures in comparison between Central and Distributed solutions.

- A set of guidelines and handbooks related to the DC business and the decision making process.

- Reports describing the cooling energy market, the energy performance evaluation as well as DC best practice and show cases.

The RESCUE project consists of seven Work Packages (WP), whereas WPs 1, 6 and 7 are dedicated for project management and communication, WP2 is dedicated to conducting a market survey for cooling in Europe and to establish how DC can contribute to the 20-20-20 targets. WP3 is to showcase examples of DC systems in Europe in order to demonstrate their performance and to provide details on the use of renewable energy sources (RES), improvements in energy efficiency and CO_2-savings. Within WP4 a "Decision Making Support Package" is developed, applied and enhanced to guide and assist LA in their decision processes regarding cooling issues in local energy concepts. The purpose of WP 5 is to provide practical information related to start-up of DC systems and the DC business in general.


WP1 Management
WP2
EU cooling market
WP3
District Cooling Show cases
WP4
Decisison making tool
WP5
Guideline – How to do it
WP6 Communication
WP7 EACI Dissemination

3. DEFINITIONS AND ABBREVIATIONS

ABS	Absorption (chiller)
CHP	Combined Heat & Power
CO_2	Carbon Dioxide
COP	Coefficient Of Performance
DC	District Cooling
DE	District Energy
DH	District Heating
DHC	District Heating & Cooling
EER	Energy Efficiency Ratio
EC	European Commission
EU	European Union
PE	Primary Energy
PEF	Primary Energy Factor
RA	Real Allocation
RES	Renewable Energy Source
Rescue	REnewable Smart Cooling for Urban Europe
SE	System Extension
SEAP	Sustainable Energy Action Plan
SSEER	System Seasonal Energy Efficiency Ratio

4. SUMMARY

It is very important to be able to evaluate DC systems' impact on the environment and that the methods and labelling criteria's correlates with current goals of the European Union renewable energy directive.

The recommendation in this report is to follow Ecoheat4cities' (2011) standards and use primary energy, carbon dioxide emissions and renewable and recycled energy fraction as indicators on district cooling's impact on the environment.

From a cooling perspective the primary energy and carbon dioxide emissions are the most important indicators due to the fact that RES is already considered in non-renewable primary energy factors and is not required as separate criteria.

The three labels weight different aspects of a produced product's environmental burden. It is important to understand this difference and how it affects district cooling. A major advantage with a DC system is that the system can use energy sources that otherwise would go to waste or use natural cooling sources that would not be used.

From a cooling perspective the labelling should have the following classes:

Class	*PEF* $f_{P,dc}$ *[-]*		*CO_2* $K_{P,dc}$ *[kg/MWh]*		*RES* R_{dc} *[-]*	
1		≤ 0,17		≤ 28		≥ 95%
2	>0,17	≤ 0,25	>28	≤ 40	<95%	≥ 93%
3	>0,25	≤ 0,35	>40	≤ 57	<93%	≥ 91%
4	>0,35	≤ 0,55	>57	≤ 89	<91%	≥ 86%
5	>0,55	≤ 0,80	>89	≤ 129	<86%	≥ 81%
6	>0,80	≤ 1,30	>129	≤ 210	<81%	≥ 73%
7	>1,30		>210		<73%	

Where:

Class 1: World class, only reachable for deep sea water cooling plants. Lower limit COP_{el} 15.

Class 2: High efficient DC plants with large amount of free cooling. Lower limit COP_{el} 10,4.

Class 3: DC plants with some free cooling. Lower limit COP_{el} 7,4.

Class 4: DC plants with cooling tower in warmer countries. Lower limit COP_{el} 4,7.

Class 5: Efficient local air cooled building solutions. Lower limit COP_{el} 3,2.

Class 6: Most older local air cooled building solutions. Lower limit COP_{el} 2,0.

Class 7: Poor performing local air cooled building solutions.

DC is not a production plant. DC is a system and it is for that reason natural to choose an allocation method that considers the whole system. It is therefore natural that SE allocation is the most transparent method for comparing DC with local alternatives. Without this perspective it is a risk that the whole chain of environmental burdens will not be included.

5. INTRODUCTION

Part of the scope in the Rescue project covers an assessment of current methods to evaluate district cooling (DC) systems' impact on the environment. There are a substantial number of methods on labelling energy. Furthermore there are a number of allocation methods on simultaneous generation of electricity, heating or cooling and their benefits and cost related of its use. There are probably as many methodologies concerning these matters today as there are energy companies. All of them, however, differ from each other considering at least one of following aspects:

- Labelling criteria
- Allocation method
- Factor values for electricity
- Factor values for fuel

Ecoheat4cities (2011) emphasise the importance of using labelling criteria that correlates with current goals of the European Union renewable energy directive and have for this purpose recommended three types of criteria:

The factor values mentioned above refer to the factor values decided in Ecoheat4cities to be used for evaluation of a system's environmental performance as resource utilisation, emissions and renewability and these are:

• Resource effectiveness	Primary Energy Factor (PEF)
• Climate impact (CO_2)	Carbon dioxide emissions
• Renewable and recycled energy (RES)	Renewable Energy Sources

The DHC+ Technology Platform[1]initiated and IEE supported project Ecoheat4cities[2] recently released a methodology, which evaluates the environmental impact of DHC by developing green labelling criteria. The methodology is described in the technical report "Ecoheat4cities Green Labelling Criteria" (IVL, 2011). The basis of the green label has been first design for DH and has afterwards been converted for DC applications. There are some distinctive differences between district heating and district cooling (DC), both concerning their production methods and that DC main purpose is to remove access heat from the customers buildings and processes. This report will work in improving the Ecoheat4cities green label from a cooling perspective.

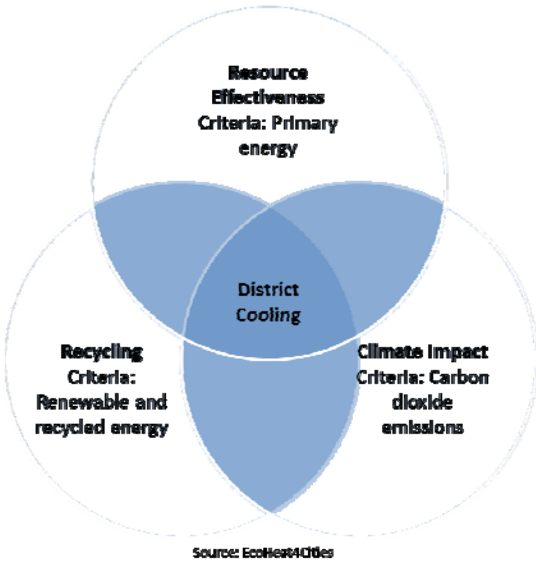


Figure 1: Labelling Criteria for District Cooling *(IVL, 2011)*

5.1 RESOURCE EFFECTIVENESS

Resource effectiveness is measured as the primary energy which is used during production and delivery of the product to the customer's door. Primary energy covers the energy in its "raw" form, before any influence from human involvements.

NON-RENEWABLE PRIMARY ENERGY FACTOR

The non-renewable primary energy factor takes the processes of extraction, processing/refining, storage and transportation of the fuel into consideration. It calculates all the energy losses that occur within the system borders.

The non-renewable primary energy factor consider if the energy source is renewable or not. Example from appendix 1:

Oil = 1,35

Bioenergy = 0,1

[1]www.dhcplus.eu
[2]www.ecoheat4cities.eu

5.2 CLIMATE IMPACT

The climate impact is measured as the amount of carbon dioxide emissions, CO_2, released in proportion to the amount of energy delivered to the customer.

5.3 AMOUNT OF RENEWABLE ENERGY

The amount of renewable or recycled fuels, RES, are measured as how much of the fuel for production that is free from fossil and nuclear fuels.

6. ALLOCATION METHOD

It is important to take into perspective what the purpose of the allocation is when deciding upon an allocation method. The difference between the two main principals is that Real Allocation (RA) focuses on the actual production whereas System Extension (SE) considers how different production units affect each other and the system in a broader perspective. A more detailed description is available in 15.2 Appendix 2 - Allocation Methods.

An already established production unit is already a part of the overall production mix. Considering this perspective it is more important to isolate the production unit and thereby identify it processes actual environmental impact. In this case it is advisable to use an RA method since they focus on the system border of the production plant.

The environmental impact on a newly introduced production unit is not solely based on its own efficiency. Its products will additionally phase-out existing products from competing production units. That is, the overall environmental footprint of a new production plant consists of the impact from its processes minus the “would have been” impact from, due to the new production plant, phased out products. For this case it is therefore preferable to instead use an SE perspective.

Simplified you could also say that RA methods are applicable when looking back in time and SE methods when prospecting the future impact of a current decision. In 2006 district cooling only had 1% percentage of the cooling market in Europe and with a potential to reach 25% and should therefore be viewed as a not yet an established technology on the market (Dalin, Nillson, & Rubenhag, EcoHeatCool, Workpackage 5, Possibilities with district cooling in Europe, 2006). Based on this reasoning it is reasonable to use an SE perspective in order to not only evaluate how efficient the technology is by itself, but also what environmental savings that can be made through phasing out inefficient production units. Following the same logic it is also preferable to use a SE method out of a political perspective. It is the best method to mediate how district cooling can replace energy sources with high environmental impacts and thereby contribute in reaching the European Union’s environmental targets.

District cooling is not a production plant. District cooling is a system and it is for that reason natural to choose an allocation method that considers the whole system. It is therefore natural that SE allocation is the most transparent method for comparing DC with local alternatives. Without this perspective it is a risk that the whole chain of environmental burdens will not be included.

