Ecoheat4cities

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Comparison of heating and cooling options

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Project Summary

Supported by the Intelligent Energy Europe Program (IEE), the Ecoheat4cities project promotes awareness and knowledge-based acceptance of District Heating and Cooling (DHC) systems through the establishment of a voluntary green heating and cooling label. The label will provide useful information on key energy related parameters of DHC systems to interested stakeholders throughout Europe and participating countries, including local policy makers, other DHC companies, citizens and related industries.

The three labeling criteria: **Renewability, Resource efficiency (Primary Energy Factor) and CO2 efficiency/emissions** reflect the aims of the EU 2020-targets and will thus enable stakeholders from all over Europe to see and show how District Heating and District Cooling can contribute to reaching the EU's energy targets and assess DHC as a competitive and viable option in Europe's heating and cooling market.

Project outcomes include:

- a label design tool, labeling governance and guidelines, including all details concerning the calculation methods as well as related technical and scientific background research on DH performance and best available and not available technologies;
- a tool enabling cities and municipal planners to compare different heating and cooling options;
- a guide for city planners and DHC companies to better understand the labeling process, also offering insight into how the label can provide added value and a green image.

The Ecoheat4cities label provides a way to measure sustainability and performance of DHC systems based on available and verified, local knowledge and resources.

If your organization would like to know more about the Ecoheat4cities green label, governance structure of the labeling scheme, or participate in any of its activities, please contact Euroheat & Power or its national partners. DHC companies and cities are actively invited to provide additional guidance and feedback about the on-going work by contacting us. All information is available on the Ecoheat4cities website at www.ecoheat4cities.eu

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Preface

This report is part of the Ecoheat4cities project, 'Guidance to cities and urban planners' and focuses on the comparison of different heating and cooling options.

The report provides guidance on the relevance and applicability of the green-labelling methodology established in the Technical report on labelling for DHC, methodology which has been finalised for implementation of the label within the 'Guidelines for labelling DHC'.

This report covers the comparison of different heating and cooling options and provides input on how to use the label parameters and selected criteria for "smart heating and cooling" actions in cities. The report covers the development of a method for the comparison of different district heating and individual heating and cooling options and provides detailed comparison on the aspects of:

- Label criteria (Primary energy factor, CO2 emissions and renewability)
- Costs (investments and exploitation)
- Other criteria (among others air quality, pollution control, safety, security of supply, opportunities for cities and end consumers)

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1 INTRODUCTION

1.1 Background

This report mainly targets cities and urban planners and provides guidance on the relevance and applicability of the green-labelling methodology established by the Ecoheat4cities project. One of the main objectives is to provide cities/communities with the information required to choose the best route for achieving their environmental aspirations. Communities as well as the final customer must be empowered to make well informed heating and cooling choices. In particular cities need tools allowing to make cost-effective choices between individual technologies/appliances and system solutions (DHC).

In this report a methodology has been developed for comparing DHC with various heating and cooling options. In addition, a tool has been developed in Excel to easily make those comparisons. Based on this methodology and the calculation tool, a preliminary comparison has been carried out on the three green label criteria: non-renewable primary energy factor ($f_{P,dh,nren}$), CO_2 emissions (K_{dh}), and renewable fractions (R_{dh})).

Additionally a methodology for comparison at cost level is presented as well as a comparison of other relevant criteria not taken into account in the label like land use, public health, CO_2 emissions, pollution control, cost-effectiveness, customer benefits, longer-term possibilities.

1.2 Description of work

This report is divided into 6 chapters. The individual performances of individual systems possibly competing with district heating are described in Chapter 2. In Chapter 3 the performances of district heating systems are summed up. The comparison methodology is set out in Chapter 4, where the calculation tool, examples and general results are presented as well. Chapter 5 treats the financial aspects of district heating and individual options and Chapter 6 describes other relevant aspects.

2 ENERGY EFFICIENCY OF INDIVIDUAL HEATING SYSTEMS

2.1 Introduction

Considering the wide variety of existing European and national standards assessing the energy performance of individual heating and cooling systems, it was decided to base in first instance the energy performance on European Ecodesign and labelling regulations[1]. In case a draft or final regulation is not yet available, the performance data will be based on the preparatory studies supporting the regulation. The current stage of relevant product lots is as follows:

Lot	Product	Current stage
1	Boilers	Product study completed
2	Water heaters	Product study completed
10	Room air conditioning appliances, local air coolers and comfort fans	Product study completed; Regulation in force
15	solid fuel small combustion installations	Product study completed
20	Local room heating products	Product study ongoing, expected May 2012
21	Central heating products using hot air to distribute heat	Product study ongoing, expected May 2012

In case the Ecodesign studies do not provide the required information, performance data were taken from [1].

2.2 Selection of individual systems

The selection of individual options was discussed and established during the Ecoheat4cities project phase and decided by the project group in a meeting in Delft (19-20 September 2011).

2.2.1 Space heating

Heat generators

The following heat generators for space heating were chosen to be considered in the comparison:

[1] http://www.eceee.org/Eco_design/products

- gas/oil/biofuel boiler
- gas/oil/biofuel co-generation boiler
- electrical resistance (Joule) heating
- electrical heat pump (+ backup boiler)
- exhaust air heat pump (+ backup boiler)

The following heat generators were chosen to be disregarded:

- gas/oil/biofuel boiler cascade configuration: there are few systems and their effect is small.
- gas absorption heat pumps: there are very few systems

Other installation components

Thermal storage tanks are taken into account if required (e.g. solid fuel boilers).

Any solar assisted space heating is disregarded due to a low efficiency for space heating. Also temperature control is ignored because its effect[2] is generally of few percent (5% at maximum), which is considered relatively small in the context of this comparison.

2.2.2 Water heating

Basically, the choice of installation components for hot-water preparation is identical as for space heating, except that solar assisted systems are taken into consideration.

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2.3 Generation efficiency for space heating

2.3.1 Energy labelling

Lot 1

Generally, the scope of Ecodesign Lot 1 includes fossil-fuel boilers and heat pumps up to 400 kW heat output, micro cogeneration up to an electrical capacity of 50 kW, and combination boilers providing heat for heating sanitary water. Current working documents were submitted in February 2012 and are under inter consultation.

[2] Lot 1 working document energy labelling regulation, February 2012

Energy labelling requirements are suggested for boilers[3] and presented in a 'product label'. Requirements for combinations of a boiler with certain additional parts such as controls, solar collectors, storage tanks and passive flue heat recovery devices are presented in a 'package label'.

Product label

The product label for boilers using fossil fuels includes an indication of seasonal space heating energy efficiency (ratio between the annual space heating demand pertaining to a designated heating season provided by a boiler, and the annual energy consumption required for its generation) with respect to the gross calorific value (GCV) of the fuel.

The product label for heat pumps includes an indication of the seasonal space heating energy efficiency in primary energy terms, assuming a primary energy factor for electricity of 2.5, for three different climates designated as 'colder climate', 'average climate' and 'warmer climate' (conditions characteristic for the cities of Strasbourg, Helsinki and Athens with average outdoor temperature of 5.5 ^{o}C, 10 ^{o}C and 16 ^{o}C).

The product label for fossil-fuel combination boilers will include both an indication of seasonal space heating energy efficiency and water heating efficiency, the latter in accordance with the label for fossil-fuel water heaters (lot 2).

The product label of cogeneration boilers provides the seasonal space heating energy efficiency, corrected by a positive contribution due to electricity production (power bonus method) with a primary energy factor for electricity of 2.5.

Package label

The package label includes an indication of seasonal space heating energy efficiency of combinations of boilers with other parts such as a storage tank, temperature control, passive flue heat recovery devices, second boiler, solar collector, and/or auxiliary heat pump. The coefficients for assessing the seasonal space heating energy efficiency to be used in the package label are derived from a mathematical model for assessing the seasonal space heating energy efficiency of such combinations[4].

Lot 15

[3] "boiler" means a device that provides heat to a water-based central heating system where the heat is obtained from combustion of gaseous or liquid fossil fuels; electric resistance heating; or capture of ambient heat from air, water or ground source, and/or waste heat;

[4] Revision draft Annex V d.d. 31.1.2008 on Eco-design implementing measures for central-heating boilers and water heaters. Accompanied by MS-Excel file with identical structure. European Commission, 15 April 2008

The scope of Ecodesign Lot 15 is limited to solid-fuel single combustion appliances <500 kW used for direct and indirect indoor space heating. Final documents of the preparatory study have been published in March 2012. No information is presently available on energy labelling requirements.

Direct competitors for DHC are solid-fuel boilers with indirect space (and water) heating. Open fireplaces and stoves are disregarded.

2.3.2 Energy efficiency design values

System and net efficiency

A distinction is often made between system efficiency and net efficiency. The net efficiency is the ratio between the annual space heating demand and the annual energy consumption required for its generation, whereas the system efficiency is the ratio between the annual energy delivered by the boiler and the annual energy consumption required for its generation.

The performance comparison between DHC and individual heating and cooling (IHC) options will be based on the system efficiency. It is therefore assumed that the heat losses due to the heat distribution system *in* the buildings will be identical for DHC and IHC.

System efficiency of heat-only fossil-fuel boilers (excluding solid fuels)

The Ecodesign lot 1 draft regulation establishes a methodology for assessing the seasonal space heating energy efficiency of these boilers. As product and package labels and information fiches are not yet on the market, the actual performance of installations, which are required for comparing these individual options with district systems, was taken from the preparatory study on Eco-design of Boilers[5] underlying the regulation. In Task 7 report of this study a list of heat-only boilers (cogeneration boilers were outside the scope of this study) is given with typical efficiencies, see Figure 1.

The system efficiency of fossil-fuel boilers listed in Figure 1 refers to an ‘average’ efficiency throughout all seasons, taking into account load and transient operation. Test standard efficiencies are usually higher and are mainly used to measure and compare appliances in an equitable and repeatable fashion.

[5] www.ecoboiler.org

Based on the Ecodesign preparatory study on boilers, typical state-of-the-art system efficiencies of heat-only generators is given in Table 1.

market share **<1%**	sys-eff >132%	net eff. **>120%**	**vertical ground-source heat pumps (GSHP)** best horizontal GSHP
market share **<1%**	sys-eff >116%	net eff. **>104%**	**gas-fired heat pump** best air-based electric heat pump average horizonal GSHP low-end vertical GSHP
market share **2,0%**	sys-eff >100%	net eff. **>88%**	**best condensing+ solar** good air-based heat pump low-end horizontal ground source el. heat pump low-end gas-fired heat pump
market share **8,0%**	sys-eff >92%	net eff. **>80%**	**best condensing** average air-based heat pump average condensing + solar
market share **10,0%**	sys-eff >84%	net eff. **>72%**	**average condensing** low-end air-based heat pump best LT + solar
market share **12,0%**	sys-eff >76%	net eff. **>64%**	**best LT** low-end condensing average LT + solar
market share **15,0%**	sys-eff >68%	net eff. **>56%**	**average LT** best atmospheric + solar low-end LT + solar
market share **30,0%**	sys-eff >60%	net eff. **>48%**	**low-end LT** **BASE CASE** best atmospheric average atmospheric + solar
market share **15,0%**	sys-eff >52%	net eff. **>40%**	**average atmospheric** electric resistance CH-boiler-systems + solar low-end atmospheric + solar
market share **6,0%**	sys-eff <52%	net eff. **<40%**	**low-end atmospheric** electric resistance CH-boiler-systems

Figure 1: Typical efficiency of various heat generators for space heating (source: preparatory study on Eco-design of Boilers, Task 7 Final report)

Table 1: System efficiency of individual heat-only fossil-fuel boilers (gross calorific values) for space heating, excluding solid-fuel boilers

Boiler type	η_{heat} (%)
Boiler condensing high-end	96
Boiler condensing average	88
Boiler condensing low-end	80
Boiler LT high-end	80
Boiler LT average	72
Boiler LT low-end	64
Boiler atmospheric high-end	64
Boiler atmospheric average	56
Boiler atmospheric low-end	46

System efficiency of heat pumps

Electrical heat pumps are also covered by Ecodesign lot 1, see Figure 1. Typical state-of-the-art system efficiencies of heat pumps are given in Table 2.

Performance data of air-based heat pumps in a colder and warmer climate region are estimated to differ a factor 0.90 and 1.15 from the average climate situation, based on Carnot cycle efficiency and 45 ^{o}C water supply temperature.

Table 2: System efficiency of individual electrical heat pumps for space heating

Boiler type	η_{heat} (%)
Ground-source HP vertical high-end	390
Ground-source HP vertical average	350
Ground-source HP vertical low-end	310
Ground-source HP horizontal high-end	350
Ground-source HP horizontal average	310
Ground-source HP horizontal low-end	270
Air-based HP average climate high-end	310
Air-based HP average climate good	270
Air-based HP average climate average	240
Air-based HP average climate low-end	220
Air-based HP cold climate high-end	280
Air-based HP cold climate good	240
Air-based HP cold climate average	220
Air-based HP cold climate low-end	200
Air-based HP warm climate high-end	360
Air-based HP warm climate good	310
Air-based HP warm climate average	280
Air-based HP warm climate low-end	250

[#]not listed in preparatory study task 7 report; extrapolated value

System efficiency of individual co-generation boilers

Cogeneration-boilers <50kW electricity output form part of Ecodesign lot 1 but were outside the scope of the preparatory study. Several technologies exist for small-scale co-generation of heat and power, such as the Stirling motor, gas engine, steam engine, gas turbine, organic Rankine cycle and fuel cell. Of these, the Stirling motor and gas engine are currently on the market. The other technologies still need further development, either fundamentally or for small-scale applications. Introduction of fuel cell CHP is foreseen in 2015.

Typical test-standard system efficiencies of currently available small-scale CHP boilers were taken from [1]. As the (seasonal) system efficiency for heating is usually lower than the test standard efficiency, a correction factor is introduced for the conversion. It is estimated that the system efficiency of combustion boilers is 10% lower than the test standard efficiency. This correction factor is assumed to apply only for the heating efficiency of co-generation boilers, not for the electric efficiency.

Energy performance data are given in Table 3.

Table 3: System efficiency of individual co-generation boilers (gross calorific values) for space heating

Boiler type	η_{heat} (%)	η_{elec} (%)
Cogen boiler Stirling high-end	69	18
Cogen boiler Stirling average	74	13
Cogen boiler Stirling low-end	75	11
Cogen boiler Gas Engine high-end	57	23
Cogen boiler Gas Engine average	61	18
Cogen boiler Gas Engine low-end	62	16
Cogen boiler Fuel Cell high-end	36	36
Cogen boiler Fuel Cell average	41	32
Cogen boiler Fuel Cell low-end	45	27

System efficiency of solid-fuel boilers

According to the Ecodesign lot 15 preparatory study, the test standard energy efficiency (NCV) of wood chip and pellet boiler can reach 95%. Considering that fact that gas-fuelled boilers reach an NCV efficiency of 105%, it is estimated that the efficiency of these solid-fuel boilers is globally10% lower . This estimate only holds for forced draught and pellet boilers. The efficiency of other combustion technologies, such as natural draught and retort boilers, are about 13%pt or 8%pt lower than that of forced draught and pellet boilers, respectively.

Energy efficiency of solid-fuel heat-only forced draught and pellet boilers is given in Table 4.

Table 4: System efficiency of individual solid-fuel heat-only forced draught and pellet boilers (gross calorific values) for space heating

Boiler type	η_{heat} (%)
Solid-fuel boiler condensing high-end	86
Solid-fuel boiler condensing average	79
Solid-fuel boiler condensing low-end	72
Solid-fuel boiler LT high-end	72
Solid-fuel boiler LT average	65
Solid-fuel boiler LT low-end	58
Solid-fuel boiler atmospheric high-end	58
Solid-fuel boiler atmospheric average	50
Solid-fuel boiler atmospheric low-end	41

2.4 Generation efficiency for water heating

2.4.1 Energy labelling

Ecodesign Lot 2

The scope of Ecodesign and labelling Lot 2 includes fossil-fuel, electrical and heat pump water heaters, storage tanks < 2000 dm^3 and solar assisted systems with a heat output < 400 kW. Current working documents were submitted in February 2012 and are under inter consultation.

Energy labelling requirements for water heaters and storage tanks are presented in a ‘product label’. Requirements for combinations of a water heater with additional parts such as a storage tank and solar collectors are presented in a ‘package label’.

The product label for conventional fossil-fuel water heaters includes an indication of the heating energy efficiency (ratio between the annual hot water heating demand at the tap, and the annual energy consumption required for its generation) with respect to the gross calorific value of the fuel. For conventional electric water heaters a primary energy factor for electricity of 2.5 is assumed.

The product label for heat pump water heaters includes an indication of the heating energy efficiency in primary energy terms for three different climates designated as ‘colder climate’, ‘average climate’ and ‘warmer climate’. These three climate conditions are also distinguished in the package label for solar-assisted systems.

Package label

The package label includes an indication of the heating energy efficiency of combinations of boilers with other parts such as a storage tank and solar collectors.

The coefficients for assessing the heating energy efficiency to be used in the package label are derived from a mathematical model for assessing the seasonal space heating energy efficiency of such combinations[6].

The energy label distinguishes between load profiles for hot water tapping in classes XXS, XS, S, M ,L, XL, XXL, 3XL and 4XL, of which the S, M, L and XL classes together represent more than 90% of the market. The XXS and XS profile concern single tapping points, while the XXL, 3XL and 4XL concern multi-family dwellings or other utilities with high hot-water demands (larger restaurants, saunas, hotels, swimming pools).