7. CALCULATION METHODOLOGY

This section describes calculation methods for obtaining factor values for PEF, carbon dioxide and amount of renewable. The methodology will provide advisable equations for how to calculate factor values for both DH and DC systems.

7.1 NON-RENEWABLE PRIMARY ENERGY FACTORS

The power bonus method was decided to be used for calculating the primary energy factor values for DHC systems in the Ecoheat4cities project. The system border starts where the fuel is delivered at the production plant and ends at the customers' delivery points.

The chapters below describe how the calculation for DH is simplified for district cooling since there is no need for allocation between simultaneous heat and power production.

7.1.1 DISTRICT COOLING.

EN 15316-4—5 shows how to calculate the primary energy factor value for DH systems and is also valid for DC systems. Primary energy for all fuels in production is summed and fuel allocated for electricity production subtracted from the resulting volume. The result is the primary energy value for the overall DH or DC production. Dividing the primary energy value with amount of delivered heat or cooling results in the actual primary energy factor for the chosen period.

EN 15316-4-5 is also applicable to DC systems with the simplification that no allocation takes place which can be seen in Equation 1.

Equation 1: Non-renewable primary energy factor for delivered cooling

$$f_{P,dc,nren} = \frac{\sum_{i=1}^{n} E_{F(i)} * f_{P,F,nren(i)}}{\sum_{j=1}^{m} Q_{del,j}}$$

Where

$f_{P,dc,nren}$ =	non-renewable primary energy factor for delivered cooling delivered to the building from a DC grid and/or individual cooling system within a considered period in kWh/kWh.
$f_{P,F,nren(i)}$ =	non-renewable primary energy factor for the fuel *i, see appendix 1.*
$E_{F(i)}$ =	net energy content of fuel *i* delivered to the gate where it is finally converted to cooling.
$Q_{del,j}$ =	delivered cooling to the building, j, at system boundary 1 (see Annex B). For DC this is the same as measured cooling at system boundary 2 which is the primary side of the substation.

7.2 CARBON DIOXIDE EMISSION FACTORS

EN15316-4-5 was modified in the Ecoheat4cities project to handle CO_2 emissions with a modified version of the power bonus method for calculating the carbon dioxide emission factor.

7.2.1 DISTRICT HEATING AND COOLING

The carbon dioxide emission factor use the same concept as for deciding the primary energy factor with the exception of replacing non-renewable energy factors with carbon dioxide emission factors The resulting equation can be seen in Equation 2.

Equation 2: Carbon dioxide emissions factor for delivered heat

$$K_{dh} = \frac{\sum_{i=1}^{n} E_{F(i)} * K_{F,tot(i)} - \left(\sum_{i=1}^{n} \frac{E_{el,chp(i)} * K_{F,chp(i)}}{\eta_{el(i)}}\right)}{\sum_{j=1}^{n} Q_{del(j)}}$$

Where

K_{dh} =	carbon dioxide factor for delivered heat provided to the building, in kg CO_2 /MWh.
$K_{F,tot(i)}$ =	carbon dioxide factor for fuel *i*, in kg CO_2 /MWh_{fuel}.
$E_{F(i)}$ =	net energy content of fuel *i* delivered to the gate where it is finally converted to heat (using lower heating value).
$E_{el,chp(i)}$ =	*net*produced electricity in co-generation plant from fuel *i* (Produced electricity minus auxiliary electricity use). Only applicable for CHP. If more than one fuel is used in CHP mode the electricity produced from fuel *i* can be approximated the energy input fraction from fuel *i* to the CHP ($E_{F(i)}/E_{F,chp}$).
$K_{F,chp(i)}$ =	total greenhouse gas emission factor for electricity.
$Q_{del(j)}$ =	delivered heat to the building, j, at system boundary for DH

7.2.2 DISTRICT COOLING

Based on Equation 2 the carbon dioxide emission calculation can be simplified since the cooling production doesn't need to consider the electricity production in CHP plants. Allocation between heating and electricity is managed with Equation 2, Electricity is regarded as an input of fuel.

Equation 3: Carbon dioxide emissions factor for delivered cooling.

$$K_{dc} = \frac{\sum_{i=1}^{n} E_{F(i)} * K_{F,tot(i)}}{\sum_{j=1}^{n} Q_{del(j)}}$$

Where

K_{dc} =	carbon dioxide factor for delivered heat provided to the building, in kg CO_2 /MWh.
$K_{F,co2(i)}$ =	carbon dioxide factor for energy source *i*, in kg CO_2 /MWh_{fuel}.
$E_{F(i)}$ =	net energy content of energy source *i* delivered to the gate where it is finally converted.
$K_{F,chp(i)}$ =	Total CO_2 emission factor of energy source i.
$Q_{del(j)}$ =	delivered cooling to the building, j, at system boundary for DC

7.3 RENEWABLE AND RECYCLED ENERGY FRACTION

The renewable and recycled energy fraction is calculated multiplying all consumed fuels' energy content with their renewable and recycled energy fraction and dividing the sum with the total energy delivered to the gate where the fuels are finally converted to electricity and heat, see Equation 4.

Same calculation is valid for both district heating and district cooling.

Equation 4: Renewable and recycled energy fraction

$$R_{dh,dc} = 100 * \frac{\sum_{i=1}^{n} E_{F(i)} * R_{F(i)}}{E_F}$$

Where

$R_{dh,dc}$ =	share of renewable and recycled energy of the district heating or district cooling system, in %.
$R_{F(i)}$ =	renewable and recycled energy factor for energy source *i*.
$E_{F(i)}$ =	energy content of energy source *i* delivered to the gate where it is finally converted to heat or cooling (using lower heating value).
E_F =	energy content of all energy sources delivered to the gate where they are finally converted to heat or cooling (using lower heating value)

The cold water used for free cooling and also for cooling of chiller condensers must be considered as an energy source in the equation above.

7.3.1 DISTRICT COOLING

The main source of energy in the case of cooling is the ambient. The ambient is either air or water from a river, lake, sea, underground water or any other water source. There are many types of equipment available to make the ambient energy available as primary cooling (with a sufficient low temperature to be useful for cooling) in a building cooling system or a DC system.

The RES directive article 5 para 4 and its appendix VII (European Commission Directive 2009/28/EC, 2009) defines how RES should be handled, quote:

“Aerothermal, geothermal and hydrothermal heat energy captured by heat pumps shall be taken into account for the purposes of paragraph 1(b) (calculation of RES, authors comment) provided that the final energy output significantly exceeds the primary energy input required to drive the heat pumps.”

This definition of what is RES and what isn’t is a technicality in order to avoid heat pumps on the heating market that makes the calculation complex.

From a cooling perspective it’s not necessary to create technicalities in order to avoid heat pumps/chillers in the cooling system. Most cooling systems are built with chillers and the calculation of RES can therefore be made in a technically simplified and consistent way where the water or air is regarded as RES in all cases. The application of the calculation can therefore be made independent of the technology used to make the primary cooling available.

In the Ecoheat4cities report “Guidelines for technical assessment of district heating systems” (Lubinski & Weidlich, 2012), the section describing the renewable cooling are based on a RES from a heating perspective where energy from heat pumps are not regarded as RES which makes the calculations technology dependent. It’s stated that:

“R is the ratio of cooling from renewable and/or surplus heat carriers to total cooling in %. If electricity is used as fuel (e.g. for heat pumps or electric chillers) 20% of this electricity is regarded as renewable. ***Auxiliary electricity is not considered****. If heat is used as fuel (absorption chillers) R of this cooling output is the same as R of the heat.* ***Free cooling is renewable. The exhaust heat from the recooling circuits of chillers is not regarded as free cooling input to the cooling system****”*.

In the report it is further stated that:

“*R is not an energy performance indicator that reflects efficiency but an energy source indicator that shows the origin of the energy. Thus only this attribute Ri of the energy input to the system is considered, not the amount . Auxiliary electricity influences neither the energy source as an attribute nor the composition of the total produced cooling. Therefore auxiliary electricity is not considered*”.

This second statement is a misinterpretation of Equation 4, defined above, for Renewable fraction. The Renewable fraction should be related to the input of energy and not to the produced or delivered cooling as defined in the Ecoheat4cities reports.

All energy input must be considered which also includes auxiliary electricity, It should not matter what the electricity is used for as long as it’s used for the purpose of producing cooling.

Both statements lead to a technology dependent calculation, i.e. the production method must be known in order be able to perform the calculation. This is visualised with the following two examples:

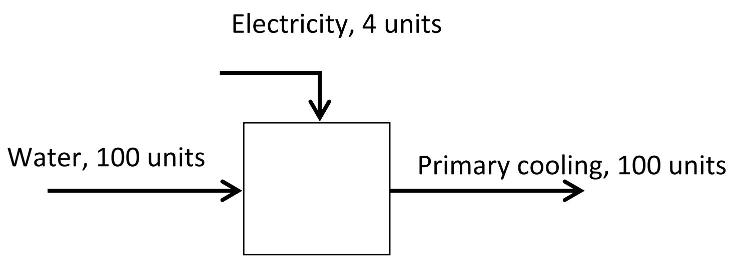
1. Free cooling

2. Electrical chillers:

Basic input: Renewable factor for electricity as stated above to 0.2.

In the figures below the arrows signifies energy flow, and the text above the arrow is: energy source, energy units.

1. Free cooling - example

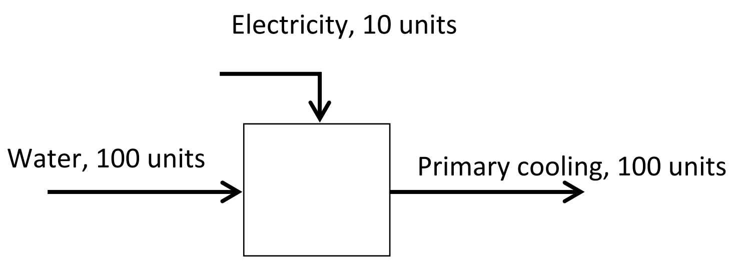


The Renewable factor for this system according to the report would be

R = 100 * 1 / 100 = 1.

The water is renewable and the auxiliary electricity is excluded according to the report.

2. Electrical chiller - example



The Renewable factor for this system according to the report would be

R = 20 * 0,2 / 20 = 0,2.

The water is not renewable according to (Lubinski & Weidlich, 2012) because it is an electrical chiller and the electricity is included.

If the chiller would be extremely efficient with a system COP of 10, which would be possible at low water temperatures, 10 units of electricity would be required. Compare that with a deep sea water system pumping water for a very long distance (kilometres) and that has a system COP of 10, would require 10 units of electricity. The chiller system have R = 0,2 and the deep sea water system 1 according to the technical guideline.

These two examples clearly show that the application in the technical guideline is not technology independent. It should not matter what is inside the box. Both the electricity and the water is a “fuel” and the energy content of both must be considered as a fuel for all cooling applications in Equation 4 (free cooling, electrical chiller, absorption chiller, heat pump, etc.).

If the water as energy source in example 2 above would be changed to air (dry air cooling or air via a cooling tower) should make no difference. The technology used may not influence the calculation.

If RES is calculated from a cooling perspective and Equation 4 is applied for the two examples above the Renewable factor would be technically independent:

Example 1 – free cooling.
R= (100 * 1 + 4* 0,2) / (100 + 4) = 0,97.

Example 2 – electrical chiller, water cooled COP 5.
R= (100 * 1 + 20* 0,2) / (100 + 20) = 0,87.

Example 3 – electrical chiller, air cooled COP 5.
R= (100 * 1 + 20* 0,2) / (100 + 20) = 0,87. (in reality an air cooled chiller would have a lower COP and thus a lower R.

Example 4 – electrical chiller, air cooled COP 2,5.
R= (100 * 1 + 40* 0,2) / (100 + 40) = 0,77.

Calculating the RES technology independent as proposed above will give district cooling an advantage over local cooling solution that can't cool with water. High efficient water cooled chillers and local air cooled solution will be equal if all energy coming from a heat pump/chiller is regarded as non-renewable.

8. SPECIAL ALLOCATION PRINCIPLES

This chapter describes special allocation principles for simultaneous production of heating and cooling.

DC systems are not limited to one technical solution. They are instead adapted to what the local environment has to offer. This flexibility of production has led to a wide variety of DC system solutions. Many of them are however only feasible for very specific circumstances. The scope of this report will be limited to the more generally used solutions free cooling (natural cooling), absorption chillers, electrical chillers and heat pumps.

Free cooling, absorption chillers and electrical chillers are all common production units in a DC plant. It is also easy to calculate their environmental impact based on existing methods and should therefore be included in an environmental impact analysis for district cooling systems.

A heat pump is not as commonly used and its environmental impact is more dynamic and complex than the other mentioned DC methods since it produces both heating and cooling. An allocation method for heat pumps would need to be constructed.

If only cooling is produced, cooling will be allocated 100% of the resources and emissions. But in some applications as heat pumps and in tri-generation, simultaneous production of power, heating and cooling, both heating and cooling will be produced simultaneously and that requires an allocation method.

This chapter will describe how the resources and emissions are allocated depending on the application of heat pumps and tri-generation.

8.1 HEAT PUMP

An electrical chiller is a type of heat pump where only the cold side is utilised and 100% of all resource usage, emissions etc. is allocated to the cooling. Electricity is required to run a compressor in order to be able to cool the water to the desired temperature and to be able to cool the rejected heat to the ambient (air or water).

A heat pump that only utilise the warm side will allocate 100% of all resource usage, emissions etc. to the heating.

With a heat pump that is used for production of both heating and cooling simultaneously, it's necessary to be able to allocate the input fuel and emissions to respectively production in order for the products to share the environmental burden. The difficulty that arises is how the fuel shall be allocated to heating, respectively cooling. Heating will probably be the main product during winter time when the outdoor temperature is low whereas cooling demand increases during the summer. The allocation factor should therefore be dynamic over the year and specific to each individual system.

A heat pump takes water from a low temperature level and lifts it to a useful temperature level with a compressor. The useful temperature level depends on what type of application it is used in. Depending on the temperature used in the local DH system, the temperature must be lifted from 45-50 °C (low temperature networks) up to 90°C. The required compressor work depends on the temperature lift. The higher lift the more compressor work is required and thus lower efficiency.

When both the cold and warm side is utilised simultaneously an allocation of the environmental load on the both products, heating and cooling is necessary.

If only the warm side is utilised, heating will carry the whole fuel allocation and vice versa if only cooling is utilised.

ENERGY METHOD

The most direct allocation method is the energy method where the input of resources is allocated on each product proportional to the quantity of produced heating and cooling from the same production unit. The heating and cooling is valued equally.

$$\alpha_h = \frac{Q_h}{Q_h + Q_c} = \frac{1 + \frac{1}{EER_{c,h+c}}}{2 + \frac{1}{EER_{c,h+c}}}$$

$$\alpha_c = \frac{Q_c}{Q_h + Q_c} = \frac{1}{2 + \frac{1}{EER_{c,h+c}}}$$

or,

$$\alpha_c = 1 - \alpha_h$$

$\alpha_h = 1 - \alpha_c$

where,

α_h	= Allocation factor for heating
α_c	= Allocation factor for cooling
Q_h	= Produced heating in kWh/year
Q_c	= Produced cooling in kWh/year
$EER_{c,h+c}$	= Energy Efficiency Ratio cooling at simultaneous heating and cooling production
EER_c	= Useful energy on the cooling side divided with electrical input, calculated on yearly basis
EERh	= Useful energy on the heating side divided with electrical input, calculated on yearly basis

The EER's are calculated on the cooling side. Actual EER for the specific application should be used. If the EER data is not available the following EER should be used:

$EER_{c,C}$ = 5

$EER_{c,H+C}$ = 2

Calculation example

$$\alpha_h = \frac{Q_h}{Q_h + Q_c} = \frac{1 + \frac{1}{EER_{c,h+c}}}{2 + \frac{1}{EER_{c,h+c}}} = \frac{1 + \frac{1}{2}}{2 + \frac{1}{2}} = 0{,}6$$

ALTERNATIVE PRODUCTION METHOD

This method considers the impact each produced product would have on the environment had they been produced separately (i.e. the alternative). A separate production requires more fuel to produce the same amount of energy. Heating and cooling produced in a heat pump will share the benefits of these environmental savings.

$$\alpha_h = \frac{\frac{EER_{h,H+C}}{EER_{h,H}}}{\frac{EER_{h,H+C}}{EER_{h,H}} + \frac{EER_{c,H+C}}{EER_{c,C}}}$$

where,

α_h	= Allocation factor for heating
$EER_{h,H+C}$	= Energy Efficiency Ratio heating in combined heating and cooling mode

$EER_{h,H}$	= Energy Efficiency Ratio heating in heating mode
$EER_{c,H+C}$	= Energy Efficiency Ratio cooling in combined heating and cooling mode
$EER_{c,C}$	= Energy Efficiency Ratio cooling in chiller mode

The standard choice of alternative heating production has in this case been defined as a heat pump which only produces heating. The $EER_{h,H+C}$ and $EER_{h,H}$ are then the same since the EER depends mainly on the higher temperature level which is the same in both combined mode and heating mode, thus the formula is reduced to:

$$\alpha_h = \frac{1}{1 + \frac{EER_{c,H+C}}{EER_{c,C}}}$$

$$\alpha_c = 1 - \alpha_h$$

where,

α_h	= Allocation factor for heating
α_c	= Allocation factor for cooling
$EER_{c,C}$	= Energy Efficiency Ratio cooling for production of cooling in chiller mode
$EER_{c,H+C}$	= Energy Efficiency Ratio cooling for production of cooling in combined heating and cooling mode

The EER's are calculated on the cooling side. Actual EER for the specific application should be used. If the EER data is not available the following EER should be used:

$EER_{c,C}$	= 5
$EER_{c,H+C}$	= 2

Calculation example

$$\alpha_h = \frac{1}{1 + \frac{EER_{c,H+C}}{EER_{c,C}}} = \frac{1}{1 + \frac{2}{5}} = 0{,}71$$

ENERGY+ADDITIONAL METHOD

If the energy from both sides of a heat pump (low temperature condensing) is utilised and allocated according to the Energy method, the cooling and heating are given the same exergy value.

The low temperature water on the warm side is normally not useful and must be lifted to a higher temperature level. The higher the temperature the more electrical power input is required.

In this method, this additional electricity required to lift the warm side to a useful temperature is allocated to 100% to the heating.