[6] Revision draft Annex V d.d. 31.1.2008 on Eco-design implementing measures for central-heating boilers and water heaters. Accompanied by MS-Excel file with identical structure. European Commission, 15 April 2008

The link between energy efficiency of the system and energy label class depends on the load profile class. For a larger load profile, higher efficiencies are required to obtain the same energy label class. The rationale behind this is that systems with higher energy efficiency (e.g. heat pumps and solar systems) are economically more viable when the heating load is high.

2.4.2 Energy efficiency design values

The draft regulation establishes a methodology for assessing the seasonal energy efficiency of water heaters. Product labels are not yet on the market; therefore the actual performance is taken from the preparatory study on Eco-design of Water Heaters[7] underlying the regulation. As part of this study, a technical model has been developed to assess the energy efficiency, available as an Excel file[8]. This model has been used here to assess the performance of fossil-fuel and electrical water heaters.

System and net efficiency

A distinction is made between system efficiency and net efficiency. The net efficiency is the ratio between the annual water heating demand at the tapping points and the annual energy consumption required for its generation, whereas the system efficiency is the ratio between the annual energy delivered by the boiler and the annual energy consumption required for its generation.

As for space heating, the performance comparison between DHC and individual heating and cooling (IHC) options will be based on the system efficiency. The heat losses due to the heat distribution system *in* the buildings are assumed to be identical for DHC and IHC. It is a reasonable assumption for load profiles ≥S, where central heat generation is likely to occur. The comparison between DHC and IHC therefore excludes situations where XXS and XS loads affect the total hot water demand of a district.

System efficiency

System efficiency of heat-only fossil-fuel boilers (excluding solid fuels)

According to the Ecohotwater model, for gas instantaneous water heaters with electronic ignition and load size ≥M, the system efficiency is about 60%. The system efficiency of storage systems are very similar, therefore identical efficiencies are suggested as for gas instantaneous systems.

In this comparison this value is adopted as the ‘average’ performance. The range of performance of water heaters is large. Gas boilers are on the market today that reach an

[7] www.ecohotwater.org
[8] Ecohotwater model, draft v.2 (9 May 2007)

efficiency of 80%, while low-end boilers may reach an efficiency of merely 40%. To substantially cover this range, low-end boilers are suggested to have a 16% lower efficiency, and high-end boiler a 16% higher efficiency.

Table 5: System efficiencies of individual fossil-fuel boilers for water heating (gross calorific values)

Boiler type	η_{heat} (%)
Gas instantaneous high-end	76
Gas instantaneous average	60
Gas instantaneous low-end	44
Fossil-fuel storage high-end	76
Fossil-fuel storage average	60
Fossil-fuel storage low-end	44

System efficiency of electric boilers

According to the Ecohotwater model, the system efficiency of electric storage boilers (Joule heating) considerably depends on the load profile, see Table 6. For small loads, the standby heat losses are relatively high.

Table 6: System efficiencies of individual electric boilers for water heating depending on load profile and tank size according to the Ecohotwater model

Boiler type	profile class	tank size (L)	η_{heat} (%)
Electrical storage	S	20	63
Electrical storage	M	50	76
Electrical storage	L	120	80
Electrical storage	XL	150	85

For the comparison, a more global subdivision is considered adequate that distinguishes only small (20 L storage) and large (120 L storage) tanks with low-end, average and high-end categories differing 8%pt, resulting in system efficiencies as outlined in Table 7. The efficiency of electrical instantaneous systems (electrical heating at tapping point) is given as well.

Table 7: System efficiencies of individual electric boilers for water heating

Boiler type	η_{heat} (%)
Electrical large storage high-end	88
Electrical large storage average	80
Electrical large storage low-end	72
Electrical small storage high-end	71
Electrical small storage average	63
Electrical small storage low-end	55
Electrical instantaneous	97

System efficiency of heat pumps

System efficiencies of heat pump water heaters were taken from [1]. A distinction is made between heat pumps using ventilation exhaust air from the building[9], heat pumps using ground water or soil, or heat pumps using outside air.

Performance data of air-based heat pumps in a colder and warmer climate region are estimated to differ a factor 0.95 and 1.10 from the average climate situation, based on Carnot cycle efficiency and 65 ^{o}C water supply temperature.

Table 8: System efficiencies of individual heat pump for water heating

	η_{heat} (%)
HP boiler exhaust air high-end	360
HP boiler exhaust air average	280
HP boiler exhaust air low-end	220
Ground-source HP high-end	240
Ground-source HP average	210
Ground-source HP low-end	190
Air-based HP average climate high-end	240
Air-based HP average climate average	210
Air-based HP average climate low-end	190
Air-based HP cold climate high-end	230
Air-based HP cold climate average	200
Air-based HP cold climate low-end	180
Air-based HP warm climate high-end	260
Air-based HP warm climate average	230
Air-based HP warm climate low-end	210

System efficiency of solid-fuel boilers

The same procedure as for space heating is followed: it is estimated that the efficiency of solid-fuel boilers is globally10% lower than of fossil-fuel boilers. The system efficiency for water heating of solid-fuel heat-only forced draught and pellet boilers is given in Table 9.

Table 9: System efficiency of individual solid-fuel heat-only forced draught and pellet boilers (gross calorific values) for water heating

Boiler type	η_{heat} (%)
Solid-fuel storage high-end	68
Solid-fuel storage average	54
Solid-fuel storage low-end	40

[9] Note that taking exhaust ventilation air as heat source rules out ventilation heat recovery.

System efficiency of individual co-generation boilers

No information was found regarding the system efficiency of individual co-generation boilers for water heating. It is assumed that the ratio of efficiency for space and water heating for this type of boiler will be equal to that of fossil-fuel boilers, which is about 0.8. Efficiency of electricity generation is not affected.

Table 10: System efficiency of individual co-generation boilers (gross calorific values) for water heating

Boiler type	η_{heat} (%)	η_{elec} (%)
Cogen boiler Stirling high-end 2010	55	18
Cogen boiler Stirling average 2010	59	13
Cogen boiler Stirling low-end 2010	60	11
Cogen boiler Stirling high-end 2020	49	27
Cogen boiler Stirling average 2020	52	23
Cogen boiler Stirling low-end 2020	55	18
Cogen boiler Gas Engine high-end 2010	52	23
Cogen boiler Gas Engine average 2010	55	18
Cogen boiler Gas Engine low-end 2010	57	16
Cogen boiler Gas Engine high-end 2020	49	27
Cogen boiler Gas Engine average 2020	52	23
Cogen boiler Gas Engine low-end 2020	55	18
Cogen boiler Fuel Cell high-end 2010	42	36
Cogen boiler Fuel Cell average 2010	46	32
Cogen boiler Fuel Cell low-end 2010	49	27
Cogen boiler Fuel Cell high-end 2020	36	45
Cogen boiler Fuel Cell average 2020	42	36
Cogen boiler Fuel Cell low-end 2020	49	27

Solar assisted systems

As the design, layout and construction of solar collector systems vary widely and their contribution to water heating depend on heat load characteristics, advanced technical calculation models are required to assess their performance. Such a detailed analysis is outside the scope of the present work. Although the contribution of solar energy to water heating will be taken into account in the comparison, the link between this contribution and actual system characteristics is not elaborated on.

The heating efficiency of solar collectors is taken as 100% in order to correctly determine the renewable energy share in the energy mix of a building (see later).

REFERENCES

[1] Opwekkingsrendementen lokale technieken onder laboratoriumomstandigheden (Generation efficiencies of local techniques under laboratory conditions). TNO-rapport 034-APD-2010-00155, March 2010 (in Dutch).

3 ENERGY CHARACTERISTICS OF DISTRICT HEATING SYSTEMS

3.1 Introduction

The basic information for calculating the performance of district heating has been layed down in the Ecoheat4cities technical report on labelling DHC [1], the technology catalogue [2] and system catalogue [3] of the Ecoheat4Cities project, both combined in the report ‘Best available/Best not yet available technology’.

The first report defines the three labelling criteria primary energy, carbon dioxide emissions and share of renewable and recycled energy, and a methodology for the calculation of these.

In the ‘Best available/Best not yet available technology report’, technology report separately describes technological aspects of district heating that all together forms the district heating system: ‘Buildings and heat consumption’, ‘Building substations and installations’, ‘Distribution pipes and pumps’ & ‘Fuels and production’. Each technology is divided into ‘best available’ (BAT) and ‘best not yet available technology’ (BNAT). These technologies are combined in the system catalogue, which discusses calculation examples of complete district heating systems.

This chapter outlines the calculation method to assess the energy performance of district heating systems which is required for the comparison with individual heating options.

3.2 District heat consumption

Information on the total heat consumption of all buildings in a district is first required to assess the performance of the district heating system (distribution efficiency) which, in turn, affects the performance of each connected building.

The heat consumption of a district has been addressed in the technology report on district heating systems [2]. Basic elements of that approach are reproduced here for convenience.

The energy consumption at the gate where heat is delivered to buildings may be expressed as heat consumption per unit building net floor area (building specific heat consumption in kWh/m^2). Another dimension is how dense buildings are built in a certain urban district to be supplied with district heating. To describe that, the plot ratio is used which expresses how much building net floor area there is per area of land. The plot ratio is small in park areas with detached houses and high in inner cities.

Both plot ratio and building specific heat consumption has a large impact on the relative heat losses from district heating distribution networks. High building specific heat consumption and high plot ratio will result in relatively low distributions losses, whereas low building specific heat consumption and low plot ratio gives relatively high losses.

Plot ratio and building specific heat consumption are often multiplied resulting in the area specific heat consumption ε (kWh/m^2), most often on a yearly basis.

Base case, BAT and BNAT regarding building heat consumption are addressed in the technology report from which the following table resulted:

Table 11: Area specific heat consumption ε depending on plot ration and building specific heat consumption [2].

Area heat consumption [kWh/m^2]			Specific heat consumption [kWh/m^2]			
			2020 - BNAT	2010 - BAT	Existing, low	Existing, high
			30	75	150	300
Plot ratio [m^2/m^2]	Inner city	1	**30**	**75**	**150**	**300**
	Inner city	0,6	**18**	**45**	**90**	**180**
	Outer city	0,4	**12**	**30**	**60**	**120**
	Park area	0,15	**4,5**	**11,25**	**22,5**	**45**

For example, for an outer city area with a plot ratio of 0.4 and BAT buildings with a building specific heat consumption of 75 kWh/m^2, the area specific heat consumption equals ε = 0.4*75 = 30 kWh/m^2.

3.3 Distribution efficiency

Heat losses in the distribution network must be accounted for. Basic technologies for the distribution system are described in [2] while in [3] the distribution efficiency of some design networks is calculated. Although advanced models exist for calculating the heat loss of a complete network, such calculations are considered too detailed for the present comparison. A simple model, easy to use but fitting well real efficiency data, is therefore suggested to assess the network efficiency with sufficient accuracy, as will be outlined below.

3.3.1 Simplified model

It is assumed that the distribution network efficiency as a function of the specific area heat consumption and other network characteristics can be described as:

$$\eta_{hn} = 1 - \frac{1.8}{\varepsilon} \cdot f_{\text{temp}} \cdot f_{\text{pipe}} \cdot f_{\text{series}} \cdot f_{\lambda} \qquad (1)$$

where ε is the area specific heat consumption (kWh/m^2), and f_{temp}, f_{pipe}, f_{series} and f_λ are correction factors for temperature, pipe system, insulation series and pipe insulation heat conduction coefficient λ_{ins}.

The term

$$1 - \frac{1.8}{\varepsilon}$$

is the network efficiency for a reference system for which all correction factors are unity. This is the case when

- supply temperature 60 ^{o}C, return temperature 30 ^{o}C, environment 10 ^{o}C
- single pipe distribution system
- pipe insulation series 2
- λ_{ins} = 0.023 W/mK

In principle, all pipe diameters and their lengths in a network should be considered when calculating the total heat loss. The intention here is however to have a reasonable estimate of the distribution efficiency at an accuracy of about 5%. Besides, the exact network layout is not a priori known. The above approximation assumes that the heat losses are mainly determined by the smaller diameter pipes in a system as a result of their larger length.

The correction factors are defined as follows:

Temperature
Heat losses are mainly determined by the average temperature difference between the fluid in the pipe and the environment. For the latter we may use outside air temperature.

$$f_{\text{temp}} = \frac{\frac{T_{\text{supply}} + T_{\text{return}}}{2} - T_{\text{env}}}{35}$$

where

T_{supply} = supply temperature (^{o}C)
T_{return} = return temperature (^{o}C)
T_{env} = average outside temperature during operation (^{o}C)

Pipe system

Distribution pipes are discussed in the technology report [2] where a main distinction is made between distribution networks with a pair of single pipes (single supply and single return) and twin pipes that combine supply and return in one insulated casing. The ratio of heat loss between these two types is only weakly dependent on pipe diameter. For smaller diameter pipes we have:

$f_{\text{pipe}} = 1$	pair of single pipes
$f_{\text{pipe}} = 0.66$	twin pipe

Insulation series

Pipe manufacturers indicate the insulation thickness by the insulation series number. Series 1, 2, and 3 are defined and correspond to an increasing insulation quality. The ratio of heat loss between these series appears rather independent of pipe diameter and are given by

$f_{\text{series}} = 1.15$	series 1
$f_{\text{series}} = 1$	series 2
$f_{\text{series}} = 0.85$	series 3

Insulation heat conduction coefficient

The effect of the heat conduction of the insulation material may be calculated as

$$f_{\lambda} = \frac{\left(0.023^{-1} + 3\right)}{\left(\lambda_{ins}^{-1} + 3\right)}$$

where the factor 3 accounts for the heat resistance of the soil.

Calculation examples

The system catalogue [3] presents some examples of a traditional, BAT and BNAT distribution network and their distribution efficiency, see Table 12. Substituting these network parameters in the simplified model, gives distribution efficiency as given in the last row of Table 12. As can be seen, the simplified model predicts the real efficiency very well.

Table 12: Characteristics of a traditional, BAT and BNAT distribution network [3]

	Traditional	2010 (BAT)	2020 (BNAT)
Specific area heat consumption (kWh/m^2)	16	16	40
Plot ratio [-]	0.4	0.4	1.0
Pipe type [-]	Single	Twin	Twin
Insulation series [-]	1	2	2
T_{supply}/T_{return} [°C]	80/40	60/30	60/30
Insulation heat conductivity [W/(m·K)]	0.029	0.023	0.017
Efficiency	**0.78**	**0.92**	**0.97**
Efficiency simplified model	**0.771**	**0.926**	**0.978**

Validity

In this simplified model the calculated network heat loss is expected to have an inaccuracy of about 20% (consequently, the inaccuracy in the distribution efficiency can thus be very low for high-efficient networks). The model is considered adequate for a calculated efficiency $\eta_{hn} > 0.5$, which applies to almost all networks today.

Note that the model may not cover situations where the production facility is far away, and thus a relatively long large-diameter pipeline is necessary to transport the heat to and from the heating district.

3.4 Generation efficiency

The generation efficiency of heat production facilities is largely taken from [2]. The efficiencies listed here refer to BAT technologies. No distinction between low-end, average and high-end is made because the differences between efficiency values are generally small with respect to the desired accuracy of the comparison with individual options.

Table 13: Generation efficiency (LHV) of district heat production facilities

Boiler type	η_{heat} (%)	η_{elec} (%)
Advanced pulverized fuel power plant	46	40
Gas turbine single cycle, large	43	40
Gas turbine single cycle, medium	45	38
Gas turbine single cycle, small	51	32
Gas turbine combined cycle, steam extraction	29	57
Gas turbine combined cycle, back pressure	38	48
Gas engine	49	43
Waste-to-energy chp plant	75	24
Medium-scale biomass power plant, wood chips	64	34
Medium-scale biomass power plant, straw	69	29
Gas engine, gasifiers, biomass	65	38
Solid oxide fuel cells	44	46
Heat pump electric, large, ambient air	280	0
Heat pump electric, large, heat source 35°c	360	0
Heat pump absorption, large, fluegas condensation	170	0

Heat pump absorption, large, geothermal	170	0
Electric immersion boilers	99	0
Waste-to-energy district heating plant	96	0
District heating boiler, wood-chips fired	108	0
District heating boiler, gas fired, condensing	101	0
District heating boiler, gas fired, traditional	95	0

Note that the generation efficiencies listed here refer to the lower heating value of the fuel. As the efficiency of individual heating systems is given on higher heating value basis, a conversion step is required depending on fuel type, see § 4.3.2.

REFERENCES

[1] Ecoheat4cities 'Technical report on labelling DHC', IVL Swedish Environmental Research Institute
[2] Ecoheat4cities BAT/BNAT Benchmark for performance levels: Technology Catalogue, Danish Technological Institute
[3] Ecoheat4cities BAT/BNAT Benchmark for performance levels: System Catalogue, Danish Technological Institute

4 ENERGY PERFORMANCE OF DISTRICT HEATING AND INDIVIDUAL HEATING OPTIONS

4.1 Introduction

Cities and costumers need qualified information to make conscious choices between individual technologies and district heating system solutions. In this chapter the energy performance of both systems will be analysed and compared.

In this chapter, the analysis will be based on the three environmental criteria of the green label as defined in the 'Technical report on labelling DHC' [1], of which the corresponding calculation methods have been further refined and specified in 'guidelines on test-labeling'[10].

Basically two energy performance indicators are assessed:

- $f_{P,dh,nren}$, the non-renewable primary energy factor of DH
- $K_{P,dh,nren,}$ the non-renewable primary CO_2-emission coefficient of DH in kg/MWh

in addition to one energy source indicator:

- R_{dh}, the ratio of heat from renewable/recycled energy carriers to the total heat.