The Energy+additional method share the environmental load evenly between heating and cooling for the chiller operating conditions but the heating will be allocated all additional electricity required to make the heat useful.

$$\alpha_h = \frac{EER_{c,H+C}}{EER_{c,C}} \times \left(\frac{1 + \frac{1}{EER_{c,C}}}{2 + \frac{1}{EER_{c,C}}} + \frac{EER_{c,C}}{EER_{c,H+C}} - 1 \right)$$

$\alpha_c = 1 - \alpha_h$ where,

α_h	= Allocation factor for heating
α_c	= Allocation factor for cooling
$EER_{c,C}$	= Energy Efficiency Ratio cooling for production of cooling in chiller mode
$EER_{c,H+C}$	= Energy Efficiency Ratio cooling for production of cooling in combined heating and cooling mode

All EER's are calculated on the cooling side. Actual EER for the specific application should be used. If the EER data is not available the following EER should be used:

$EER_{c,C}$ = 5

$EER_{c,H+C}$ = 2

Calculation example

$$\alpha_h = \frac{EER_{c,H+C}}{EER_{c,C}} \times \left(\frac{1 + \frac{1}{EER_{c,C}}}{2 + \frac{1}{EER_{c,C}}} + \frac{EER_{c,C}}{EER_{c,H+C}} - 1 \right) = \frac{2}{5} \times \left(\frac{1 + \frac{1}{5}}{2 + \frac{1}{5}} + \frac{5}{2} - 1 \right) = 0{,}81$$

8.2 TRI-GENERATION

Tri-generation is the simultaneous production of electricity, heating and cooling. The electricity is mainly produced with a gas turbine or a gas engine. The exhaust heat is recovered in a boiler that produces heat (some of the heat can be used for production of additional electricity in a steam turbine). The production of electricity, heat and cooling shall be produced within a production plant where the production equipment is directly connected.

The main products are electricity and heat and the environmental allocation between the electricity and heat is made according to the method described in the Ecoheat4cities report.

In the case of tri-generation, the heat is used for district heating and/or to produce cooling in an absorption chiller. Both DH and the absorption chiller require prime temperature water so the exergy energy should be valued the same.

The allocation between heating and cooling should be made proportionally to the quantity of heat required to produce the district heating and cooling.

9. LABELLING CRITERIA FOR DC

The purpose of using labelling criteria is to be able to evaluate different cooling solutions and to compare these solutions with each other. In the Ecoheat4cities report "Guidelines for technical assessment of district heating systems" (Lubinski & Weidlich, 2012), chapter "Definition of the reference district cooling system" a proposal of a labelling system is presented in a table defining the different class levels for labelling of a cooling system is presented, see Table 1 below. The labelling system is created for the purpose to make a comparison between different cooling systems energy indicators.

Labelling classes from the report

Class	PEF $f_{P,dc}$ [-]		CO_2 $K_{P,dc}$ [kg/MWh]		RES R_{dc} [-]	
1		≤ 0,37		≤ 60		≤ 60%
2	> 0,37	≤ 0,74	> 60	≤ 120	> 60%	≤ 20%
3	> 0,74	≤ 1,11	> 120	≤ 180	> 20%	≤ 16%
4	> 1,11	≤ 1,49	> 180	≤ 240	> 16%	≤ 12%
5	> 1,49	≤ 1,86	> 240	≤ 300	> 12%	≤ 8%
6	> 1,86	≤ 2,23	> 300	≤ 360	> 8%	≤ 4%
7	> 2,23		> 360		> 4%	

Table 1.Old proposal of labelling classes.

The class limit between class 2 and 3 is determined by a cooling plant with COP 3,5. With this class limit definition, most of the older local building bound air cooled chillers (as rooftops) would end up in class 3. Some modern local building installations could reach up to level 2. Most known district cooling systems in for instance Sweden would be a class 1 plant, class 1 being the best.

If the purpose of the labelling is to distinguish between cooling systems the class limits must be changed so that there are more classes for district cooling systems. Below is one example of how different cooling systems could be distinguished.

New proposed labelling classes from a cooling perspective

Class	PEF $f_{P,dc}$ [-]		CO_2 $K_{P,dc}$ [kg/MWh]		RES R_{dc} [-]	
1		≤ 0,17		≤ 28		≥ 95%
2	>0,17	≤ 0,25	>28	≤ 40	<95%	≥ 93%
3	>0,25	≤ 0,35	>40	≤ 57	<93%	≥ 91%
4	>0,35	≤ 0,55	>57	≤ 89	<91%	≥ 86%
5	>0,55	≤ 0,80	>89	≤ 129	<86%	≥ 81%
6	>0,80	≤ 1,30	>129	≤ 210	<81%	≥ 73%
7	>1,30		>210		<73%	

Table 2.New proposal of labelling classes.

Class 1: World class, only reachable for deep sea water cooling plants. Lower limit COP_{el} 15.

Class 2: High efficient DC plants with large amount of free cooling. Lower limit COP_{el} 10,4.

Class 3: DC plants with some free cooling. Lower limit COP_{el} 7,4.

Class 4: DC plants with cooling tower in warmer countries. Lower limit COP_{el} 4,7.

Class 5: Efficient local air cooled building solutions. Lower limit COP_{el} 3,2.

Class 6: Most older local air cooled building solutions. Lower limit COP_{el} 2,0.

Class 7: Poor performing local air cooled building solutions.

10. LABELLING CRITERIA FOR DIFFERENT DC TECHNOLOGIES

10.1 GENERAL INPUT

The calculation for different DC technologies will be made for the defined labelling criteria

- Resource effectiveness: Primary Energy
- Climate impact: Carbon dioxide emissions.
- Recycling: Renewable and recycled energy

The calculation will consider the entire system during a whole season of operation, including all equipment required to run a cooling production plant as:

- Chilled water distribution pumps
- Cooling water pumps
- Circulation pumps
- Other auxiliary equipment

- Coolers, cooling towers (when applicable)
- Electrical equipment and losses
- Etc.

Primary energy, CO_2 and renewable and recycled energy factors for electricity and fuels will use the factor values according to Ecoheat4cities, see chapter 0.

Primary Energy is calculated according to chapter 0.

Carbon dioxide emissions are calculated according to 0.

Renewable Energy Source is calculated according 0.

10.2 CONDITIONS FOR THE CALCULATION

FREE COOLING

Free cooling can only be applied when the natural water source is a few degrees lower than the desired DC supply temperature.

The SSEER (System Seasonal Energy Efficiency Ratio) is normally between 20 and 35, depending on pumping distances etc. Here it is assumed to be 30 on a yearly average.

ELECTRICAL COMPRESSOR CHILLER

Chillers can be used in many different configurations and in many different ambient conditions. A water cooled chiller can be installed in northern Scandinavia where the water is relatively cold during the whole year (below 20 °C in summer) or in southern Europe where water temperatures can be 30 °C. The same is valid for cooling towers and air coolers.

The calculation has been performed for conditions in northern Europe.

ABSORPTION CHILLER

Labelling criteria is only calculated for water cooled application since cooling tower and air coolers are normally not economic viable solutions in district cooling production plants. Due to the low COP of an absorption chiller, around 0,7, the energy input is relatively high and thus also the rejected heat to the ambient (typically twice as high as for electrical chiller) which makes the electricity demand for cooling pumps and cooling towers relatively high. Cooling towers also use a lot of water.

The absorption calculation is made for a single stage chiller that use district heating water. The DH water is produced for a DH system and delivered to the cooling production plant.

The criteria are calculated for DH produced with different DH production technologies and fuel sources.

HEAT PUMP

The allocation of labelling criteria is made according to the Energy+additional method described in chapter 0.

10.3 RESULTS

Technology	Application	Fuel	PEF $f_{P,dc}$ [-]	CO_2 $K_{P,dc}$ [kg/MWh]	RES R_{dc} [-]
Free cooling	Deep sea water	Electricity	0,09	14	0,97
Chiller	Water cooled	Electricity	0,37	60	0,90
Chiller	Cooling tower	Electricity	0,43	70	0,88
Chiller	Air cooled	Electricity	0,87	140	0,80
Chiller	Old air cooled	Electricity	1,04	168	0,77
ABS	Water cooled	Waste heat	0,16	26	0,98
ABS	Water cooled	CHP Waste incineration	0,16	26	0,97
ABS	Water cooled	Bio	0,62	63	0,97
ABS	Water cooled	Gas CHP	1,16	191	0,41
ABS	Water cooled	Gas boiler	2,70	439	0,41
Heat pump	Water cooled	Electricity	0,24	39	0,73

Table 3. Labelling criteria for different cooling technologies.

10.4 COMMENTS

The use of cooling towers in cooling processes is very common all over Europe. A cooling tower consumes large amount of water that is evaporated to the air and also bled to the sewage system for water quality control purposes.

The electricity to run the cooling towers has to be included in the total auxiliary electricity demand and will therefor influence the evaluated resource, emission and renewable factors.

The water usage, on the other hand, is not included in any of the calculations since it’s not regarded as a fuel.

Water is a resource that is required for a cooling tower process to function. All required resources should be included in the calculation, not only electricity and fuels.

If water were to be regarded as a resource, which it is since it requires energy to extract, transport and transform it to drinking water, it could be accounted for in the formulas for primary resource, CO_2-emission and renewable factors elaborated by Ecoheat4cities. The factor values for different type of waters could be calculated and implemented. There can be a large difference in factor values on local level depending on how the water is produced. Consider the difference between desalinated sea water and fresh water pumped from a reservoir.

11. CASE STUDY

This chapter includes a case study for illustrating the labelling criteria for a utility company having both DH and DC systems. Note that every DH and DC system will be based on the local conditions. All systems must be analysed based on their local fuel mix.

The estimated annual cooling demand of the DC system is 120 GWh/year and a monthly DC production variation according to Figure 2.

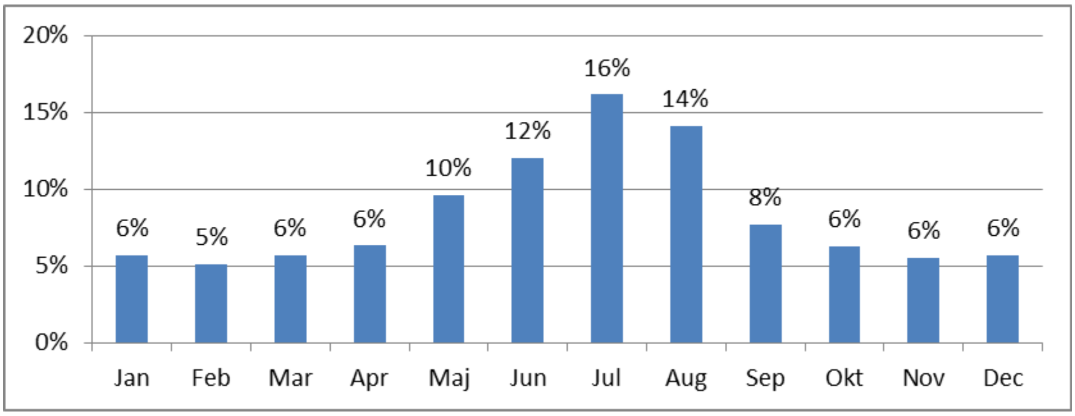


Figure 2: Monthly distribution of the DC production

The production mix is based on natural cooling, absorption chillers and electrical chillers. The river which is planned to be used as the source for the DC system's natural cooling is only cold enough from October to April to provide 100% of the cooling needs. Figure 3 shows the city's heating demand variation over the year. The low heat demand during the summer and availability of waste heat sources leads to low heat production price level. The waste heat can then during the summer period be utilized for DC production in absorption chillers. The DC system will use electrical chillers during the remainder of the year. In practice the DC operator will always use the production unit with the lowest marginal cost first.

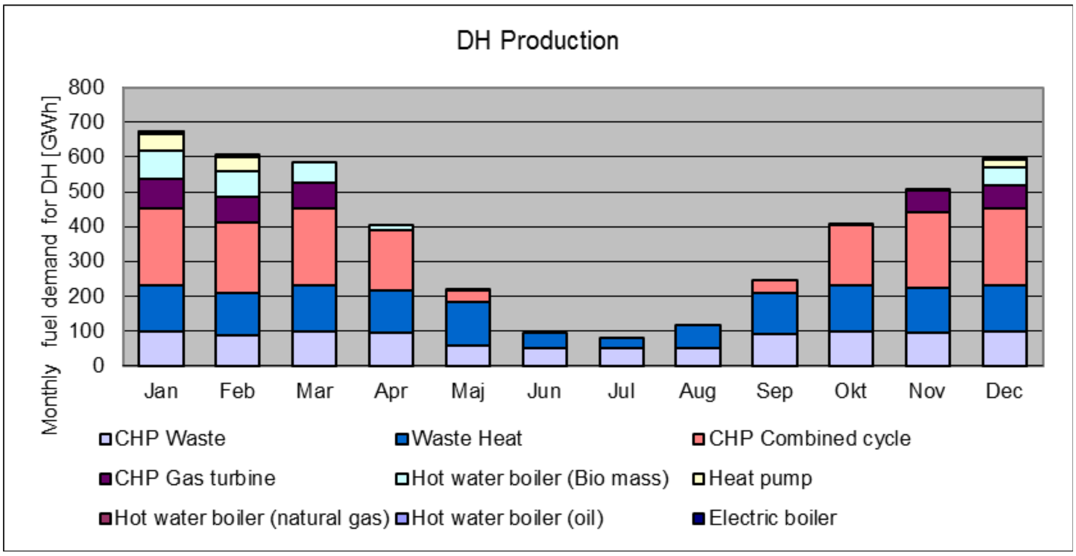
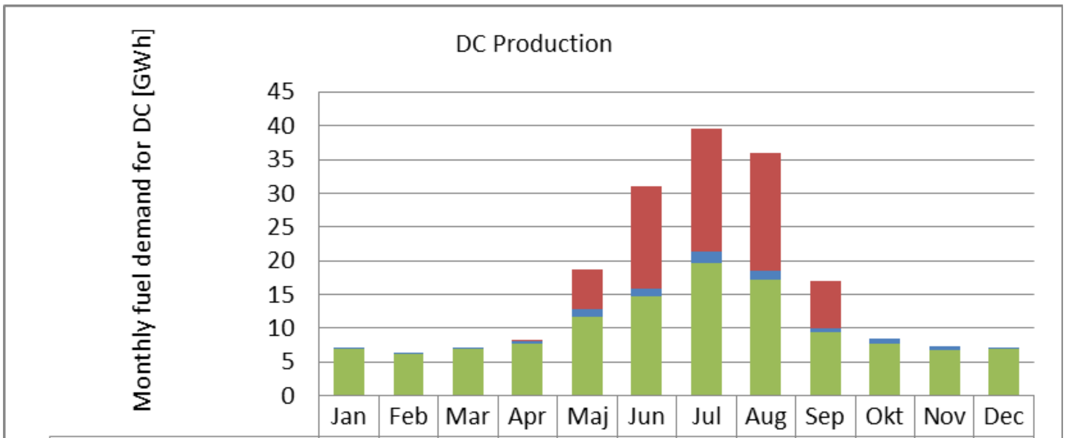


Figure 3: Example of DH production and fuel sources.

Based on known conditions the energy source for the DC system is estimated as shown in Figure 4.



	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Heat from DH system	0,0	0,0	0,0	0,2	6,0	15,2	18,2	17,5	7,0	0,0	0,0	0,0
Electricity	0,2	0,2	0,2	0,4	1,0	1,1	1,7	1,4	0,7	0,7	0,5	0,2
Natural cooling	6,9	6,2	6,9	7,7	11,7	14,6	19,6	17,2	9,4	7,7	6,7	6,9

Figure 4: DC fuel demand

The DC network have a predicted efficiency of 0,96 because the temperature difference between ground and DC water is much smaller than for a DH grid.

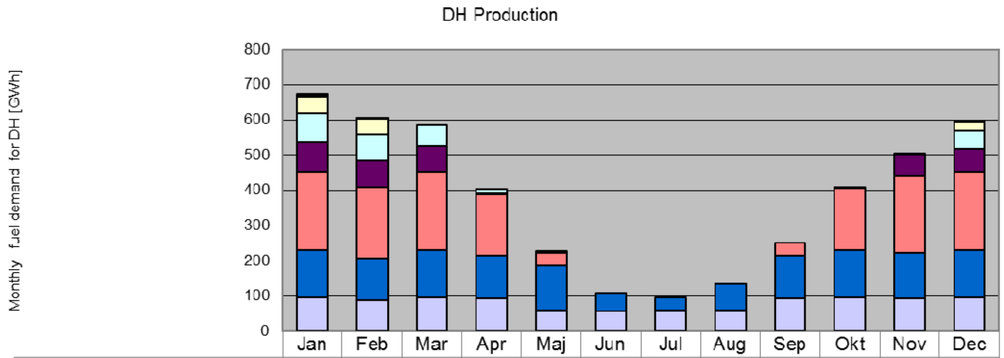
11.1 CALCULATING ENVIRONMENTAL FACTOR VALUES

With the information provided for this case study it is now possible to calculate PEF-, carbon dioxide emissions- and renewable factors for the DH and DC systems.

From a cooling perspective it's very important to use factor values for District Heating if the cooling production includes absorption cooling. The economic viability of absorption technology relies on waste energy availability. In cold climate there is normally not waste heat available during the winter period. Yearly average values for evaluation of absorption's environmental performance will be unfair and it's therefore monthly values are preferred, see appendix 3 for further details.

11.1.1 DISTRICT HEATING

The first step is to update the production profile so that district cooling is included as a new customer. The production profile then looks like Figure 5.



	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Electric boiler	1	-	-	-	-	-	-	-	-	-	-	-
Hot water boiler (oil)	1	1	-	-	-	-	-	-	-	-	-	1
Hot water boiler (natural gas)	2	2	-	-	-	-	-	-	-	-	-	2
Heat pump	48	44	-	-	-	-	-	-	-	-	-	22
Hot water boiler (Bio mass)	82	74	60	13	-	-	-	-	-	-	1	52
CHP Gas turbine	82	74	71	1	4	-	-	-	-	4	63	63
CHP Combined cycle	223	202	223	173	37	-	-	-	36	175	216	223
Waste Heat	134	121	134	122	126	50	37	74	122	134	130	134
CHP Waste	97	87	97	94	60	58	60	60	94	97	94	97

Figure 5: DH production profile with supply to absorption chillers for DC.

Using equations and fuel factor values defined in this report will then provide the environmental factors for the DH system shown in Figure 5.

Environmental factors, DH	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PEF	-	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CO_2	kg/MWh	94	116	116	95	79	49	22	21	23	42	80	100	106
% Renew able		47%	41%	41%	38%	45%	72%	98%	98%	98%	78%	44%	34%	39%

Table 4: Environmental factors for the DH system, where European marginal electricity factors are used.

It is noteworthy that the PEF throughout the year is zero. The reason for this is that the production benefits from its CHP electricity production which is much more sustainable appreciated than the marginal electricity production used for the electrical chillers. The carbon dioxide factor is high and amount of renewable low during winter, spring and autumn. The DC will however only purchase heat from May to September, a period when DH has a relatively limited effect on the environment.

11.1.2 DISTRICT COOLING

Using annual factors for DH will instead result in the environmental factors shown in Table 5. The CO_2 factor is now higher and amount of renewables lower. This example does not take into consideration whether heat is used during summer when DH has a low environmental impact or the winter when the impact is high.