The method for calculating the three criteria for district heating systems as outlined in the guidelines can also be applied to individual heating systems. It is therefore chosen to assess the performance both type of heating systems using this methodology. However, the draft Ecodesign methodology for energy labelling of individual boilers only takes the energy efficiency into consideration. For that reason, this quantity will also be taken into account.

In principle, the analysis of DH can be based on design or real districts. Here fictitious districts are chosen mainly because it provides city planners insight in the heating options in the design phase of a new district. As the number of model parameters describing the heating characteristics of a district, and which are required to make the comparison, are quite limited, city planners or their advisers should be able to assess these parameters without extensive effort.

A tool has been developed in Excel to make the comparison based on district characteristics and heating options. This enables city planners to make the comparison in an early design phase themselves.

[10] The calculations in this chapter are based on the guidelines of 26 April 2012.

4.2 Performance of district heating systems

The energy performance of district heating systems is determined by a great deal of parameters. In this section, an effort is made to provide more insight into the main influencing factors. The objective is to provide the information is such a way that cities and costumers can make a balanced and conscious choice between options in the early planning phase. Chosen options may be further analysed for feasibility by experts.

As a first analysis step, the number of parameters will be lowered by grouping, and by limiting the scope. This will be outlined in the following paragraphs.

4.2.1 Fuel grouping

Some overview may be obtained by lumping similar fuel types with respect to non-renewable energy factor and specific CO_2-emission, see Table 14.

Table 14: Aggregation of fuel types

fuel nr.	fuel type	$f_{P,nren}$	K_P (kg/MWh)	alternative η_e
1	Electricity	2.6	420	-
2a	Fossil fuel, gas	1.1	230	0.53
2b	Fossil fuel, liquid	1.1	280	0.44
2c	Fossil fuel, solid	1.1	370	0.44
3a	Bio and residual fuels, gas and liquid	0.15	30	0.43
3b	Bio and residual fuels, solid	0.15	30	0.30
4	Waste as fuel	0	0	0.30
5	Geothermal, solar and waste heat	0	0	-

Here the fossil fuels have been divided into three categories depending physical state, and average values for bio and residual fuels are taken since their range is relatively small. In some cases an average value for the alternative electric efficiency is taken.

4.2.2 Production grouping

Heat generation

For combined heat and power generation, the grouping is done based on the heat and electricity generation efficiency. Generally, a higher electric efficiency corresponds to a lower heating efficiency, and a higher heating efficiency corresponds to a higher total efficiency. Based on a trend analysis the following is obtained for average current technologies:

Table 15: Aggregation of CHP production facilities

prod. nr.	production type	η_{heat} (%)	η_e (%)	η_{total} (%)
1	CHP low heat, high electric	38	47	85
2	CHP mean heat, mean electric	53	38	91
3	CHP high heat, low electric	68	30	98

with the grouping as shown in Table 16

Table 16: Grouping of CHP production facilities.

prod. nr.	production type	Production description
1	CHP low heat, high electric	Advanced pulverized fuel power plant Gas turbine single cycle, large Gas turbine single cycle, medium Gas turbine combined cycle, steam extraction Gas turbine combined cycle, back pressure Solid oxide fuel cells
2	CHP mean heat, mean electric	Gas turbine single cycle, small Gas engine
3	CHP high heat, low electric	Waste-to-energy chp plant Medium-scale biomass power plant, wood chips Medium-scale biomass power plant, straw Gas engine, gasifiers, biomass

For heat only boilers, excluding heat pumps, a general heating efficiency (LHV) of 100% is a representative value for current technology. For heat pumps, a distinction is made between electric and absorption heat pumps. Efficiency values of these generation systems are shown in Table 17. The efficiency of solar collectors, geothermal and waste heat is of no importance because of zero non-renewable primary energy factor, zero CO_2-emission and 100% renewability/recycled energy. Its value can be arbitrarily set at 100%.

Table 17: Aggregation of heat-only production facilities

prod. nr.	production type	η_{heat} (%)
4	Heat-only boilers, excluding heat pumps	100
5	Heat pump, electric	320
6	Heat pump, absorption	170
7	Solar collectors	100
8	Geothermal and waste heat	100

4.2.3 Combinations of fuel type and a single production type

Since there are 8 fuel type groups and 8 production type groups, a total of 64 combinations are obtained. However, not every combination is possible or realistic. For example, an absorption heat pump cannot be combined with electricity as fuel. In the end, only 20 combinations make sense, listed in Table 18.

Table 18: Possible combinations of fuel type and production type.

comb. nr	prod. nr.	production type	fuel nr.	fuel type
1	1	CHP low heat, high electric	2a	Fossil fuel, gas
2	1	CHP low heat, high electric	3a	Bio and residual fuels, gas and liquid
3	2	CHP mean heat, mean electric	2a	Fossil fuel, gas
4	2	CHP mean heat, mean electric	2b	Fossil fuel, liquid
5	2	CHP mean heat, mean electric	2c	Fossil fuel, solid
6	2	CHP mean heat, mean electric	3a	Bio and residual fuels, gas and liquid
7	3	CHP high heat, low electric	3b	Bio and residual fuels, solid
8	3	CHP high heat, low electric	4	Waste as fuel
9	4	Heat-only boilers, excl. heat pumps	1	Electricity
10	4	Heat-only boilers, excl. heat pumps	2a	Fossil fuel, gas
11	4	Heat-only boilers, excl. heat pumps	2b	Fossil fuel, liquid
12	4	Heat-only boilers, excl. heat pumps	2c	Fossil fuel, solid
13	4	Heat-only boilers, excl. heat pumps	3a	Bio and residual fuels, gas and liquid
14	4	Heat-only boilers, excl. heat pumps	3b	Bio and residual fuels, solid
15	4	Heat-only boilers, excl. heat pumps	4	Waste as fuel
16	5	Heat pump, electric	1	Electricity
17	6	Heat pump, absorption	2a	Fossil fuel, gas
18	6	Heat pump, absorption	3a	Bio and residual fuels, gas
19	7	Solar collectors	5	Solar heat
20	8	Geothermal and waste heat	5	Geothermal and waste heat

Distribution efficiency

In the calculations, the distribution efficiency is simply set at a constant value of 90%, which is a realistic value for modern distribution systems in city areas.

Results

The three performance indicators of the selected combinations are listed in Table 19 and shown in Figure 2. In this figure:

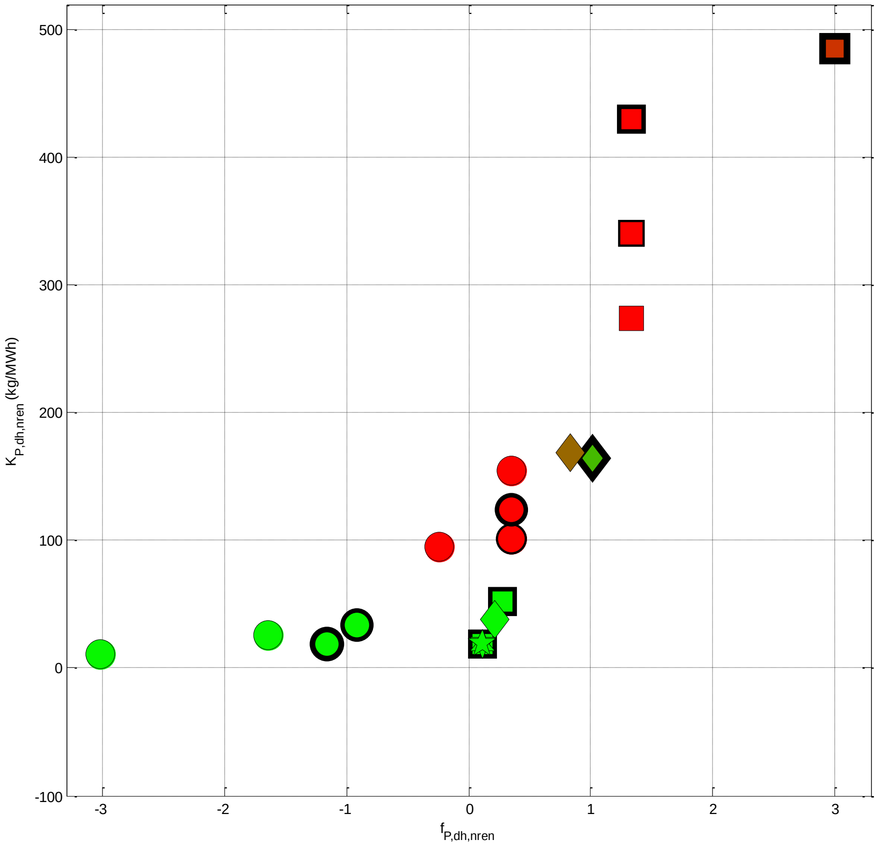
- the non-renewable primary energy factor $f_{P,dh,nren}$ is plotted on the horizontal axis
- the non-renewable primary CO_2-emission coefficient K_P is plotted on the vertical axis

- the ratio of heat from renewable/recycled energy carriers to the total heat R_{dh} is shown as the fill colour of the markers ranging from green (100% renewability) to red (0% renewability).
- the production type is associated with a marker type
- the fuel type is associated with the line width of each marker:
    - solar, geothermal and waste heat very thin line
    - gas thin line
    - liquid normal line
    - solid rather thick line
    - waste thick line
    - electricity very thick line

Note that in all results listed in this chapter, a negative value may be stated for the non-renewable primary energy factor $f_{P,dh,nren}$. Formally, a negative end-result for $f_{P,dh,nren}$ must be rounded to 0 (zero). However, negative values are retained in the figures (and tables) in this chapter to show the actual performance. When combinations of DH-plants are considered, such negative values for each individual plant are indispensable for deducing the performance of the combination.

Table 19: Performance indicators for selected combinations of fuel type and production type, distribution efficiency 90%.

comb. nr	production type	fuel type	$f_{P,dh,nren}$	$K_{P,dh,nren}$ (kg/MWh)	R_{dh} (%)
1	CHP low heat, high electric	Fossil fuel, gas	-0.2	95	0
2	CHP low heat, high electric	Bio and residual fuels, gas and liquid	-3.0	11	100
3	CHP mean heat, mean electric	Fossil fuel, gas	0.4	155	0
4	CHP mean heat, mean electric	Fossil fuel, liquid	0.4	102	0
5	CHP mean heat, mean electric	Fossil fuel, solid	0.4	124	0
6	CHP mean heat, mean electric	Bio and residual fuels, gas and liquid	-1.6	26	100
7	CHP high heat, low electric	Bio and residual fuels, solid	-0.9	33	100
8	CHP high heat, low electric	Waste as fuel	-1.2	19	100
9	Heat-only boilers, excl. heat pumps	Electricity	3.0	485	20
10	Heat-only boilers, excl. heat pumps	Fossil fuel, gas	1.3	274	0
11	Heat-only boilers, excl. heat pumps	Fossil fuel, liquid	1.3	341	0
12	Heat-only boilers, excl. heat pumps	Fossil fuel, solid	1.3	430	0
13	Heat-only boilers, excl. heat pumps	Bio and residual fuels, gas and liquid	0.3	52	100
14	Heat-only boilers, excl. heat pumps	Bio and residual fuels, solid	0.3	52	100
15	Heat-only boilers, excl. heat pumps	Waste as fuel	0.1	19	100
16	Heat pump, electric	Electricity	1.0	165	75
17	Heat pump, absorption	Fossil fuel, gas	0.8	169	41
18	Heat pump, absorption	Bio and residual fuels, gas	0.2	38	100
19	Solar collectors	Solar heat	0.1	19	100
20	Geothermal and waste heat	Geothermal and waste heat	0.1	19	100


500
400
300
200
100
0
-100
-3
-2
-1
0
1
2
3
$K_{P,dh,nren}$ (kg/MWh)
$f_{P,dh,nren}$

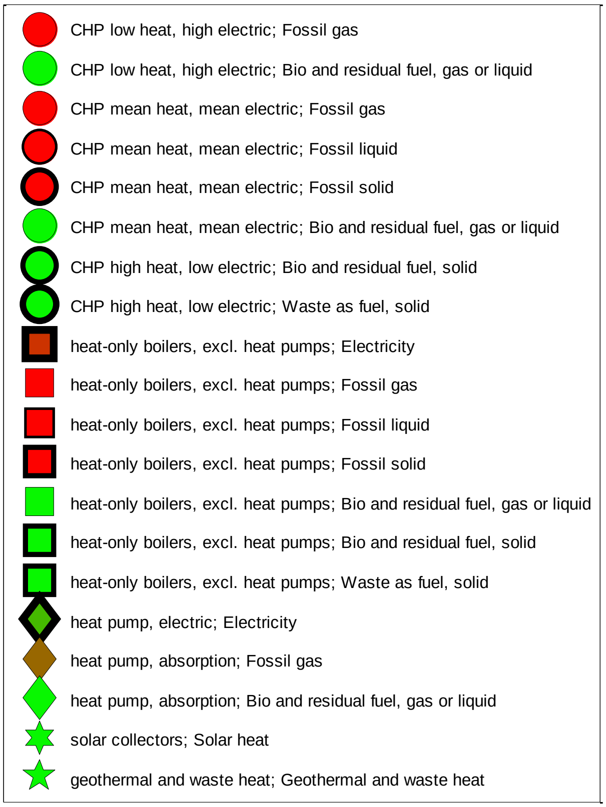


Figure 2: Performance indicators for selected combinations of fuel type and production type, distribution efficiency 90%.

Based on Figure 2, it is seen that the combinations can be subdivided into groups with similar performance, as shown in Figure 3.

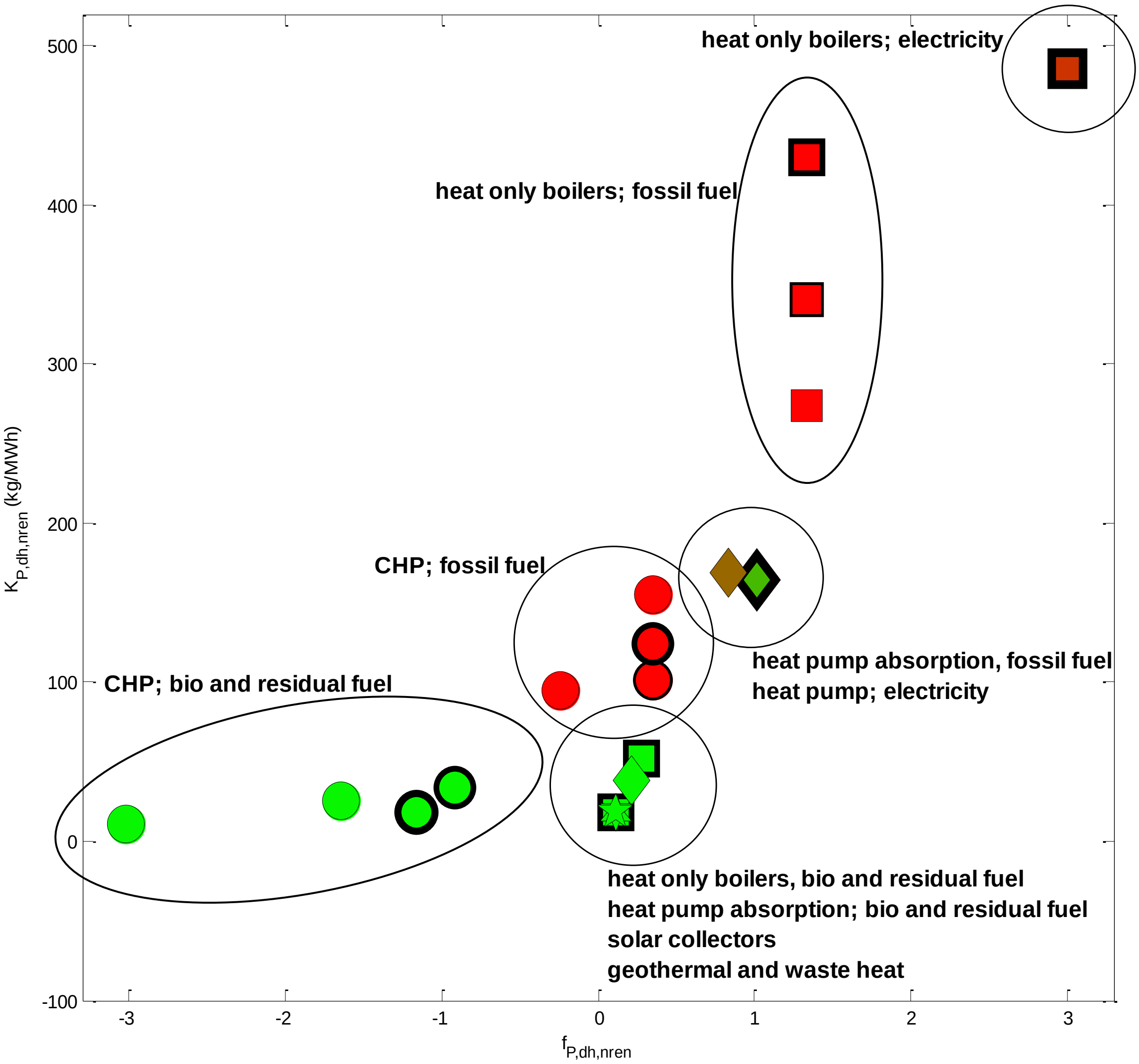


Figure 3: Grouping of the combinations based on performance indicators, distribution efficiency 90%.

These groups with their approximate range of the performance indicators are given in Table 20, and corresponding classification in Table 21. Note that the classification of R_{dh} will be country specific. Here, the classification for R_{dh} is based on the default DH reference system and default EU27 renewable/recycle share of 20% (Tier 1).