Environmental factors, DC	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PEF	-	0,29	0,12	0,12	0,12	0,20	0,36	0,32	0,37	0,34	0,31	0,39	0,34	0,13
CO_2	kg/MWh	141	40	40	40	70	168	208	215	211	175	129	112	43
% Renewable		78%	97%	97%	97%	94%	78%	70%	71%	70%	74%	92%	93%	97%

Table 5: Environmental factors for the DC system, using annual DH values

Using monthly values for heat will result in the environmental factors shown in Table 6.The amount of renewables is high since most part of the energy sources consists of natural cooling from the river which is 100% renewable. PEF and CO_2 are higher when the ambient temperature increases and the chillers come into production. The reason why the DC system has an environmental impact when only natural cooling is in production is that electricity is needed to circulate the water in the DC grid.

Environmental factors, DC	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PEF	-	0,29	0,12	0,12	0,12	0,20	0,36	0,32	0,37	0,34	0,31	0,39	0,34	0,13
CO_2	kg/MWh	106	40	40	40	69	144	129	144	136	134	129	112	43
% Renewable		93%	97%	97%	97%	94%	86%	95%	95%	95%	87%	92%	93%	97%

Table 6: Environmental factors for the DC system, using monthly DH values

12. DISCUSSION

12.1 LABELLING CRITERIA

The recommendation is to follow Ecoheat4cities' (2011) standards and use primary energy, carbon dioxide emissions and renewable and recycled energy fraction as indicators of district cooling's impact on the environment.

The three labels weight different aspects of a produced product's environmental burden. It is important to understand this difference and how it affects district cooling. A major advantage with a DHC system is that the system can use energy sources that otherwise would go to waste. The waste that is left after recycling can be used as fuel in special boilers of electricity and heat. Industrial waste heat can be distributed to a DH plant where additional heat through boilers is added.

Both examples have a very low primary energy factor but instead suffer from carbon dioxide emissions due to the combustion process. The examples also have high renewable factors since they use fuel that has a short recuperate time in comparison to fossil and nuclear fuel. For this reason it is important not to only focus on one of the three factors but instead focus on the overall impact.

The non-renewable primary energy factor already considers if a fuel is renewable or not and it's therefor not necessary to use the RES in the labelling criteria.

The goal for EU to increase the renewable energy fraction to 20% would be easy to reach by installing heat pumps if the RES would consider the actual renewable energy that is the main energy source for heat pumps.

Since heat pumps reduce the available heat sinks in a district heating system production of electrical power in CHP plants will be reduced and the lost power must be replaced with condensing alternatives that are less efficient. It can be argued that it can also be replaced with wind power or other renewable sources, but on the margin it is coal condensing that is the alternative in Europe.

Due to this fact it's not recommendable to install heat pumps where district heating can be a potential heat sink for a CHP plant. EU has recognised this and in the Renewable Energy Source directive 2009/28/EC Article 5 §4 and in Annex VII the possibility to account for the renewable energy from heat pumps has been reduced by implementing technical limits for when heat pumps can be considered as a RES.

The primary energy takes into account both energy savings and the increase in renewable sources. Using RES only complicates the calculations and make them technology dependent and more inconsistent.

From a cooling perspective it's not necessary to find technicalities in order to avoid heat pumps/chillers in the cooling system. Most cooling systems are built with chillers and the calculation of RES can therefore be made in a technically simplified and consistent way where the water or air is regarded as RES in all cases.

13. CONCLUSION

13.1 RES

RES is already considered in the non-renewable primary energy factors and is not required as separate criteria.

If RES has to be a criteria, it is from a cooling perspective recommended to consider all renewable sources equally independent of the technology used to produce the cooling. This will give an advantage for District Cooling compared with local cooling solution that cannot use water for free cooling or condenser cooling.

13.2 FACTOR VALUES

The recommendation of this report from Rescue is to use the Ecoheat4cities' (2011) list of factor values for fuels also for DC when national or local specific values are not available. They can be viewed in 15.1 Appendix 1 – Factor Values: Ecoheat4cities default values.

Electricity should be viewed from a European marginal production perspective. Political incentives contributes in erasing existing bottlenecks in the distribution system between national borders which consequentially leads new production plants mainly impacts the European marginal.

13.2.1 WHEN DH IS AN ENERGY SOURCE FOR DC

DH is, just like DC, locally produced and its factor values are therefore extremely geographical specific. It is therefore advisable to use case-specific values for DH when heat is used for absorption chillers in the cooling production.

It is also recommended to use monthly- instead of annual values. The same company in a city usually delivers both DH and DC. In these cases it should be plausible to provide monthly heating factor values as input for DC.

14. BIBLIOGRAPHY

Boverket. (2012, 08 23). *Vad är Atemp för något?* Retrieved 02 04, 2013, from Boverket: http://www.boverket.se/Kontakta-oss/Fragor-och-svar/Boverkets-byggregler-BBR/Om-avsnitt-9-i-BBR/Atemp/Vad-ar-Atemp-for-nagot/

Building Area Measurement LLC. (2009, 01 25). *Glossary of square footage terms*. Retrieved 02 04, 2013, from Building Area Measurement LLC: http://www.buildingareameasurement.com/glossary.htm

Commission Decision 92/42/EEC. (2007). Establishing harmonised efficiency reference values for separate production of electricity and heat in applicaiton of Directive 2004/8/EC of the European Parliament and of the Council. *Official Journal of the European Union*, 183-188.

Dalin, P., Nillson, J., & Rubenhag, A. (2006). *EcoHeatCool, Workpackage 5, Possibilities with district cooling in Europe.* Brussels: EuroHeat & Power.

Dalin, P., Nilsson, J., & Rubenhag, A. (2006). *EcoHeatCool, Workpackage 2, The european cold market.* Brussels: Euroheat & Power.

European Commission Directive 2009/28/EC. (2009). *Directive 2009/28/EC of the European Parliament and the Council.* Brussels: European Commission.

Gode, J., Byman, K., Persson, A., & Trygg, L. (2009). *Miljövärdering av el ur systemperspektiv.* IVL.

IVL. (2011). Ecoheat4Cities Work Package 2 Green Labelling Criteria. *EcoHeat4Cities*.

Lubinski, B., & Weidlich, I. (2012). *Guidelines for technical assessment of district heating systems.* Intelligent Energy Europe.

Martinsson, F., Gode, J., & Ekvall, T. (2012). *Kraftvärmeallokeringar.* Stockholm: Svensk Fjärrvärme, Fjärrsyn.

PSR 1998:1. (2000). *Produkspecifika regler för certifierade miljövarudeklarationer för el- och fjärrvärmeproduktion.* EPD.

Sköldberg, H., Unger, T., & Olofsson, M. (2006). *Marginalel och miljövärdering av el.* Elforsk.

Sweden Green Building Council. (2012). Treatment of Scandinavian District Energy Systems in LEED. *Energy Models for LEED EA credit 1*.

Värmemarknadskommittén. (2012). *Överenskommelse i Värmemarknadskommittén om synen på bokförda miljövärden för fastigheter uppvärmda med fjärrvärme.* Värmemarknadskommittén.

15. APPENDICES

15.1 APPENDIX 1 – FACTOR VALUES: ECOHEAT4CITIES DEFAULT VALUES

15.1.1 EU DEFAULT VALUES FOR FUELS – $F_{P,F,NREN}$, K_{DH}, R_{DH}

Fuel/Energy Carrier	Primary Factor Values		*Carbon Dioxide Emission Values*		*Amount of renewables*	
	fP,F,nren	Source	$K_{F(i)}$ *(kg CO_2 MWh)*	Source	*RF(i)*	
Lignite	1.02	ELCD DATBASE 2.0	369	ELCD DATBASE 2.0/IPCC 2006	0	
Hard Coal	1.19	CEN 15603:2008	369	IVL 2010/IPCC 2006	0	
Heavy fuel oil	1.35	CEN 15603:2008	296	IVL 2010/IPCC 2006	0	
Light fuel oil	1.35	CEN 15603:2008	283	IVL 2010/IPCC 2006	0	
Natural Gas	1.36	CEN 15603:2008	222	IVL 2010/IPCC 2006	0	
Peat	1.02	IVL 2010	417	IVL 2010/Swedish NIR	0	
Bioenergy (primary)	0.1	CEN 15603:2008	7	IVL 2010	1	
Bioenergy (refined)7	0.2	AGFW FW 309	12	IVL 2010	1	
Bioenergy (secondary)	0.06	CEN 15603:2008	3	IVL 2010	1	
Residual fuel8	0.05	IVL 2010	88	IVL 20108	1	
Waste as fuel	0	PCR	94	IVL 2010/IPCC 2006	1	
Electricity (input and output)	2.6	Calculation based on Eurostat statistics9	420	Calculation based on Eurostat statistics9	0,19	
Industrial waste heat	0	By definition (see chapter 8.3)	0	By definition (see section 8.3)	1	
Geothermal heat10	0	AGFW FW 309	0	AGFW FW 309	1	
Solar heat	0	Does not include the plant construction etc.	0	Does not include the plant construction etc.	1	

Fuel	Renewable energy factor	Recycled energy factor	*RF(i)*
Lignite	0	0	0
Hard Coal	0	0	0
Heavy fuel oil	0	0	0
Light fuel oil	0	0	0
Natural Gas	0	0	0
Peat	0	0	0
Bioenergy (primary)	1	0	1
Bioenergy (refined)	1	0-1	1
Bioenergy (secondary)	1	1	1
Residual fuel	0-1	1	1
Waste as fuel	0.5	1	1
Electricity (consumed)	0.17	0.02	0.19
Industrial surplus heat	0-1	1	1
Geothermal heat	1	0	1
Solar heat	1	0	1

15.2 APPENDIX 2 - ALLOCATION METHODS

This section describes various methods used for allocating heat and power in combined heat and power (CHP) production plants. There are in general two allocating principals: real allocation (RA) and system extension (SE). The difference between them is their distinction of where their system borders are drawn.