Table 20: Performance indicators of combination groups, distribution efficiency 90%.

group nr.	production type	fuel type	$f_{P,dh,nren}$	$K_{P,dh,nren}$ (kg/MWh)	R_{dh} (%)
1	CHP	Bio and residual fuel, waste as fuel	-3.0 – -0.8	0 – 50	100
2	Solar collectors geoth. and waste heat	Solar geoth. And waste heat	0.1	20	100
3	Heat only boilers heat pump absorption	Bio and residual fuel, waste as fuel	0.1 – 0.3	20 – 50	100
4	CHP	Fossil fuel	-0.2 – +0.5	95 – 155	0
5	Heat pump absorption	Fossil fuel	0.8	170	40
6	Heat pump	Electricity	1	165	75
7	Heat only boilers	Fossil fuel	1.3	270 - 430	0
8	Heat only boilers	Electricity	3	485	20

Table 21: Indication for the classification of performance indicators of combination groups, distribution efficiency 90%.

group nr.	production type	fuel type	Class $f_{P,dh,nren}$	Class $K_{P,dh,nren}$	Class R_{dh}
1	CHP	Bio and residual fuel	1	1	1
2	Solar collectors geoth. and waste heat	Solar geoth. and waste heat	1	1	1
3	Heat only boilers heat pump absorption	Bio and residual fuel waste as fuel	1	1	1
4	CHP	Fossil fuel	1	1 - 2	7
5	Heat pump absorption	Fossil fuel	2 - 3	2	2
6	Heat pump	Electricity	3	2	1
7	Heat only boilers	Fossil fuel	4	3 - 4	7
8	Heat only boilers	Electricity	7	5	3

4.2.4 Systems with a non-preferential heat-only fossil fuel boiler

Many DH facilities combine two (or more) production types. The base load may be provided by a CHP, geothermal, waste heat or heat pump facility, while the peak load is provided by heat only boilers. Back-up heat only boilers may also run when the main production facility is out of order. In this paragraph the performance of such systems is analysed.

The preferential production types taken into consideration are given in Table 22.

Table 22: Preferential production types.

nr.	preferential production type	fuel type
1	CHP, mean heat, mean electric	Bio and residual fuel, gas or liquid
2	Geothermal and waste heat	Geothermal and waste heat
3	Heat only boilers (heat pump absorption)	Bio and residual fuel waste as fuel
4	CHP	Fossil liquid
5	Heat pump absorption	Fossil fuel, gas
6	Heat pump	Electricity

These are combined with a heat only boiler that uses a liquid fossil fuel. A further parameter in the analysis is the share of heat produced by the preferential production unit, for which values of 100%, 75% and 50% are taken.

The results for the performance indicators are shown in Figure 4 for currently available technologies. It is seen that the data for each preferential production type varies linearly with the share of heat produced, between the two data points with 100% and 0% share (the latter is indicated by the performance of a liquid fossil fuel heat-only boiler, top right in the graph). Corresponding numerical data is given in Table 23

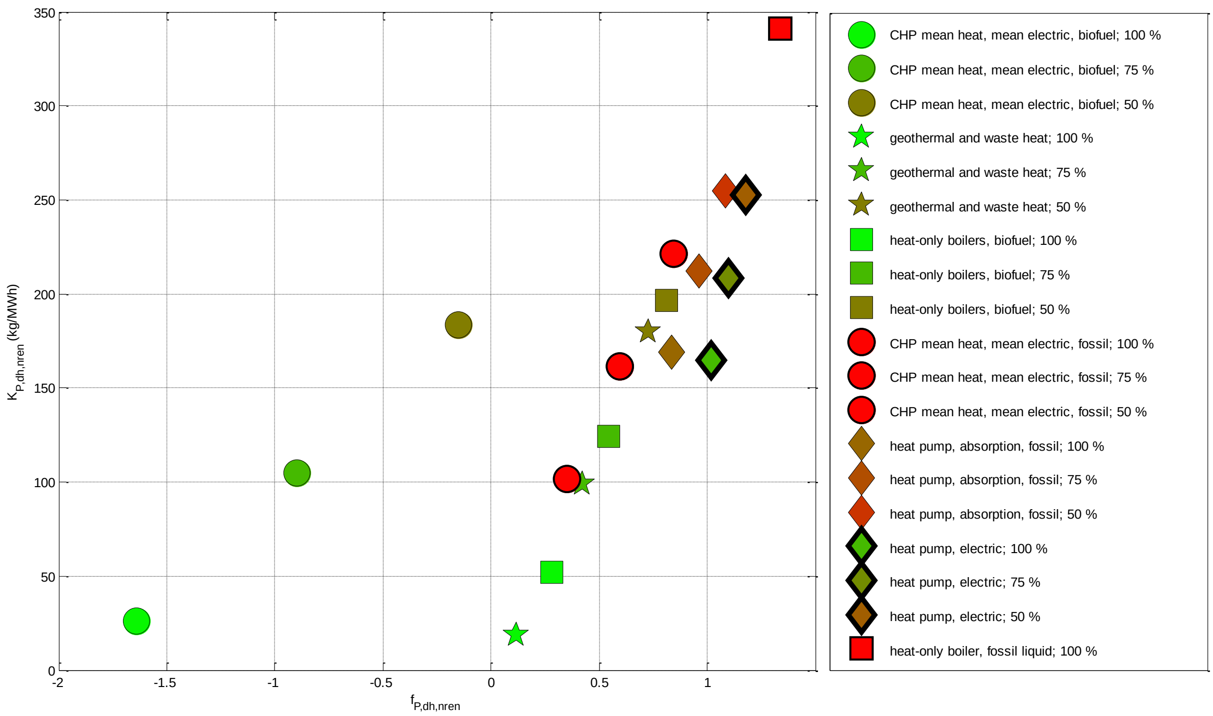


Figure 4: Performance indicators for selected combinations of preferential production types and a non-preferential heat only liquid fossil fuel boiler, distribution efficiency 90%.

Table 23: Performance indicators for selected combinations of preferential production types and a non-preferential heat only liquid fossil fuel boiler, distribution efficiency 90%.

preferential production type	$f_{P,dh,nren}$	$K_{P,dh,nren}$ (kg/MWh)	R_{dh} (%)
CHP mean heat, mean electric, bio fuel; 100 %	-1.6	26	100
CHP mean heat, mean electric, bio fuel; 75 %	-0.9	105	75
CHP mean heat, mean electric, bio fuel; 50 %	-0.2	183	50
Geothermal and waste heat; 100 %	0.1	19	100
Geothermal and waste heat; 75 %	0.4	99	75
Geothermal and waste heat; 50 %	0.7	180	50
Heat-only boilers, bio fuel; 100 %	0.3	52	100
Heat-only boilers, bio fuel; 75 %	0.5	124	75
Heat-only boilers, bio fuel; 50 %	0.8	196	50
CHP mean heat, mean electric, fossil; 100 %	0.4	102	0
CHP mean heat, mean electric, fossil; 75 %	0.6	161	0
CHP mean heat, mean electric, fossil; 50 %	0.8	221	0
Heat pump, absorption, fossil; 100 %	0.8	169	41
Heat pump, absorption, fossil; 75 %	1.0	212	31
Heat pump, absorption, fossil; 50 %	1.1	255	21
Heat pump, electric; 100 %	1.0	165	69
Heat pump, electric; 75 %	1.1	209	52
Heat pump, electric; 50 %	1.2	253	34

Table 24: Indication for the classification of performance indicators for selected combinations of preferential production types and a non-preferential heat only liquid fossil fuel boiler, distribution efficiency 90%.

preferential production type	Class $f_{P,dh,nren}$	Class $K_{P,dh,nren}$	Class R_{dh}
CHP mean heat, mean electric, bio fuel; 100 %	1	1	1
CHP mean heat, mean electric, bio fuel; 75 %	1	1	1
CHP mean heat, mean electric, bio fuel; 50 %	1	2	2
Geothermal and waste heat; 100 %	1	1	1
Geothermal and waste heat; 75 %	2	1	1
Geothermal and waste heat; 50 %	2	2	2
Heat-only boilers, bio fuel; 100 %	1	1	1
Heat-only boilers, bio fuel; 75 %	2	2	1
Heat-only boilers, bio fuel; 50 %	3	2	2
CHP mean heat, mean electric, fossil; 100 %	1	1	7
CHP mean heat, mean electric, fossil; 75 %	2	2	7
CHP mean heat, mean electric, fossil; 50 %	3	2	7
Heat pump, absorption, fossil; 100 %	3	2	2
Heat pump, absorption, fossil; 75 %	3	2	2
Heat pump, absorption, fossil; 50 %	3	3	2
Heat pump, electric; 100 %	3	2	1
Heat pump, electric; 75 %	3	2	2
heat pump, electric; 50 %	3	3	2

4.2.5 Effect of distribution efficiency

In the analysis so far, a constant distribution efficiency of 90% has been taken in all calculations.

In case of another distribution efficiency of the heating network, other values are obtained for $f_{P,dh,nren}$ and $K_{P,dh,nren}$. Because the governing equations for these indicators are linear[11], their values scale proportionally with the reciprocal value of the distribution efficiency. For example $f_{P,dh,nren}$ and $K_{P,dh,nren}$ increase by a factor 0.9/0.6 = 1.5 when the distribution efficiency drops from 90% to 60%. This specific example is, for the 20 combination of § 4.2.3 shown in Figure 5.

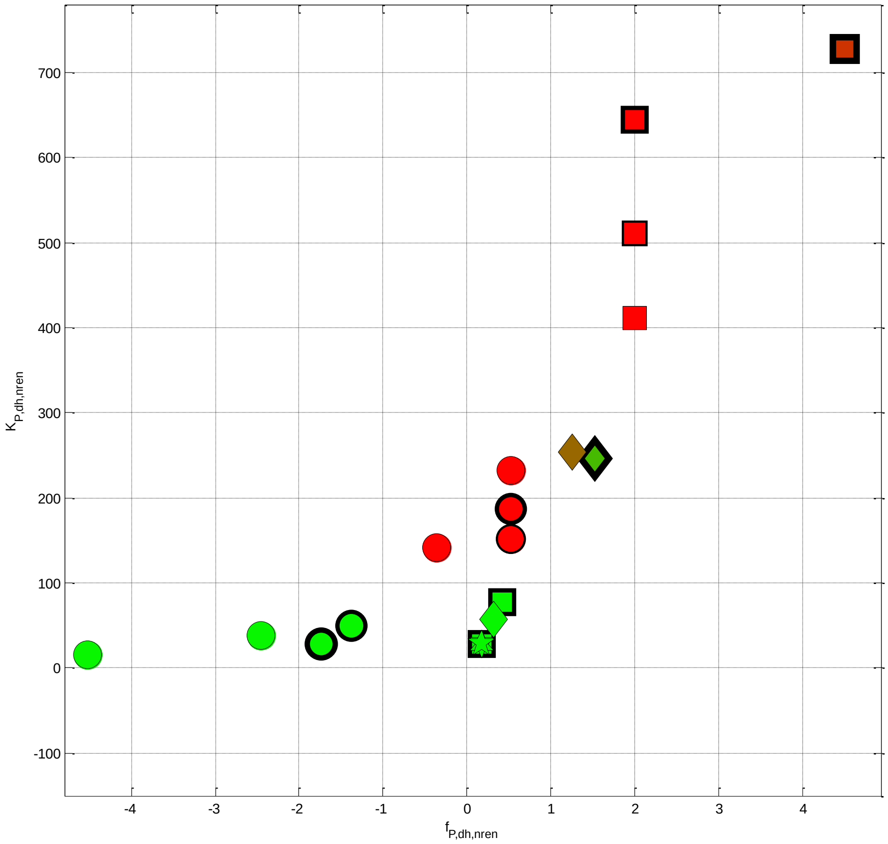


Figure 5: Performance indicators of the 20 combinations for a network distribution efficiency of 60%. Legend see Figure 2.

Note that a negative value for $f_{P,dh,nren}$ will become even more negative when the distribution efficiency gets worse.

[11] Excluding influences of external heat supply and assuming that the auxiliary electricity to run the network scales with the heat produced.

The value of R_{dh} is unaffected by the network distribution efficiency.

4.2.6 Sensitivity to the properties of electricity

All the calculations so far take the current EU-average properties for the electrical grid. However, the share of renewable fuels to generate electricity across Europe is foreseen to gradually increase in the coming years (decarbonisation). Especially the Ecoheat performance of systems that use or produce electricity may therefore change as well. In this paragraph this dependence is discussed.

Properties of electricity

Currently, for the EU-average we have for electricity:

$f_{P,el}$ = 2.6
$K_{P,el}$ = 420 kg/MWh
R_{el} = 20 %.

Now, assuming that f and K vary linearly with the extreme situation of a fully decarbonised grid:

$f_{P,el}$ = 0
$K_{P,el}$ = 0 kg/MWh
R_{el} = 100 %,

we can define the following relations, taking R_{dh} as independent variable:

$f_{P,el} = (100 - R_{dh})/80*2.6$
$K_{P,el} = (100 - R_{dh})/80*420$ kg/MWh

Results

Calculations on selected DH-systems were done for EU-average electricity values, as well as for the extreme situation of a fully 100% renewable electrical grid. The selected DH-systems are given in Table 25. These calculations were done with a 90% distribution efficiency. The corresponding results are shown in Figure 6.

Table 25: Selected combinations of fuel type and production type

comb. nr	production type	fuel type
5	CHP mean heat, mean electric	Fossil fuel, solid
6	CHP mean heat, mean electric	Bio and residual fuels, gas and liquid
9	Heat-only boilers, excl. heat pumps	Electricity
11	Heat-only boilers, excl. heat pumps	Fossil fuel, liquid
13	Heat-only boilers, excl. heat pumps	Bio and residual fuels, gas and liquid
16	Heat pump, electric	Electricity
17	Heat pump, absorption	Fossil fuel, gas
18	Heat pump, absorption	Bio and residual fuels, gas
19	Solar collectors	Solar heat
20	Geothermal and waste heat	Geothermal and waste heat

Clearly, decarbonisation of the electrical grid has the most positive impact on:

- heat-only electrical boilers
- electrical heat pumps

a minor positive impact on:

- absorption heat pumps
- heat-only boilers using fuel (no electricity)
- solar and geothermal systems
- electrical heat pumps

and a negative impact on

- combined heat and power plants

For example, with the current EU-average grid, electrical heat pumps perform worse than fossil-fuel CHP. However, for a 40% renewable electrical grid, electrical heat pump and fossil fuel CHP perform equally well (on *f* and *K*). For a further decarbonised grid, electrical heat pumps outperform fossil fuel CHP.

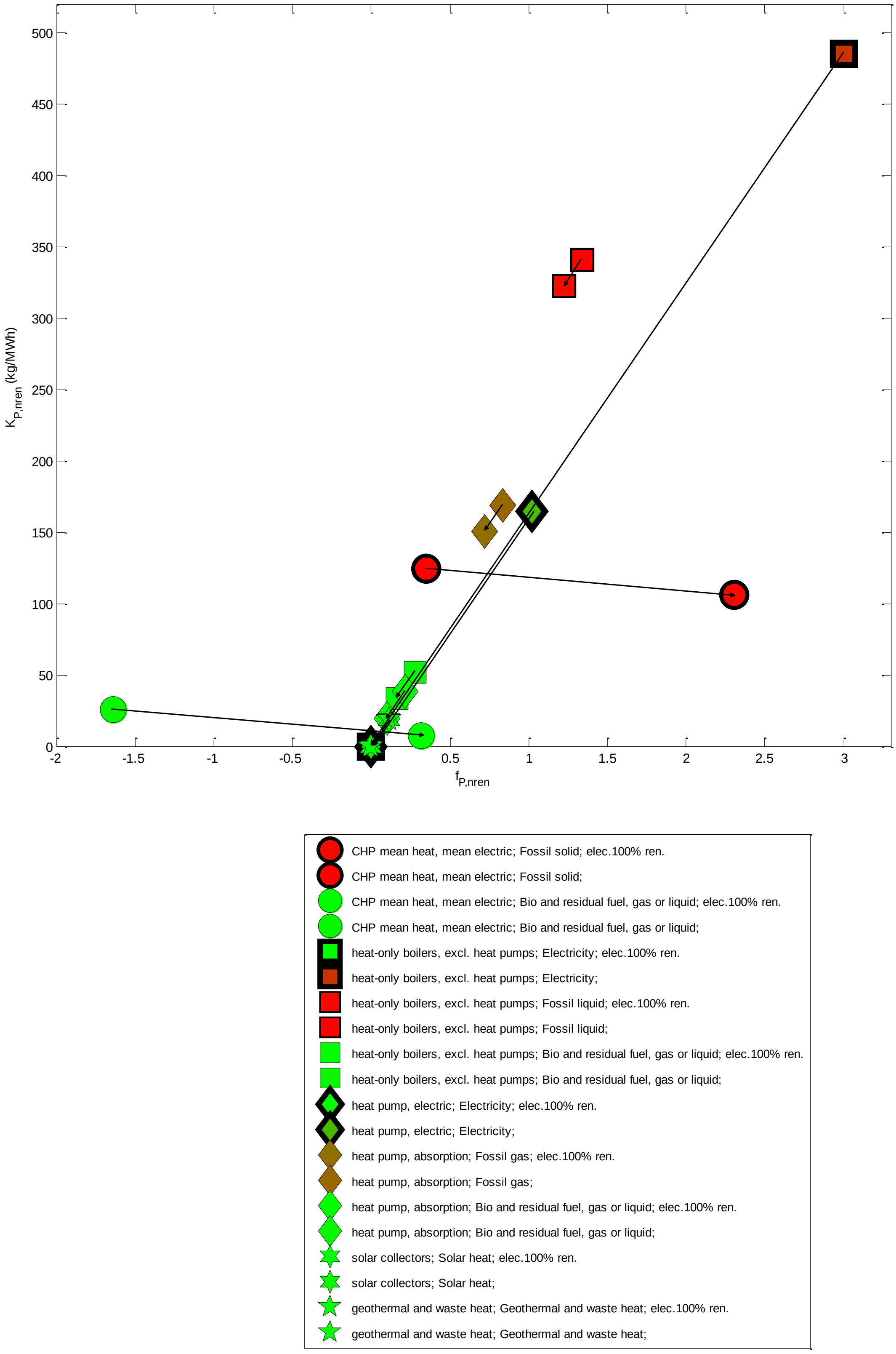

K_P,nren (kg/MWh)
f_P,nren
500
450
400
350
300
250
200
150
100
50
0
-2
-1.5
-1
-0.5
0.5
1
1.5
2
2.5
3
CHP mean heat, mean electric; Fossil solid; elec.100% ren.
CHP mean heat, mean electric; Fossil solid;
CHP mean heat, mean electric; Bio and residual fuel, gas or liquid; elec.100% ren.
CHP mean heat, mean electric; Bio and residual fuel, gas or liquid;
heat-only boilers, excl. heat pumps; Electricity; elec.100% ren.
heat-only boilers, excl. heat pumps; Electricity;
heat-only boilers, excl. heat pumps; Fossil liquid; elec.100% ren.
heat-only boilers, excl. heat pumps; Fossil liquid;
heat-only boilers, excl. heat pumps; Bio and residual fuel, gas or liquid; elec.100% ren.
heat-only boilers, excl. heat pumps; Bio and residual fuel, gas or liquid;
heat pump, electric; Electricity; elec.100% ren.
heat pump, electric; Electricity;
heat pump, absorption; Fossil gas; elec.100% ren.
heat pump, absorption; Fossil gas;
heat pump, absorption; Bio and residual fuel, gas or liquid; elec.100% ren.
heat pump, absorption; Bio and residual fuel, gas or liquid;
solar collectors; Solar heat; elec.100% ren.
solar collectors; Solar heat;
geothermal and waste heat; Geothermal and waste heat; elec.100% ren.
geothermal and waste heat; Geothermal and waste heat;

Figure 6: Performance indicators for selected combinations, with current EU-average electricity grid and a 100% renewable grid, see Table 25. The arrows indicate the change when going from the current 20% renewable grid toward an imaginary 100% renewable grid.