Figure 6 shows the life cycle of energy, from when the fuel is extracted until the net energy finally is transformed. Losses will occur throughout the refining chain and the primary energy factor is an indication of how efficient a specific refinement process is. RA methods' borders are drawn by the power & heat production plant's border (between system boundaries 3 and 2), whereas SA methods consider the whole chain from extraction to the end customer's door (between system border 5 and 1).

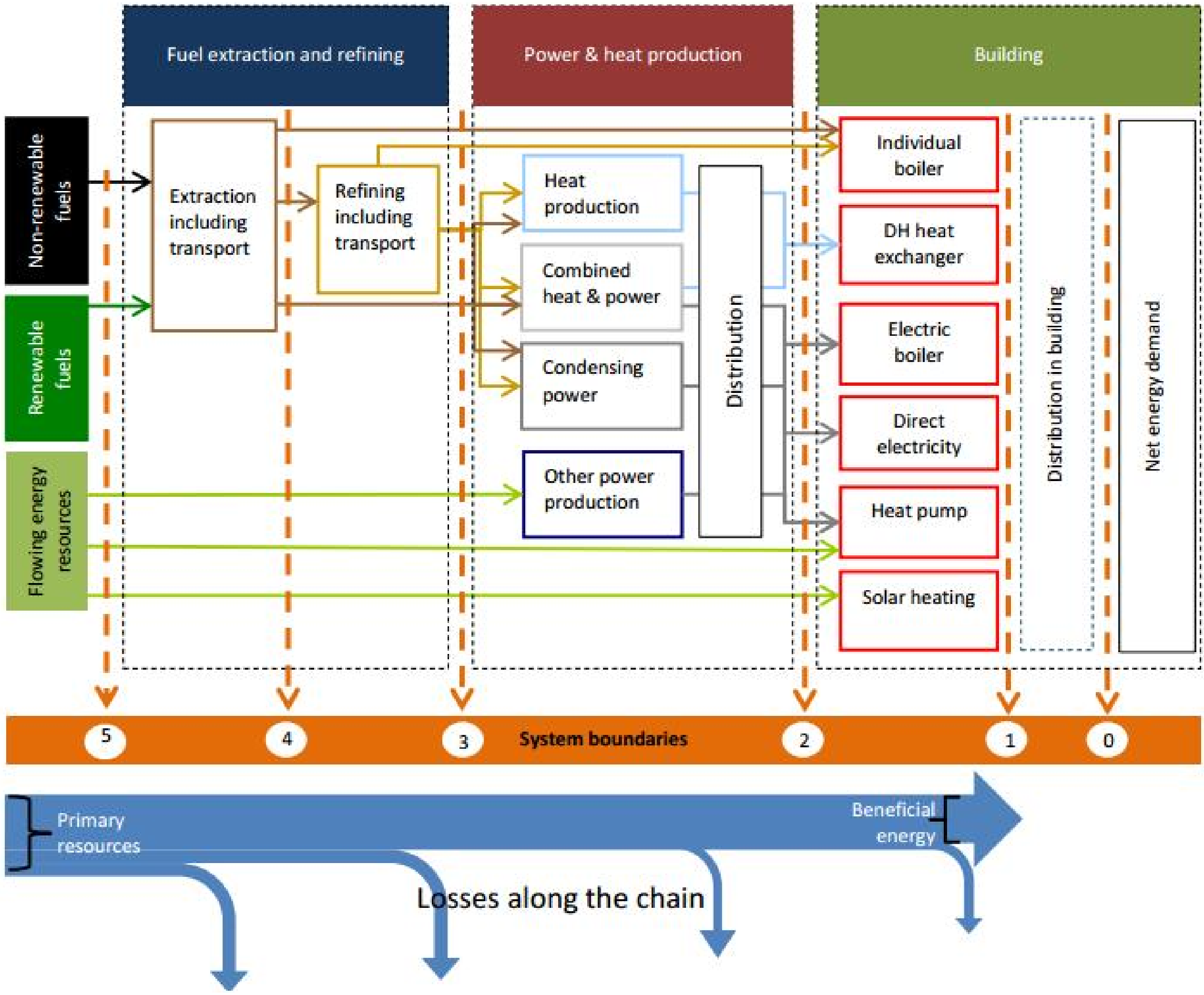


Figure 6: Illustration of alternative system boundaries and of losses along the energy chain from primary resource to heating of a building. (Source: IVL, Ecoheat4cities Work Package 2 Green Labelling Criteria, 2011)

15.2.1 REAL ALLOCATION METHODS

Energy Method

The allocation is proportional to the quantity of produced electricity and heat from the same production unit. According to this method, the same quantity of heat and electricity is valued equally.The energy method is used by the Swedish Energy Service and Statistics Sweden for allocating CHP. (Martinsson, Gode, & Ekvall, 2012)

Exergy Method

This method is an adjustment of the energy method. The environmental impact is instead allocated based on the exergy level of the produced products and will thereby take the aspect of energy quality into consideration. The LCA database EcoInvent uses exergy allocations. (Martinsson, Gode, & Ekvall, 2012)

Economic Allocation Method

According to this method, the environmental impact is allocated based on the economic value of all produced products. A problem with the economic allocation method is its uncertainty. Constant fluctuations due to market demand and tax regulations are example of factors that might affect the price. Another aspect which makes the calculations more problematic is the energy tax, which is included in the price for electricity but not for heat. (Martinsson, Gode, & Ekvall, 2012)

Alternative Production Method

This method considers the impact each produced product would have on the environment, had they been produced separately. A separate production needs more fuel to produce the same amount of energy. Heat and electricity produced in a CHP plant will share the benefits of these environmental savings.

An uncertainty with this method is to evaluate the efficiency of the products alternative production systems. Considering heat for example; would the alternative production be a regular steam cycle, a steam cycle with condensation or a combination cycle?

PSR 1998:1 (PSR 1998:1, 2000) and the cogeneration directive (Commission Decision 92/42/EEC, 2007) are examples of standardized methods to evaluate the alternative production efficiency.

The Alternative Production Method is also used by the Swedish Environmental Management Council when creating environmental declarations for heat and power, where it goes by the name “Alternative generation method”.Other examples ofnames for the method are “Benefit sharing method” and “Efficiency method”. (Martinsson, Gode, & Ekvall, 2012)

Martinsson et al. (2012) recommend the alternative production method for accountancy records of attributes (e.g. emissions and primary energy factors), since it provides benefits both for electricity and heat in combined production. Furthermore, it is the recommended method by EPD®system’s environmental product declarations and the GHG-protocol. (Martinsson, Gode, & Ekvall, 2012)

Värmemarknadskommittén (IVL, 2011) and LEED (Sweden Green Building Council, 2012) use the alternative allocation method in their systems to calculate environmental factors.

The use of the alternative allocation method in Sweden reflects the contemporary need for both heating and electricity during the winter. A CHP in Sweden is built for the purpose of producing both heat and electricity and both heat and electricity should benefit from the combined production method.

This might not be the case in other European countries where the peak electricity demand occurs during summer when there is little or no heat demand. A more suitable allocation method reflecting the national conditions should be used in these countries.

15.2.2 SYSTEM EXTENSION METHODS

Power Bonus Method

The power bonus method considers heat as the main product and electricity as a bi-product. According to this view the electricity produced in a CHP plant replaces other sources of electricity produced in the electricity power system.

The method is described in the European standard EN 15316-4-5. The standard does however not specify how the replaced electricity should be evaluated; if the system perspective should be on a regional, national or European level and if an average or marginal perspective for the replaced production should be used.

The power bonus method is constructed specifically for primary energy. Ecoheat4cities (2011) has developed a modification of the method adapted for carbon dioxide emissions. This method specifically uses replaced electricity produced from condensing power plants.

Martinson et al. (2012) mentions that this method is preferable when investigating what impact a new CHP plant would have on a system perspective, by identifying what electricity that would be replaced. For the same reason they also advise a marginal perspective (Martinsson, Gode, & Ekvall, 2012).

Ecoheat4cities (2011) uses the power bonus method to calculate the non-renewable primary energy factors and uses a European average for electricity factor.

15.3 APPENDIX 3 - FACTOR VALUES

Ecoheat4cities (2011) has developed EU default values for fuels and our recommendation is to use these if no more specific information is available. For occasions were local case-specific values are applied.

15.3.1 MARGINAL OR AVERAGE PERSPECTIVE

The limitation with a marginal perspective is that it only considers the current marginal production for an investment which is designed to last for up to 25-30 years. The chance that the same production will be on the margin throughout this time is very unlikely. It is however hard to forecast what production that will be on the margin at a later stage. Many unknown factors such as political regulations, future investments and customer demand might affect the current marginal. (Sköldberg, Unger, & Olofsson, 2006)

Based on previous reasoning it would be beneficial for not yet established production plant such as a DC system to use a marginal perspective when considering the environmental savings from the phased out production. DC production contributes in mitigating the electrical demand and the first electricity production units that will be phased out are those on the margin.

15.3.2 NATIONAL OR EUROPEAN PERSPECTIVE

In different reports a number of different input is used on calculation environmental impact. To achieve a joint perspective and view is not easy. First of all it is easier to understand local impact but harder to understand global system impact. Especially to evaluate the impact from the electricity market is complicated. There are a number of used definitions of local or global electricity markets used by different stakeholders. Endless discussions are spent on trying to identify from where the electricity is produced and to what extent changes are affecting a mixed production or the marginal production of electricity. It cannot be ignored that interconnections do exist and more integrations are being built.