4.2.7 Ecodesign efficiency method

So far, the analysis has been based on the three environmental criteria of the Ecoheat4Cities heating performance label. On the other hand, the European Ecodesign and labelling regulations for *individual* boilers takes the approach of only considering the efficiency as criterion. For that reason, and to obtain a complete picture, this performance indicator is presented in this paragraph for both district heating and individual options.

Definition of efficiency

In principle, the system efficiency according to the Ecodesign approach, may calculated as:

$$\eta_{sys} = \frac{Q_{del} + \dfrac{(E_{el,cogen} - E_{el,aux})}{\eta_{el,ref}}}{E}$$

where

Q_{del} = heat delivered by the heat generation system (MWh)

$E_{el,cogen}$ = cogenerated electricity (MWh)

$E_{el,aux}$ = auxiliary electricity (MWh)

$\eta_{el,ref}$ = reference electrical generation efficiency (43%[12])

E = energy content of input to the heat generation system (MWh, LHV-basis)

The efficiency η_{sys} as defined here uses lower heating value of the fuel. Note that the Ecodesign uses higher heating values.

Results

The selected DH-systems as given in Table 18 were used in the calculations, taking a 90% distribution efficiency. Results are shown in Table 26.

[12] Higher heating value in Ecodesign method is 40%. The value of 43% is an estimate based on HHV/LHV ratios of fuels to generate electricity, see also Table 30.

Table 26: System efficiency of combinations as defined in Table 18, distribution efficiency 90%

comb. nr	production type	fuel type	η_{sys}
1	CHP low heat, high electric	Fossil fuel, gas	140
2	CHP low heat, high electric	Bio and residual fuels, gas and liquid	140
3	CHP mean heat, mean electric	Fossil fuel, gas	131
4	CHP mean heat, mean electric	Fossil fuel, liquid	131
5	CHP mean heat, mean electric	Fossil fuel, solid	131
6	CHP mean heat, mean electric	Bio and residual fuels, gas and liquid	131
7	CHP high heat, low electric	Bio and residual fuels, solid	125
8	CHP high heat, low electric	Waste as fuel	125
9	Heat-only boilers, excl. heat pumps	Electricity	35
10	Heat-only boilers, excl. heat pumps	Fossil fuel, gas	81
11	Heat-only boilers, excl. heat pumps	Fossil fuel, liquid	81
12	Heat-only boilers, excl. heat pumps	Fossil fuel, solid	81
13	Heat-only boilers, excl. heat pumps	Bio and residual fuels, gas and liquid	81
14	Heat-only boilers, excl. heat pumps	Bio and residual fuels, solid	81
15	Heat-only boilers, excl. heat pumps	Waste as fuel	81
16	Heat pump, electric	Electricity	111
17	Heat pump, absorption	Fossil fuel, gas	137
18	Heat pump, absorption	Bio and residual fuels, gas	137
19	Solar collectors	Solar heat	infinite
20	Geothermal and waste heat	Geothermal and waste heat	-$

$Geothermal and waste heat not defined in Ecodesign

Globally, the efficiency performance of these systems may be grouped as given in Table 27.

Table 27: Typical system efficiency of DH plants, distribution efficiency 90%.

production type	fuel type	η_{sys}
CHP	Any type, except electricity	125 - 140
Heat-only boilers	Electricity	35
Heat-only boilers	Any type, except electricity	80
Electric heat pumps	Electricity	110
Absorption heat pumps	Any type, except electricity	135
Solar collectors	Solar heat	infinite

The approximate performance hierarchy when considering the efficiency is as follows:

Table 28: Approximate energy performance hierarchy of DH production facilities according to Ecodesign efficiency principles.

nr.	production type	fuel type
1	Solar collectors[$]	-
2	CHP and absorption heat pumps	any type, except electricity
3	Electric heat pumps	Electricity
4	Heat-only boilers	any type, except electricity
5	Heat-only boilers	Electricity

[$]Geothermal and waste heat may rank first as well

Geothermal and waste heat are not considered in the Ecodesign. One may argument that these should be treated equal to solar energy and therefore also rank first.

As the efficiency is the only performance criterion in the Ecodesign method, the classification is not as refined as in the performance assessment method developed in the Ecoheat4Cities project. The additional ordering in the latter approach is largely due to the consideration of the renewability of the fuels and/or whether these are recycled. These fuels rank relatively high in the Ecoheat4Cities assessment method.

4.2.8 Performance hierarchy

The energy performance in terms of the indicators

- $f_{P,dh,nren}$, the non-renewable primary energy factor of DH
- $K_{P,dh,nren,}$ the non-renewable primary CO_2-emission coefficient of DH
- R_{dh}, the ratio of heat from renewable/recycled energy carriers to the total heat

for DH single production types, based on calculations with a limited set of realistic combinations of DH production facility and fuel type as outlined in § 4.2.3, show that an approximate energy performance hierarchy can be established. When the emphasis is put on the primary energy factor en CO_2-emission, the order of performance is as follows, starting with the best performing combination:

Table 29: Approximate energy performance hierarchy of current DH production facilities when emphasis is put on primary energy factor and CO_2-emission.

gr.	production type	fuel type	Class $f_{P,dh,nren}$	Class $K_{P,dh,nren}$	Class R_{dh}
1	CHP	Bio and residual fuel	1	1	1
2	Solar collectors geoth. and waste heat	Solar geoth. and waste heat	1	1	1
3	Heat only boilers heat pump absorption	Bio and residual fuel waste as fuel	1	1	1
4	CHP	Fossil fuel	1	1 – 2	7
5	Heat pump absorption	Fossil fuel	2 - 3	2	2
6	Heat pump	Electricity	3	2	1
7	Heat only boilers	Fossil fuel	4	3 – 4	7
8	Heat only boilers	Electricity	7	5	3

Generally, the best performing production facilities use either bio fuel, residual fuel, solar energy, geothermal heat or waste heat. Of these, combined heat and power production using bio or residual fuel ranks first (1), followed by solar, geothermal and waste heat (2), and subsequently by heat only boilers and absorption heat pumps (3).

Using fossil fuels or electricity always gives a lower performance. But if these are being used, combined heat and power production is the best option (4) (if the share of renewable/recycle fuel carriers is discarded), followed by absorption heat pumps (5) and electric heat pumps (6). Lowest performance is seen for heat only boilers on fossil fuel (7) or electricity (8).

If the performance hierarchy would focus on the share of renewable/recycled fuel carriers, best options are then to use bio en residual fuels, solar heat, geothermal heat and waste heat (100% share). Electrically driven heat pumps are characterised by a reasonably high share (≈75%), followed by fossil fuel driven absorption heat pumps (≈40%). Electricity for Joule heating has a renewable/recycled share of 20%. The use of fossil fuels in CHP of heat only boilers gives the lowest share (0%).

4.3 Performance of individual heating systems

4.3.1 Heat consumption of individual buildings

When considering individual systems, one needs to consider the energy consumption for space and water heating separately as a result of possibly different generation efficiencies. Therefore, the heat consumption is split into building specific heat consumption for space heating ε_H (kWh/m^{2}y) and a building specific heat consumption for water heating ε_W (kWh/m^{2}y)

Values for ε_H and ε_W may be taken from energy performance calculations of planned buildings in a district. Values may also be obtained from data of existing buildings that are similar to the planned buildings with respect to heat consumption. For example, for a Dutch dwelling $\varepsilon_W \approx 25$ kWh/m^{2}y based on a distribution efficiency in the dwelling of 75% and no heat recovery appliances like e.g. a shower heat exchanger.

Design data for the total specific heat consumption of buildings were given in Table 11.

4.3.2 Calorific values

Efficiencies for individual systems are normally given as higher heating value (HHV), whereas the Ecoheat4Cities labelling method is based on lower heating values (LHV) of the fuel. Therefore a conversion is necessary to obtain an unbiased comparison. The ratio HHV/LLV of the fuels is listed in Table 30.

Table 30: Ratio HHV/LLH of fuels.

Fuel	HHV/LLH	Reference
Lignite	1.1	UN studies in methods, series F, nr. 44
Hard Coal	1.05	UN studies in methods, series F, nr. 44, wet basis
Heavy fuel oil	1.06	EN 677:1998
Light fuel oil	1.06	EN 677:1998
Natural Gas	1.11	EN 677:1998
Peat	1.29	based on 20% moisture
Gas and liquid bio fuel	1.1	Estimate
Gas and liquid residual fuel	1.1	Estimate
Gas and liquid waste as fuel	1.1	Estimate
Solid bio fuel	1.23	based on 20% moisture, e.g. wood
Solid bio fuel, refined	1.12	based on 10% moisture, e.g. pellets
Solid residual fuel	1.23	based on 20% moisture
Solid waste as fuel	1.23	based on 20% moisture

4.3.3 Fuel grouping

The same lumping as in § 4.2.1 is used, except that waste as fuel is discarded, see also Table 14.

4.3.4 Production grouping

Heat-only boilers for space heating

For heat only boilers, excluding heat pumps, the heating efficiency (HHV) ranges between 40% for very low-end boilers to 100% for high-end condensing or electrical boilers. In this analysis four categories are chosen with an efficiency of 40%, 60%, 80% and 100% respectively.

For electrical heat pumps, efficiency (COP) values range approximately between 200% for low-end air source heat pumps to 400% for high-end ground source heat pumps. These generation systems are shown in Table 31.

Table 31: Aggregation of heat-only individual systems for space heating

prod. nr.	production type	η_{heat} (%)
1	Heat pump 200%	200
2	Heat pump 300%	300
3	Heat pump 400%	400
4	Boiler 40%	40
5	Boiler 60%	60
6	Boiler 80%	80
7	Boiler 100%	100

Heat-only boilers for water heating

For heat only boilers, excluding heat pumps, the heating efficiency (HHV) ranges between 40% for very low-end boilers to 76% for high-end boilers. In this analysis four categories are chosen with an efficiency of 40%, 52%, 64% and 76% respectively. Electrical instantaneous systems have an efficiency of nearly 100%.

For electrical heat pumps, the efficiency (COP) values range from 180% for low-end air source heat pumps, 240% for high-end ground source heat pumps, until over 300% for high-end exhaust air heat pumps. These generation systems, including solar collectors, are shown in Table 31.

Table 32: Aggregation of heat-only individual systems for water heating

prod. nr.	production type	η_{heat} (%)
1	Heat pump 180%	180
2	Heat pump 210%	210
3	Heat pump 240%	240
4	Heat pump exhaust air 300%	300
5	Boiler 40%	40
6	Boiler 52%	52
7	Boiler 64%	64
8	Boiler 76%	76
9	Instantaneous electrical	100

Cogeneration

Individual co-generation systems are considered separately because their electrical power output is generally not proportional to the heating power output. The electrical power is often lower as a result of a mismatch with electrical demand and/or limitations of delivering electricity to a (public) network. Co-generation systems can therefore be seen as a bivalent system with a preferential co-generation boiler and a non-preferential heat-only boiler. The share of the preferential system varies significantly with the heat demand profile in relation to the capacity of the system.

The grouping of cogeneration boilers is based on technology type. For the current technology of Stirling and gas engines, the efficiencies for space and water heating are given in Table 33 and Table 34.

Table 33: Aggregation of individual cogeneration systems for space heating.

prod. nr.	production type	η_{heat} (%)	η_e (%)
1	Cogen, low electric	75	11
2	Cogen, high electric	65	23

Table 34: Aggregation of individual cogeneration systems for water heating.

prod. nr.	production type	η_{heat} (%)	η_e (%)
1	Cogen, low electric	60	11
3	Cogen, high electric	52	23

Auxiliary electricity use

The auxiliary electricity use of all individual systems was set at 1% of the produced heat.

4.3.5 Combinations

The number of possible combinations for individual systems is much larger than for district heating systems. This is due to a separation of heat generation into space and water heating, a larger range of energy efficiencies of systems and varying share of space and heating demand. Therefore, a further selection is suggested.

4.3.5.1 Combination set #1

A first selection considers:

- monovalent heat-only systems
- systems with the same fuel type for space and water heating
- generally matching the energy efficiency of the space heating system with the efficiency of the water heating system. In other words, it is expected that high-end space heating will be combined with high-end water heating, and vice versa.
- ratio of space heat demand to water heat demand equals 1. This is representative for well-insulated modern dwellings

From these conditions, 28 combinations follow, listed in Table 35.

The three performance indicators of the selected combinations, in addition to the total primary energy factor, are listed in Table 36 and shown in Figure 7. In this figure:

- the non-renewable primary energy factor $f_{P,dh,nren}$ is plotted on the horizontal axis
- the non-renewable primary CO_2-emission coefficient K_P is plotted on the vertical axis
- the ratio of heat from renewable/recycled energy carriers to the total heat R_{dh} is shown as the fill colour of the markers ranging from green (100% renewability) to red (0% renewability).
- the production type is associated with a marker type
- the fuel type is associated with the line width of each marker:
    - solar, geothermal and waste heat very thin line
    - gas thin line
    - liquid normal line
    - solid rather thick line
    - waste thick line
    - electricity very thick line
- for heat-only boilers, higher-end systems are associated with a bigger marker

Table 35: Combination set #1 for individual systems.

comb. nr	space heating	water heating	fuel type
1	Heat pump 200%	Heat pump 180%	Electricity
2	Heat pump 300%	Heat pump 210%	Electricity
3	Heat pump 400%	Heat pump 240%	Electricity
4	Heat pump 200%	Heat pump exh. air 300%	Electricity
5	Heat pump 300%	Heat pump exh. air 300%	Electricity
6	Heat pump 400%	Heat pump exh. air 300%	Electricity
7	Boiler 100%	Boiler 76%	Electricity
8	Boiler 100%	Instantaneous electrical	Electricity
9	Boiler 40%	Boiler 40%	Fossil solid
10	Boiler 60%	Boiler 52%	Fossil solid
11	Boiler 80%	Boiler 64%	Fossil solid
12	Boiler 100%	Boiler 76%	Fossil solid
13	Boiler 40%	Boiler 40%	Fossil liquid
14	Boiler 60%	Boiler 52%	Fossil liquid
15	Boiler 80%	Boiler 64%	Fossil liquid
16	Boiler 100%	Boiler 76%	Fossil liquid
17	Boiler 40%	Boiler 40%	Fossil gas
18	Boiler 60%	Boiler 52%	Fossil gas
19	Boiler 80%	Boiler 64%	Fossil gas
20	Boiler 100%	Boiler 76%	Fossil gas
21	Boiler 40%	Boiler 40%	Bio and residual fuel, solid
22	Boiler 60%	Boiler 52%	Bio and residual fuel, solid
23	Boiler 80%	Boiler 64%	Bio and residual fuel, solid
24	Boiler 100%	Boiler 76%	Bio and residual fuel, solid
25	Boiler 40%	Boiler 40%	Bio and residual fuel, gas or liquid
26	Boiler 60%	Boiler 52%	Bio and residual fuel, gas or liquid
27	Boiler 80%	Boiler 64%	Bio and residual fuel, gas or liquid
28	Boiler 100%	Boiler 76%	Bio and residual fuel, gas or liquid

Table 36: Performance indicators combination set #1, see Table 35.

comb. nr	space heating	water heating	fuel type	$f_{P,nren}$	$K_{P,nren}$ (kg/MWh)	R (%)
1	HP 200%	HP 180%	Electricity	1.4	226	58
2	HP 300%	HP 210%	Electricity	1.1	174	68
3	HP 400%	HP 240%	Electricity	0.9	144	73
4	HP 200%	HP e. air 300%	Electricity	1.1	179	67
5	HP 300%	HP e. air 300%	Electricity	0.9	144	73
6	HP 400%	HP e. air 300%	Electricity	0.8	127	77
7	Boiler 100%	Boiler 76%	Electricity	3.0	491	20
8	Boiler 100%	Instant. elec.	Electricity	2.6	424	20
9	Boiler 40%	Boiler 40%	Fossil solid	2.6	885	0
10	Boiler 60%	Boiler 52%	Fossil solid	1.9	637	0
11	Boiler 80%	Boiler 64%	Fossil solid	1.5	500	0
12	Boiler 100%	Boiler 76%	Fossil solid	1.2	412	0
13	Boiler 40%	Boiler 40%	Fossil liquid	2.6	688	0
14	Boiler 60%	Boiler 52%	Fossil liquid	1.9	495	0
15	Boiler 80%	Boiler 64%	Fossil liquid	1.5	389	0
16	Boiler 100%	Boiler 76%	Fossil liquid	1.2	321	0
17	Boiler 40%	Boiler 40%	Fossil gas	2.5	522	0
18	Boiler 60%	Boiler 52%	Fossil gas	1.8	376	0
19	Boiler 80%	Boiler 64%	Fossil gas	1.4	296	0
20	Boiler 100%	Boiler 76%	Fossil gas	1.2	244	0
21	Boiler 40%	Boiler 40%	Bio/res., solid	0.3	65	100
22	Boiler 60%	Boiler 52%	Bio/res., solid	0.2	48	100
23	Boiler 80%	Boiler 64%	Bio/res., solid	0.2	38	100
24	Boiler 100%	Boiler 76%	Bio/res., solid	0.2	32	100
25	Boiler 40%	Boiler 40%	Bio/res., gas/liq.	0.4	72	100
26	Boiler 60%	Boiler 52%	Bio/res., gas/liq	0.3	53	100
27	Boiler 80%	Boiler 64%	Bio/res., gas/liq.	0.2	43	100
28	Boiler 100%	Boiler 76%	Bio/res., gas/liq	0.2	36	100

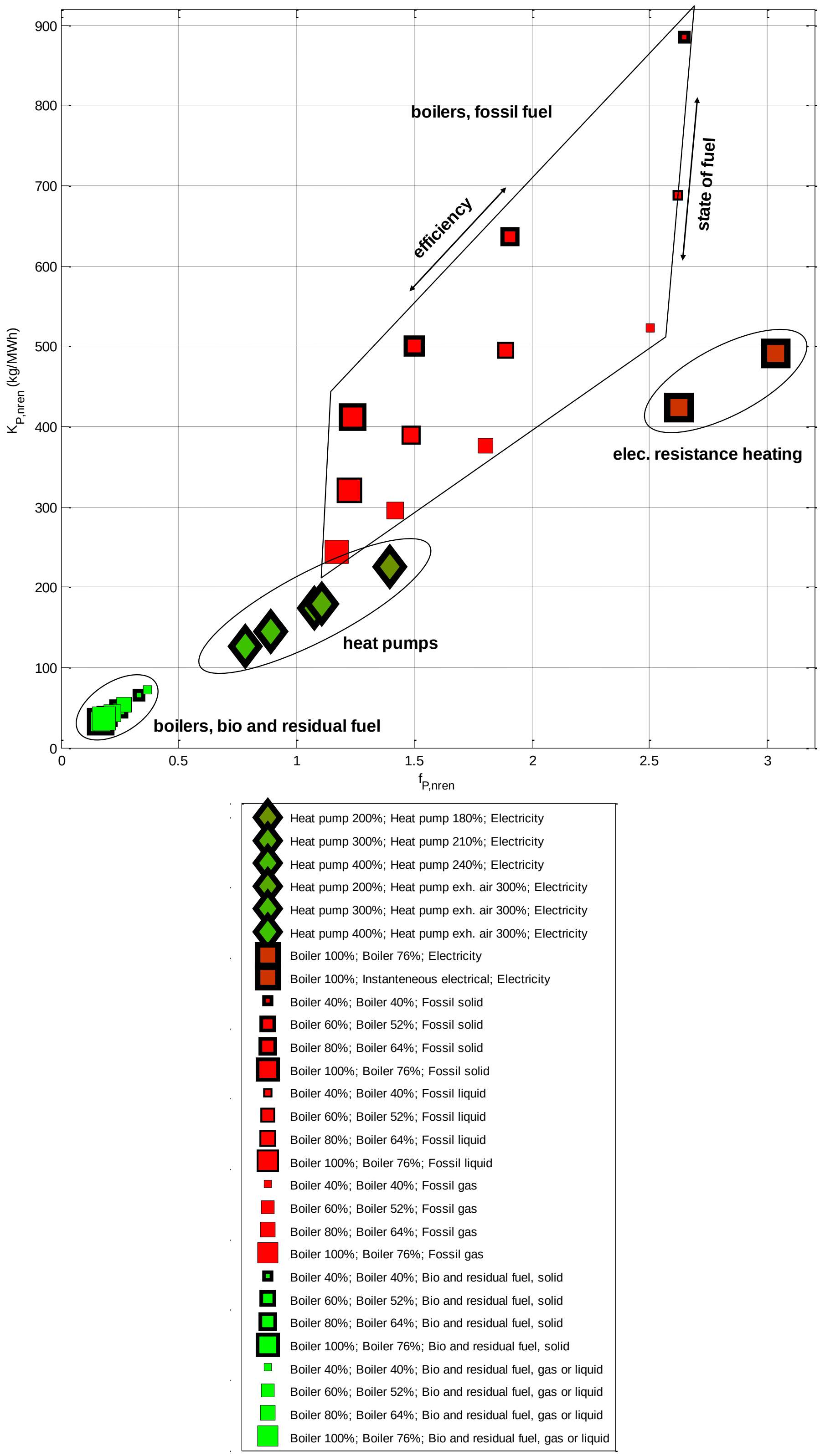


Figure 7: Performance indicators for combination set #1, see Table 35.

The combinations shown in Figure 7 may be subdivided into groups with similar performance. These groups with their approximate range of the performance indicators are given in Table 37, and corresponding classification in Table 38. The classification for R_{dh} is based on default EU27 values (Tier 1).

Table 37: Performance indicators of combination set #1, see Table 35.

group nr.	production type	fuel type	$f_{P,nren}$	$K_{P,nren}$ (kg/MWh)	R (%)
1	Heat-only boilers	Bio and residual fuel	0.2 – 0.4	30 – 70#	100
2	Heat pumps, higher end	Electricity	0.8 – 1.1	130 - 180	67 - 77
3	Heat pumps, lower end	Electricity	1.1 – 1.4	170 - 230	57 - 67
4	Heat only boilers, higher end	Fossil	1.2 – 1.6	240 – 550#	0
5	Heat only boilers, lower end	Fossil	1.6 – 2.6	330 – 890#	0
6	Electrical resistance heating	Electricity	2.6 – 3.0	420 - 490	20

#generally, the higher values for solids, the lower values for gas

Table 38: Indication for the classification of performance indicators of combination set #1, see Table 35.

group nr.	production type	fuel type	Class $f_{P,nren}$	Class $K_{P,nren}$	Class R
1	Heat-only boilers	Bio and residual fuel	1	1	1
2	Heat pumps, higher end	Electricity	2 - 3	2	1
3	Heat pumps, lower end	Electricity	3 - 4	2 - 3	1 – 2
4	Heat-only boilers, higher end	Fossil	3 - 4	3 – 5#	7
5	Heat-only boilers, lower end	Fossil	5 - 7	4 – 7#	7
6	Electrical resistance heating	Electricity	7	4 - 5	3

#generally, the poorer classification for solids, the better classification for gas

4.3.5.2 Combination set #2, cogeneration systems

Combination set #2 is formed by:

- cogeneration systems
- gas as fuel

The other conditions are the same as for combination set #1:

- systems with the same fuel type for space and water heating
- ratio of space heat demand to water heat demand equals 1

Co-generation systems can be considered as a bivalent system with a preferential co-generation boiler and a non-preferential heat-only boiler. The share of the preferential system varies significantly with the heat demand profile in relation to the capacity of the system. In this analysis, this share is varied from 30% to 70%. As individual cogeneration systems just appear on the market, the non-preferential boiler is assumed to be high-end.

From these conditions, 12 combinations follow, listed in Table 39.

Table 39: Combination set #2 for individual cogeneration systems.

comb. nr	space heating	water heating	fuel type	% share
1	Cogen, low electric	Cogen, low electric	Fossil gas	30
	Boiler 100%	Boiler 76%	Fossil gas	70
2	Cogen, low electric	Cogen, low electric	Fossil gas	50
	Boiler 100%	Boiler 76%	Fossil gas	50
3	Cogen, low electric	Cogen, low electric	Fossil gas	70
	Boiler 100%	Boiler 76%	Fossil gas	30
4	Cogen, high electric	Cogen, high electric	Fossil gas	30
	Boiler 100%	Boiler 76%	Fossil gas	70
5	Cogen, high electric	Cogen, high electric	Fossil gas	50
	Boiler 100%	Boiler 76%	Fossil gas	50
6	Cogen, high electric	Cogen, high electric	Fossil gas	70
	Boiler 100%	Boiler 76%	Fossil gas	30
7	Cogen, low electric	Cogen, low electric	Bio/residual, gas	30
	Boiler 100%	Boiler 76%	Bio/residual, gas	70
8	Cogen, low electric	Cogen, low electric	Bio/residual, gas	50
	Boiler 100%	Boiler 76%	Bio/residual, gas	50
9	Cogen, low electric	Cogen, low electric	Bio/residual, gas	70
	Boiler 100%	Boiler 76%	Bio/residual, gas	30
10	Cogen, high electric	Cogen, high electric	Bio/residual, gas	30
	Boiler 100%	Boiler 76%	Bio/residual, gas	70
11	Cogen, high electric	Cogen, high electric	Bio/residual, gas	50
	Boiler 100%	Boiler 76%	Bio/residual, gas	50
12	Cogen, high electric	Cogen, high electric	Bio/residual, gas	70
	Boiler 100%	Boiler 76%	Bio/residual, gas	30

The three performance indicators of the selected combinations, in addition to the total primary energy factor, are listed in Table 40 and shown in Figure 7

Table 40: Performance indicators combination set #2, see Table 39.

comb. nr	space and water heating	fuel type	share (%)	$f_{P,nren}$	$K_{P,nren}$ (kg/MWh)	R (%)
1	Cogen, low electric	Fossil gas	30	1.1	244	0
2	Cogen, low electric	Fossil gas	50	1.1	244	0
3	Cogen, low electric	Fossil gas	70	1.1	244	0
4	Cogen, high electric	Fossil gas	30	1.0	228	0
5	Cogen, high electric	Fossil gas	50	0.9	217	0
6	Cogen, high electric	Fossil gas	70	0.8	206	0
7	Cogen, low electric	Bio/residual, gas	30	0.1	35	100
8	Cogen, low electric	Bio/residual, gas	50	0.0	35	100
9	Cogen, low electric	Bio/residual, gas	70	-0.1	34	100
10	Cogen, high electric	Bio/residual, gas	30	-0.1	32	100
11	Cogen, high electric	Bio/residual, gas	50	-0.3	30	100
12	Cogen, high electric	Bio/residual, gas	70	-0.5	27	100

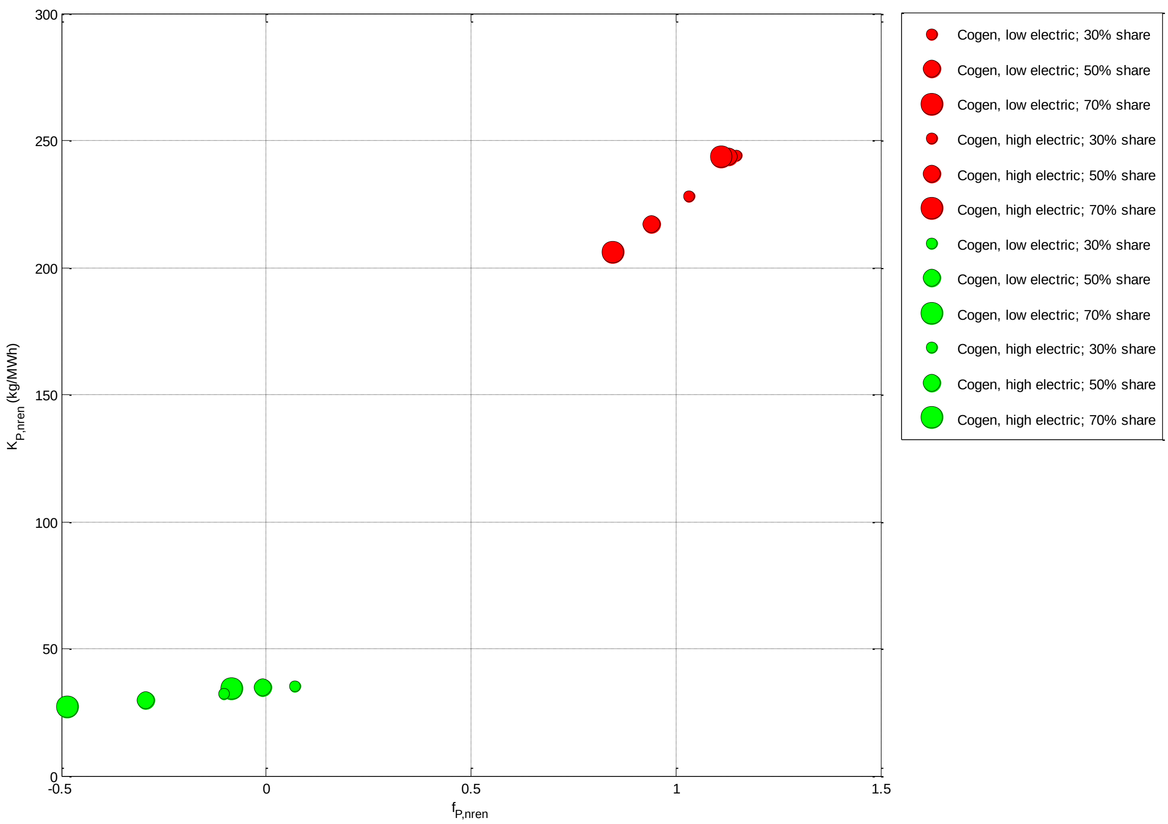


Figure 8: Performance indicators for combination set #2, see Table 39.

It is seen that the performance of individual cogeneration systems is not very sensitive to the actual electric generation efficiency and share in the total heat production. Therefore, for the given conditions, only 2 groups remain with rather similar performance, given in Table 41 with corresponding classification in Table 42. The classification for R_{dh} is based on default EU27 values (Tier 1).

Table 41: Performance indicators of combination set #2, see Table 39.

group nr.	production type	fuel type	$f_{P,nren}$	$K_{P,nren}$ (kg/MWh)	R (%)
7	Cogeneration	Bio/residual, gas	-0.5 – +0.1	30 – 40	100
8	Cogeneration	Fossil gas	0.8 – 1.1	200 – 240	0

Table 42: Indication for the classification of performance indicators of combination set #2, see Table 39.

group nr.	production type	fuel type	Class $f_{P,nren}$	Class $K_{P,nren}$	Class R
7	Cogeneration	Bio/residual, gas	1	1	1
8	Cogeneration	Fossil gas	3	2 - 3	7

4.3.5.3 Combination set #3, share space heating dominant

Combination set #3 is a subset of set #1 and set #2, but for buildings with a ratio for the space heat demand to water heat demand of 4. This demand profile is representative for existing dwellings with (still) a relatively low heat demand. As a result, the energy performance is dominated by the space heating system.

The subset is formed by taking the extremes of each group, see Table 43

Table 43: Combination set #3 for individual systems, space heating demand dominating.

comb. nr	space heating	water heating	fuel type
1	Heat pump 200%	Heat pump 180%	Electricity
2	Heat pump 400%	Heat pump exh. air 300%	Electricity
3	Boiler 100%	Boiler 76%	Electricity
4	Boiler 100%	Instantaneous electrical	Electricity
5	Boiler 40%	Boiler 40%	Fossil solid
6	Boiler 100%	Boiler 76%	Fossil solid
7	Boiler 40%	Boiler 40%	Fossil gas
8	Boiler 100%	Boiler 76%	Fossil gas
9	Boiler 40%	Boiler 40%	Bio and residual fuel, gas
10	Boiler 100%	Boiler 76%	Bio and residual fuel, gas
11	Cogen, low electric[#]	Cogen, low electric[#]	Fossil gas
12	Cogen, high electric[$]	Cogen, high electric[$]	Fossil gas
13	Cogen, low electric[#]	Cogen, low electric[#]	Bio and residual fuel, gas
14	Cogen, high electric[$]	Cogen, high electric[$]	Bio and residual fuel, gas

[#] 30% share; [$] 70% share

The performance indicators of the selected combinations, in addition to the total primary energy factor, are listed in Table 44 and shown in Figure 9.