For instance reports from different sources use:

- Electricity from marginal production
- Electricity with a EU27 mix
- Electricity from a Nordic mix
- Etc.

The electrical production in the Nordic market consists of approximately 60% renewable, 25% nuclear power and 15% fossil based electricity. EU27 instead consists of 20% renewable, 30% nuclear and 55% fossil based. (Gode, Byman, Persson, & Trygg, 2009)

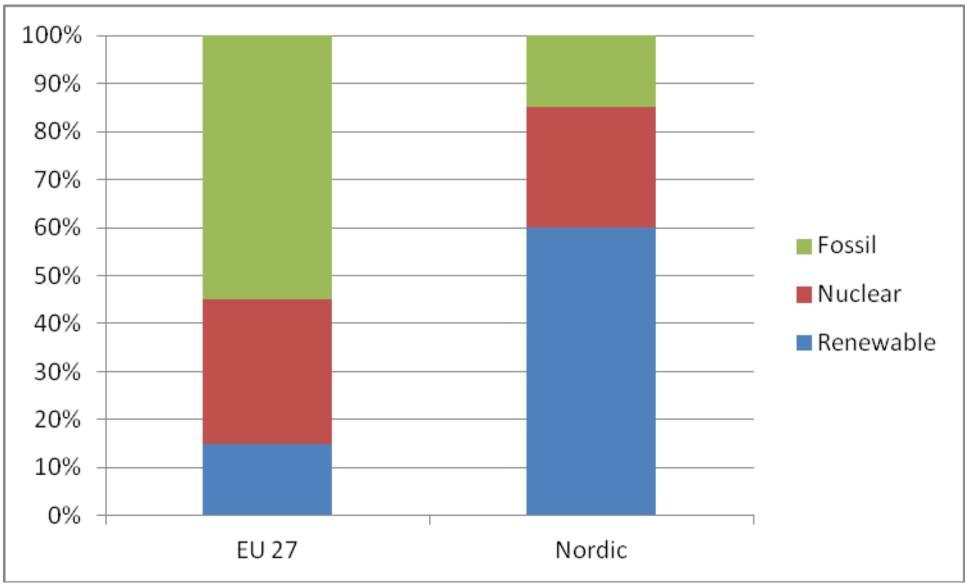


Figure 7: Electrical production mix in the Nordic and EU27 market

Whether to use a national or European perspective is an important question to answer. Above example shows the different production mixes of electricity on the Nordic and EU27 market. The choice of perspective will have a significant influence on the calculated environmental impact.

A European perspective should be used in all countries since the electrical grids and the de-regulation of the European electricity market has created a common electricity market. There is one major exception at present, the Scandinavian countries.

The Nordic countries have their own electrical market due to current bottlenecks with the rest of Europe. Bottlenecks in smaller forms do also exist within the Nordic market (Sköldberg, Unger, & Olofsson, 2006). According to Gode et al. (2009), there is a European directive with the goal to erase these bottlenecks and in the future have a fully integrated European electricity market.

The development towards a unified European electricity market will reduce existing bottlenecks and be more flexible. The Nordic electricity market is getting more and more integrated with Europe with more transition lines. This enables the potential of more export/import of electricity between the local markets. Considering an investment prospected for 20-30 years, it would therefore be logical to always use the European perspective.

15.3.3 MONTHLY OR YEARLY PERSPECTIVE

DC systems are designed based on local conditions. The energy balance will be optimised based on utilising a mix of different cooling sources. Free cooling makes use of cold water from the bottom of lakes or rivers, the air or ground water etc. and will be the first choice in the production due to the low production cost. The water will in some cases be too warm during summer periods. To secure the DC supply temperature it is then necessary to further cool the water with chillers.

Utilising absorption chillers for DC can often also have limitations during the year. If absorption chillers are driven by the DH production, it will be influenced by the DH mixed production. The exception is if the absorption chillers are driven with heat from an industrial process, with a flat annual operational condition. However with a DH system the production is also built up by utilizing different sources of waste energy or fuels. During winter periods the cheap base load can be used at the maximum capacity already. Then this is not available for driving the absorption chillers. Using DH peak production like fossil fuels, oil or gas is not an option. The COP of absorption chiller is too low for an expensive DH fuel. Absorption chillers normally have the operational window during summer periods when the heat price is low and heat sinks are needed for electricity production. Figure 8 shows an example of a DC system energy balance.

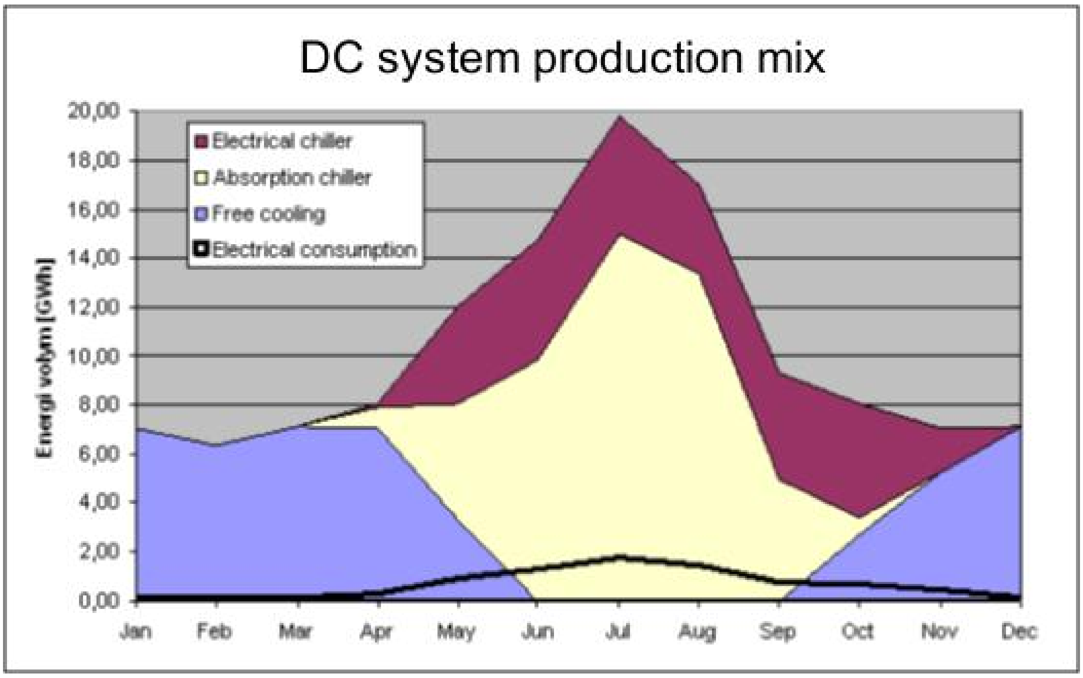


Figure 8: Example of monthly district cooling production variations

DH as a fuel is both geographical and seasonal specific; its production mix is unique compared with other district heating plants and fluctuates over the year based on customer demand. Figure 9 shows an example of district heating production mix variation over the year and how it affects its primary energy factor. Also, only when DH production is using cheap environmental fuels is it of economic interest for a DC system. A higher DH production cost often makes electrical chillers or free cooling more preferable choices. Annual general factor values will result in imprecise outcomes that ignore above mentioned variations. It is therefore recommendable to use case specific values on a monthly basis when calculating on environmental factor for DC systems utilising district heating as a fuel.

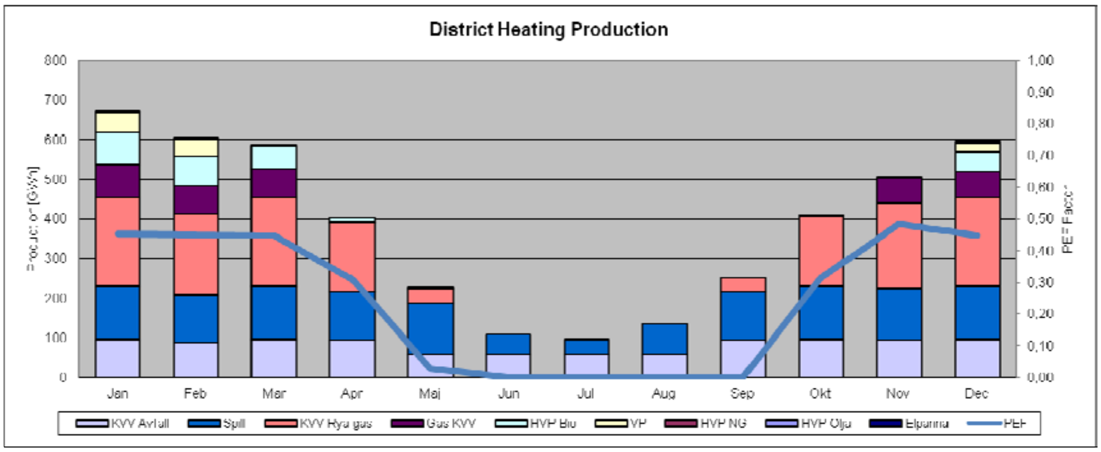


Figure 9: Example of how monthly district heating production variations affect on the primary energy factor

In conclusion natural cooling is prioritised in a DC system. Chillers are used when the DC water requires additional cooling; Absorption chillers during the summer when heat is cheap and electrical chillers during spring and autumn. Solar plants are most effective during the summer and wind mills when the wind conditions are good. Electricity is, in contrast to district heating, usually not locally produced and it is in general difficult to obtain factual monthly factor values. Our recommendation is therefore to use yearly factor values for electricity.