Table 44: Performance indicators combination set #3, see Table 43.

comb. nr	space heating	water heating	fuel type	$f_{P,nren}$	$K_{P,nren}$ (kg/MWh)	R (%)
1	HP 200%	HP 180%	Electricity	1.4	219	59
2	HP 400%	HP exh. air 300%	Electricity	0.7	116	79
3	Boiler 100%	Boiler 76%	Electricity	2.8	451	20
4	Boiler 100%	Instant. electrical	Electricity	2.6	424	20
5	Boiler 40%	Boiler 40%	Fossil solid	2.6	885	0
6	Boiler 100%	Boiler 76%	Fossil solid	1.2	412	0
7	Boiler 40%	Boiler 40%	Fossil gas	2.5	522	0
8	Boiler 100%	Boiler 76%	Fossil gas	1.2	244	0
9	Boiler 40%	Boiler 40%	Bio/res., gas	0.4	72	100
10	Boiler 100%	Boiler 76%	Bio/res., gas	0.2	36	100
11	Cogen, low el.	Cogen, low el.	Fossil gas	1.1	225	0
12	Cogen, high el.	Cogen, high el.	Fossil gas	0.8	192	0
13	Cogen, low el.	Cogen, low el.	Bio/res., gas	0.1	33	100
14	Cogen, high el.	Cogen, high el.	Bio/res., gas	-0.5	26	100

The overall picture is that the performance is slightly better compared to set #1 and set #2. This is a result of somewhat better generation efficiency for space heating. Especially heat pumps are sensitive to the temperature level that needs to be reached. The corresponding classification is given in Table 45. In this table, differences with the classification for well-insulated modern dwellings are underlined.

Table 45: Indication for the classification of performance indicators of combination set #3, see Table 35. Differences with set #1 and set #2 are underlined.

group nr.	production type	fuel type	Class $f_{P,nren}$	Class $K_{P,nren}$	Class R
1	Heat-only boilers	Bio and residual fuel	1	1	1
2	Heat pumps, higher end	Electricity	2 – 3	<u>1</u> – 2	1
3	Heat pumps, lower end	Electricity	3 – 4	2 – 3	1 – 2
4	Heat-only boilers, higher end	Fossil	3 – 4	3 – 5[#]	7
5	Heat-only boilers, lower end	Fossil	5 – 7	4 – 7[#]	7
6	Electrical resistance heating	Electricity	<u>6</u>	4 – 5	3
7	Cogeneration	Bio/residual, gas	1	1	1
8	Cogeneration	Fossil gas	<u>2</u> - 3	2 – 3	7

[#] generally, the poorer classification for solids, the better classification for gas

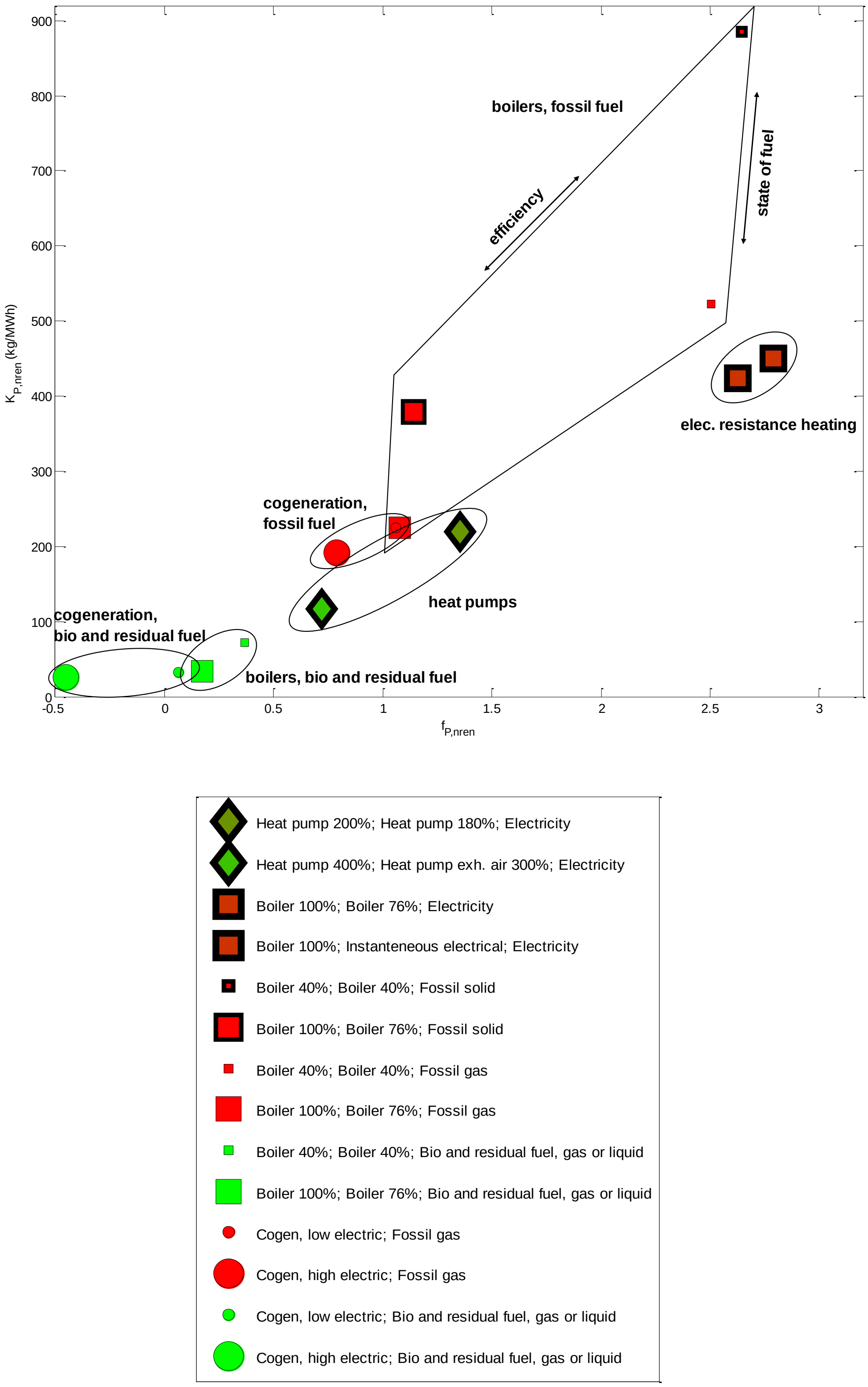


Figure 9: Performance indicators for combination set #3, see Table 43.

4.3.6 Solar assisted systems

The ecoheat performance of an installation will improve due to a contribution from active solar heat. As solar heat is fully renewable and CO_2-free, we have $f_{P,dh,nren} = 0$ and $K_{P,dh,nren} = 0$ for the solar share. Graphically, the performance of the total system is then found on the line between the origin[13] ($f_{P,dh,nren} = 0$, $K_{P,dh,nren} = 0$) and the point ($f_{P,dh,nren}$, $K_{P,dh,nren}$) of the system without active solar assistance. The position on that line depends on the share of solar heat to the total heat delivery. A 50% solar share will for example place the performance exactly in the middle of the connecting line.

It is clear that the ecoheat performance of systems already running on bio fuel will hardly take benefit from an active solar component (though fuel consumption will be lower of course).

4.3.7 Ecodesign efficiency method

Although the efficiency of the individual systems was already largely based on the Ecodesign preliminary study, it is recalculated here according to the definition of efficiency given in paragraph 4.2.7. By doing so, a complete and orderly picture of the efficiency (LHV-basis) of the above combinations for space and water heating is obtained.

Results

The efficiency of the systems given in Table 35 are shown in Table 46 and of the cogeneration systems given in Table 39 are shown in Table 47.

[13] Auxiliary electricity input to run the solar system is discarded here for convenience.

Table 46: System efficiency of combinations as defined in Table 35.

comb. nr	space heating	water heating	fuel type	η_{sys}
1	HP 200%	HP 180%	Electricity	79
2	HP 300%	HP 210%	Electricity	104
3	HP 400%	HP 240%	Electricity	126
4	HP 200%	HP e. air 300%	Electricity	101
5	HP 300%	HP e. air 300%	Electricity	126
6	HP 400%	HP e. air 300%	Electricity	144
7	Boiler 100%	Boiler 76%	Electricity	36
8	Boiler 100%	Instant. elec.	Electricity	42
9	Boiler 40%	Boiler 40%	Fossil solid	41
10	Boiler 60%	Boiler 52%	Fossil solid	57
11	Boiler 80%	Boiler 64%	Fossil solid	73
12	Boiler 100%	Boiler 76%	Fossil solid	89
13	Boiler 40%	Boiler 40%	Fossil liquid	41
14	Boiler 60%	Boiler 52%	Fossil liquid	58
15	Boiler 80%	Boiler 64%	Fossil liquid	74
16	Boiler 100%	Boiler 76%	Fossil liquid	89
17	Boiler 40%	Boiler 40%	Fossil gas	43
18	Boiler 60%	Boiler 52%	Fossil gas	60
19	Boiler 80%	Boiler 64%	Fossil gas	77
20	Boiler 100%	Boiler 76%	Fossil gas	94
21	Boiler 40%	Boiler 40%	Bio/res., solid	48
22	Boiler 60%	Boiler 52%	Bio/res., solid	67
23	Boiler 80%	Boiler 64%	Bio/res., solid	85
24	Boiler 100%	Boiler 76%	Bio/res., solid	104
25	Boiler 40%	Boiler 40%	Bio/res., gas/liq.	43
26	Boiler 60%	Boiler 52%	Bio/res., gas/liq	60
27	Boiler 80%	Boiler 64%	Bio/res., gas/liq.	76
28	Boiler 100%	Boiler 76%	Bio/res., gas/liq	93

Table 47: System efficiency of co-generation systems as defined in Table 39.

comb. nr	space and water heating	fuel type	share (%)	η_{sys}
1	Cogen, low electric	Fossil gas	30	96
2	Cogen, low electric	Fossil gas	50	98
3	Cogen, low electric	Fossil gas	70	99
4	Cogen, high electric	Fossil gas	30	105
5	Cogen, high electric	Fossil gas	50	111
6	Cogen, high electric	Fossil gas	70	116
7	Cogen, low electric	Bio/residual, gas	30	95
8	Cogen, low electric	Bio/residual, gas	50	97
9	Cogen, low electric	Bio/residual, gas	70	98
10	Cogen, high electric	Bio/residual, gas	30	104
11	Cogen, high electric	Bio/residual, gas	50	110
12	Cogen, high electric	Bio/residual, gas	70	115

Globally, the efficiency performance of these systems may be grouped and given an approximate performance hierarchy as listed in Table 48

Table 48: Indication for the efficiency hierarchy of individual heating systems according to the principles of the Ecodesign efficiency calculation method.

nr.	production type	fuel type	η_{sys}
1	Solar collectors	-	
2	Elec. heat pumps, high end	Electricity	125 - 150
3	Elec. heat pumps, average	Electricity	100 - 125
4	Cogeneration	Any type, except electricity	95 - 115
5	Heat only boilers, high-end	Any type, except electricity	85 - 100
6	Elec. heat pumps low-end	Electricity	75 - 100
7	Heat only boilers, average	Any type, except electricity	70 - 85
8	Heat only boilers, low-end	Any type, except electricity	55 - 70
9	Heat only boilers, very low-end	Any type, except electricity	40 - 55
10	Elec. resistance heating	Electricity	35 - 40

4.3.8 Performance hierarchy

The energy performance in terms of the indicators

- $f_{P,dh,nren}$, the non-renewable primary energy factor of DH
- $K_{P,dh,nren,}$ the non-renewable primary CO_2-emission coefficient of DH
- R_{dh}, the ratio of heat from renewable/recycled energy carriers to the total heat

for individual systems, based on calculations with a limited set of realistic combinations of individual production facility and fuel type as outlined in § 4.3.5.1 and § 4.3.5.2, show that an approximate energy performance hierarchy can be established. When the emphasis is put on the primary energy factor en CO_2-emission, the order of performance is as follows, starting with the best performing combination:

Table 49: Approximate energy performance hierarchy of individual heating systems when emphasis is put on primary energy factor and CO_2-emission.

nr.	production type	fuel type	Class $f_{P,nren}$	Class $K_{P,nren}$	Class R
1	Cogeneration	Bio/residual, gas	1	1	1
2	Heat-only boilers	Bio and residual fuel	1	1	1
3	Heat pumps, higher end	Electricity	2 - 3	2	1
4	Cogeneration	Fossil gas	2 - 3	2 - 3	7
5	Heat pumps, lower end	Electricity	3 - 4	2 - 3	1 – 2
6	Heat-only boilers, higher end	Fossil	3 - 4	3 – 5[#]	7
7	Heat-only boilers, lower end	Fossil	5 - 7	4 – 7[#]	7
8	Electrical resistance heating	Electricity	7	4 - 5	3

4.4 Comparing the performance of district heating and individual heating systems

The performance of DH en individual systems are given in Table 29 and Table 49, respectively. Generally, when comparing a DH production type/fuel with an identical individual production type/fuel, the performances are also quite equal. There is however one exception. District heating fossil fuel CHP scores significantly better than individual fossil fuel cogeneration systems. This is mainly due to the fact that the yearly electrical efficiency of individual systems is much lower due to technical limitations.

In addition, systems using geothermal energy and waste heat perform very well, for which there is no counterpart on an individual scale.

5 COST/BENEFIT ANALYSIS OF INDIVIDUAL AND DISTRICT HEATING SYSTEMS

5.1 Introduction

Economic feasibility plays a major role in the development or extension of CHP and district heating networks. The aim of this cost analysis is to give local governments and urban planners a general view of the relative costs of district heating and individual options. At the moment local governments are considering whether a district heating would be an option, they generally have no idea yet what cost levels are involved. This chapter intents to give the fundamentals of cost calculations at that level and to produce data useful to city planners. It cannot replace however a detailed study by specialized consultants, as the final costs may be highly dependent on local conditions and specific power plant and distribution design. To that end, an excel calculation tool was developed to assess the costs.

5.2 Choice for a calculation method: Net Present Value

The most simple method to use is the pay-back time method where the pay-back time is the initial investment divided by the annual revenues (or the annual savings). The advantage of this method is its simplicity, however it lacks precision as it does not account for inflation, changing energy prices and interests from loans for forefront investments. As the forefront investments in district heating are very high in comparison to individual options (i.e. systems with no distribution system) and the service life of district heating is also much longer than for individual options the pay-back time method may give inaccurate results, that will not tell whether the investment is finally worth it or not. That is why the preference was given to the Net Present Value method.

5.2.1 Present and future values

Since district heating networks are long lasting infrastructures (of more than 50 years), it is important to account for the long term value of invested money. The Net Present Value (NPV) method reflects on the profitability of an investment and tells us whether it is worth or not to decide for an investment in district heating, when having in mind how much return it should bring in the future. When the NPV is negative or zero, it is not profitable, when it is positive it is.

For a placement/investment with a rate of return r (also called hurdle rate), the future value of the investment next year (year 1) is $FV=PV(1+r)$, the year after (year 2) $FV=PV(1+r)(1+r)=PV(1+r)^2$, and in year n $FV=PV(1+r)^n$. (PV is the present value, i.e. the value of the investment now, in year 0)

The present value of the money flow FV_n in year n is then $PV_n=FV_n/(1+r)^n$. The higher the wanted rate of return, the lower the present value. This can be explained as follows:

Investments with a high risk have a high rate of return (e.g. 8-20%), meaning that if everything goes well the investor may have a high return in the future, but because the risks are high, the risk to lose some return in the future is also high. This is reflected in the present value: if you lose all the investments in the future, the present value of your investment I zero.

Conversely investments with a low risk have typically a low rate of return (e.g. 1 to 5 %, or at least following the inflation). The future gains are low, but because the risks are low as well, the risk of losing on your investments in the future are low, which is reflected by the high present value.

District heating systems may be generally considered as a low risk investment as they will always be a need for heating and for electricity (in the case of CHP). However, in a market where the energy demand decreases (zero-energy buildings) or where people choose for individual options (disconnecting markets), the risks may be higher, which should be reflected by a higher rate of return. The use of new, non-proven technology for a CHP-plant may also lead to the choice for a higher rate of return.

5.2.2 Net Present Value

Generally the cost analysis is not based simply on the change in time of a certain amount of money but on the net value of money inflows and outflows. FV_n is then defined as being the yearly gains, i.e. inflows (revenues R) minus the outflows (costs C) in year n. The present value of this cash flow is defined as:

$PV_n=FV_n/ (1+r)^n$, where $FV_n=(R-C)_n$ en PV_n is the present value of the gains in year n.
Of course, the gains will be accumulated over the years. The present value of the gains accumulated over n years is referred as the Net Present Value (NPV_n):

$$NPV_n= \sum_{i=0,n} (PV_i) = \sum_{i=0,n} (FV_i/(1+r)^i) = \sum_{i=0,n} ((R-C)_i/(1+r)^i)$$

The future value depends on the inflation j_1, the increase in energy prices j_2 (which is not necessarily related to the inflation) and the various interests for loans ($j_{3,\ldots}$) and of course, the various costs and revenues. Potential allowances and subsidies can be included in the revenues. The future value in year i can then be expressed as:

$$FV_i= (R-C)_i = (R1*(1+j_1)^i + R2*(1+j_2)^i +\ldots - C1*(1+j_2)^i - C2*(1+j_3)^i -\ldots)*(1-cit)$$

Note that in our calculations we included a corporate income tax (cit) on the gains as a percentage of the gains. Tax advantages for some investments can be taken into account by taking a reduced value for this corporate income tax in the calculation sheet.

The values chosen for the base-case calculations in this report are given in Table 5.1. Later in this report, a sensitivity analysis will be found on these values can be found. All these values can be modified in the Excel calculation sheet.

Parameter	% per year
Inflation	3
Interest for loans	5
Rate of return r	2.5
Increase in energy price	3
Corporate income tax	25

5.3 Ownership and Financial model

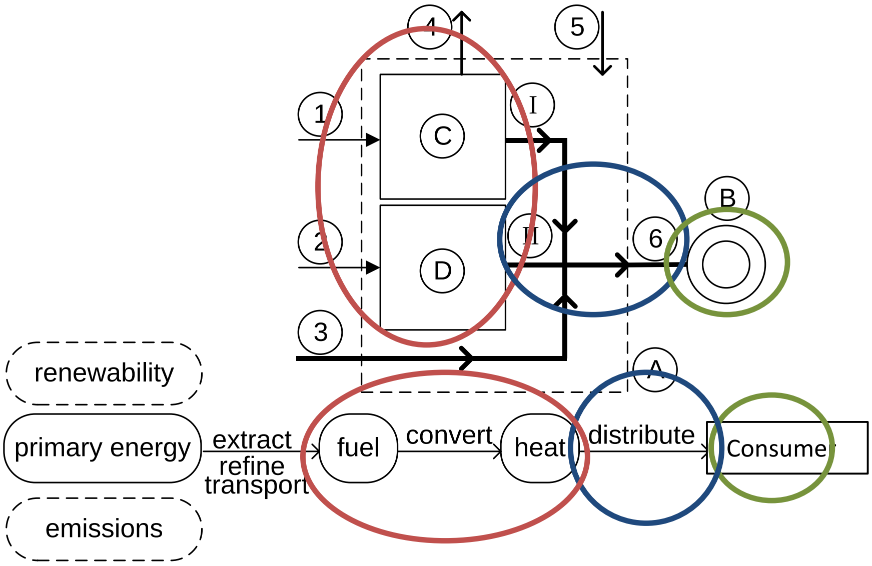
District heating and cooling covers a wide product chain from heat source to consumption, through energy conversion and large scale energy distribution. This may fit poorly in the present market where generally each link in the chain is organized separately and costs and revenues are related to the other parts of the chain ([1], [2]). Chain fragmentation can increase costs and financial risks, especially because of the complex agreements that are needed between parties and possible differences in views on amortization periods for investments and loans, that may not be in accordance with the long life time of district heating and cooling. Unfortunately, EU regulations may tend to promote this fragmentation, as seen with the electricity chain, where the ownership of production is separated from the ownership of distribution. The financial feasibility of district heating and cooling depends on the ways the ownership chain is articulated.

5.3.1 Allocation of costs and benefits

In order to clarify the effect of different ownership structures, the financial analysis of the whole chain is carried out separately for the energy conversion plant (red), the distribution system (blue) and the consumer (green), see figure 1 and report [3]. Additionally, the results will be presented also for the case of the energy conversion plant and the distribution system being owned by one owner, which is a very common case. We consider only one owner per system and therefore don't go further in details on possible complex ownership structures with a conglomerate of different parties owning the system and having an internal distribution code for costs and revenues.

For each of the different owners the costs may consist of:

- Fixed investment costs in year 0 and/or annual costs for interests and repayment of loans
- fixed annual costs for maintenance. These costs are estimated from the literature as a yearly percentage of the initial investment.
- Variable annual costs for the purchase of energy resources
- Corporate Income Tax
- Carbon tax if existing



A	system boundary	1	energy input to cogeneration unit	E_{chp}
B	heat consumers	2	energy input to heat producer	E_{hp}
C	cogeneration unit	3	heat from external source	Q_{ext}
D	heat producer	4	chp electricity	$E_{el,chp}$
		5	auxiliary electricity	$E_{el,aux}$
		6	delivered heat	Q_{del}
		I	heat from cogeneration unit	Q_{chp}
		II	heat from heat producer	Q_{hp}

Depending on the system, the revenues will consist of:

- Fixed or annual connection fees
- Annual revenues from energy sell
- Subventions
- Revenues from waste disposal fees in cases the fuel is waste

In sections 5.3.4 to 5.3.6 these costs and revenues are detailed for each of the three owners.

5.3.2 Considerations on Carbon Tax and Emission Trading System

Emission Trading System

The emission trading system (ETS) has been implemented for power plants larger than 20 MW. The principle is that the total CO_2-emission of a country are limited by a cap. A national allocation plan determines the number of carbon credits a specific company gets. The total of all issued carbon credits should not exceed the cap. If the CO_2-emissions of a specific company are below the amount of carbon credits, they can be sold to other companies who have emissions higher than allowed by their carbon credits. Generally the carbon prices vary in the range 13-22 EUR/ton CO_2, but depending on the market spikes far above and below these value are observed. At the moment the prices are below 7 EUR/ton CO_2. Emissions higher than the amount of carbon credits owned by a company result in a fine of about 100 EUR/ton CO_2.

It is almost impossible at the level of this research to evaluate the financial consequences of the ETS system for a generic DHC company because the amount of allowed carbon credits depends on the country and the national agreements on allocation, that in turn depend on the type, size and economical importance of the company. For this reason, possible revenues and costs from the ETS are not taken into account in this report. However, the ETS will certainly favour the DHC company using renewable fuels.

Carbon Tax

The carbon tax have existed prior to the ETS and has been implemented differently in each country. Carbon tax regulations have also changed rapidly in each country. It was never implemented in France. In the Netherlands it is combined with other taxes. Sometimes power plants are excluded from the carbon tax (e.g. Ireland), or are excluded when they are larger than 20 MW (e.g. the Netherlands), sometimes energy intensive industries are excluded (e.g. Finland). In Denmark, a low-rate carbon tax for households has been applied since the nineties. Generally, carbon tax and ETS cohabitates somehow. The carbon tax varies generally between 10 and 20 EUR/ton CO_2 with exceptions like in Sweden where it amounts 100 EUR/ton CO_2. The carbon tax for households in Denmark is about 5.6 EUR/ton CO_2.

In this research we used a standard carbon tax of 15 EUR/ton CO_2 for DHC plants and no carbon tax for households. Additionally a sensitivity analysis on both parameters was conducted. Both parameters can be adapted in the Excel calculation sheet.

5.3.3 The systems to be compared

Basically five options are compared:

- District heating based on Combined Heat and Power (therefore producing and selling two products: heat and electricity)
- District heating based on Heat Only Boilers (therefore producing only heat)
- Individual gas boilers, taking into account a new gas infrastructure
- Individual gas boilers, with an existing gas infrastructure
- Individual electrical heat pumps

In the next sections data on investment and maintenance costs, and on the prices of energy are given. The data are given for :

- the owner of the energy conversion plant (either DHC, HOB or gas company in the case of individual gas boilers)
- the owner of the energy distribution system (either heat in case of DHC and HOB or gas in case of individual boilers)

- the consumer (heat in case of DHC and HOB, gas in case of individual boilers, electricity in case of individual electrical heat pump)

Note that in the Excel calculation tool, gas boiler can be very easily replaced by other types of boilers (e.g. biomass boiler) by just changing the price data and setting the gas infrastructure cost at zero. Electricity infrastructure is accounted for as it is assumed to be always present.

5.3.4 Costs and revenues owner energy conversion plant

5.3.4.1 District heating (CHP and HOB)

The owner of the energy conversion plant is responsible for investments and maintenance of the plant and must purchase fuels to run the energy conversion plant. Theoretically, it could additionally be possible that he has to pay fees to the network operator. However, this case was not encountered in our study and is therefore not accounted for in the calculation tool (but could be very easily added). We also don’t go further on complex ownership structures where the electricity plant is co-owned by an electricity distributor and a heat distributor and an allocation of the revenues and costs must be performed. This detailed analysis are only needed once the global profitability of the whole has been demonstrated.

Investments costs:

In the case of a new plant, or the extension of an existing plant, investments must be made. There is very little data on aggregated investment costs for different conversion technologies. These costs may also vary a lot per country. For our study we used the data collected by [4] on the basis of a.o. the work of [5]. The costs were estimated for plants that would be built or extended in 2014, and as such, can be expected to be up to date. The costs account for size effect: $cost2/cost1 = (size2/size1)^{a}$, where the scale factor a depends on the technology. The final data can be found in Table 5.2 and in the Excel calculation tool. When using these cost data one should keep in mind that they are based on Swedish data and may not be very accurate for other countries. Own cost data can be added in the Excel sheet. We also recommend to add 5% to the price in order to account for additional design and engineering overhead.

Table 5.2 Investments and maintenance costs of DHC systems (monetary value 2004)

Technology DHC	Size*	Investment costs (MEUR/MWth)	Operation & Maintenance costs (% of investment costs per year)
Heat only boiler, Coal	S	0.37	2.5
Heat only boiler, Coal	M	0.33	2.5
Heat only boiler, Coal	L, XL	0.30	2.5
Heat only boiler, Oil	S	0.20	2
Heat only boiler, Oil	M	0.17	2
Heat only boiler, Oil	L, XL	0.16	2
Heat only boiler, Natural Gas	S	0.11	2
Heat only boiler, Natural Gas	M	0.10	2

Heat only boiler, Natural Gas	XL	0.09	2
Heat only boiler, Waste	M	1.1	3
Heat only boiler, Waste	L, XL	1.0	3
Heat only boiler, Biomass	S	0.4	2
Heat only boiler, Biomass	M	0.36	2
Heat only boiler, Biomass	L, XL	0.33	2
Electrical heat pump (COP=3.2)	S, M, L, XL	0.6	0.5
CHP Steam turbine, Coal	S	1.44	2.5
CHP Steam turbine, Coal	M	0.96	2.5
CHP Steam turbine, Coal	L	0.86	2.5
CHP Steam turbine, Coal	XL	0.80	2.5
CHP Combined cycle, Natural gas	S	1.02	2
CHP Combined cycle, Natural gas	M	0.96	2
CHP Combined cycle, Natural gas	XL	0.87	2
CHP Gas engine, Natural gas	S, M, L, XL	0.56	?
CHP Steam turbine, Waste	M, L	1.77	3
CHP Steam turbine, Waste	XL	1.79	3
CHP Steam turbine, Biomass	S	1.22	2
CHP Steam turbine, Biomass	M	0.75	2
CHP Steam turbine, Biomass	L	0.64	2
CHP Steam turbine, Biomass	XL	0.58	2
CHP Biomass integrated gasification combined cycle	Capacity (MWe/Mwth): 10/12	2.26	2.5
CHP Biomass integrated gasification combined cycle	Capacity (MWe/Mwth): 30/31	1.81	2.5
CHP Biomass integrated gasification combined cycle	Capacity (MWe/Mwth): 60/60	1.5	2.5
CHP Biomass integrated gasification combined cycle	Capacity (MWe/Mwth): 100/100	1.3	2.5
CHP Biomass integrated gasification combined cycle	Capacity (MWe/Mwth): 130/130	1.3	2.5

**S: ~60-200 GWh_{th}; M:~200-400 GWh_{th}; L: ~400-1000 GWh_{th}; XL:>1000 GWh_{th}*

Additionally, typical (Dutch) data for smaller CHP plants, and large heat pumps using aquifers as source was found in [6] For (deep) geothermal heat, data was found in [7].

Table 5.3: Investment costs of small DHC systems, geothermal and heat pumps (NL)

Small CHP-all types	
Size (kWth)	**Investment costs (MEUR/MWth)**
13	1.2
39	0.85
329	0.48
>1000	0.25
Others	
Heat pumps	0.9
Geothermal heat	1 MEUR/km

<u>Maintenance costs:</u>

The maintenance costs are based on the same studies as for the investment costs. They include maintenance, small and major repairs during the service life and related labour costs. They are expressed as an annual percentage of the initial investment costs. The percentages can be found in Table 5.2.

Annual (variable) costs for fuel purchase:
To run a power plant, fuel must be purchased. The price of these fuel resources is based on actual commodity prices from Index Mundi (Mei 2012, [8]). Also note that waste and waste biomass may also have a negative price (being then a revenue) when suppliers have to pay for disposal.

Table 5.4: Price of fuels resources for DHC companies, 2012

Fuel resources	**Price (EUR)**	**Price per MJ primary energy (Low heating value): EUR/MJ**[5]
1000 m3 of natural gas costs[1]	58	0.00165
1000 m3 of Russian natural gas costs[1]	330	0.00938
1 ton coal costs[2]	85	0.00293
1 m^3 heating oil costs	634	0.01474
1 ton biofuel costs[3]	200	0.01370
1 kWh of (auxiliary) electricity costs[4]	0.093	0.02583

[1] Note that the natural gas price was historically low in 2012. Average values in the period 2009-2011 are around 100 EUR per 1000 m^3. In the same period the price of Russian natural gas increased from 160 to 330 EUR per m^3.
[2] Based on Australian coal; Prices varied between 53 and 106 EUR/ton coals in the period 2009-2011.
[3]Note that the price of biofuels is very dependent on local biomass prices and on the humidity contents of the biomass. In [4] prices twice lower are reported. Waste biomass may have a negative price.
[4]Average EU 27 ([9]) for medium size industries. Variations in the period 2009-2011 are small. Depending on country price will vary between 0.06 and 0.12.
[5]Calculations based on the following caloric values:35.17 MJ/m^3 for gas, 29 MJ/kg for coal, 43 MJ/L for oil, 14.5 MJ/kg for biomass.

Income Taxes
The corporate income tax is set at 25% of the benefits of the company. The carbon tax is set at 15 EUR/ton CO_2.

Revenues from energy sales
In the case of a heat only boiler, only heat is sold. In the case of a CHP plant, two products are sold to consumers: heat and electricity. However, the price paid by the consumer is not the price received by the energy company because heat and electricity are submitted to energy taxes and VAT, which are transferred by the energy company to the government.

The level of taxes varies a lot between countries. Generally VAT for electricity and natural gas varies between 18 and 25% with exceptions like in UK where the VAT is only 5%. Total amount of taxes for electricity, including VAT, can be visualized in Figure 5.2 for different countries [10]. On average (EU-15)the taxes amounted ~23% of the total price of electricity and natural gas in 2006 [11]. The average price of electricity in Europe (EU-25)is around 0.13 EUR/kWh, all tax included [12], but very low prices can be found in Bulgaria (~0.07 EUR/kWh) and very high in Denmark (0.26 EUR/kWh), due to taxes amounting 50%.

Generally, there is no energy tax for heat, only VAT, and, in some cases a Carbon Tax. The price of heat varies greatly from ~ 49 EUR/MWh in Denmark , 62 EUR in Finland and Hungary, up to 80 EUR/MWh in the Netherlands [13]. On average the price of heat is around 60 EUR/MWh.

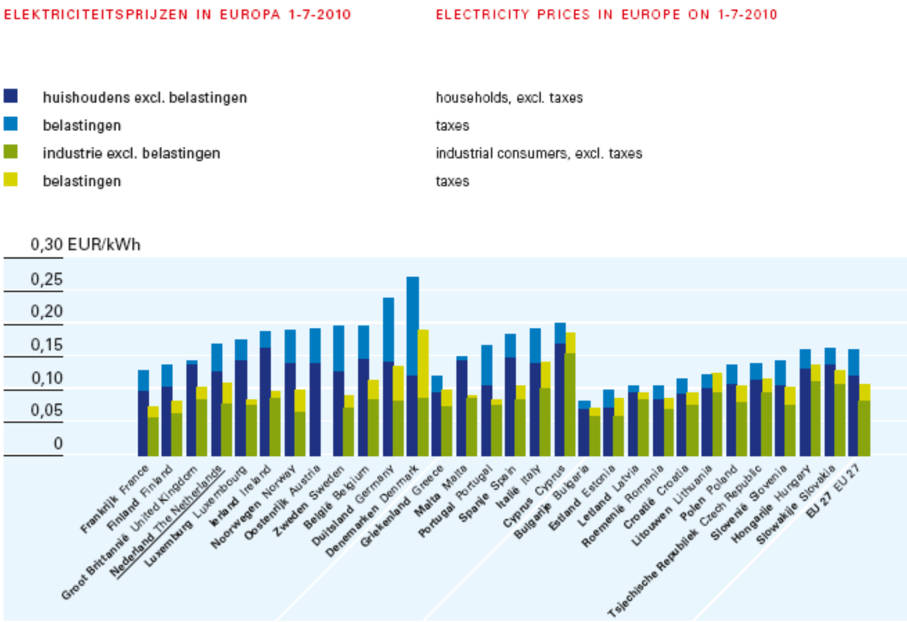


Figure 5.2: Electricity prices with and without taxes [10].

The values used in the base case are summarized in Table 5.5 – and can be adapted in the Excel sheet.

Table 5.5: revenues Energy Companies from energy sales

	Consumer price (EUR/MWh)	**Total taxes (%)**	**Revenue energy company (EUR/MWh)**
Electricity	130	23	100
Heat	60	19	49

5.3.4.2 Costs and revenues gas company (in case of individual gas boilers)

When individual gas boilers are used, gas must be supplied by a gas company. Generally, a gas company is quite the same as a gas distribution company, however in some countries, like the Netherlands, gas is paid by consumer to a ‘gas company’, whereas connection fees to the network are paid to a distribution company (see section 5.3.5).
In this research we assumed that the national high pressure distribution infrastructure (high calorific gas) is present. The only needed conversion is that from the high pressure net to the regional low pressure distribution net (low calorific gas) that takes place in a conversion station (where nitrogen is added and components adding the typical gas smell). Therefore the gas company has almost no

investments in infrastructure and therefore no maintenance costs. This is because no conversion plant is needed, only gas stations to adapt the pressure level and calorific value in the pipelines. In our study, these costs are considered to belong to the distribution company (network operator, see section 5.3.5.2).

The costs of gas purchase by the gas company can be found in Table 5.3, first two lines. The revenues from gas sales and the consumer prices can be visualized in Figure 5.3 and the values used in this report are summarized in Table 5.6.

Table 5.6: revenues Gas Companies from gas sales

	Consumer price (EUR/m^3)	**Total taxes (%)**	**Revenue energy company (EUR/m^3)**
Gas	0.58	23	0.45

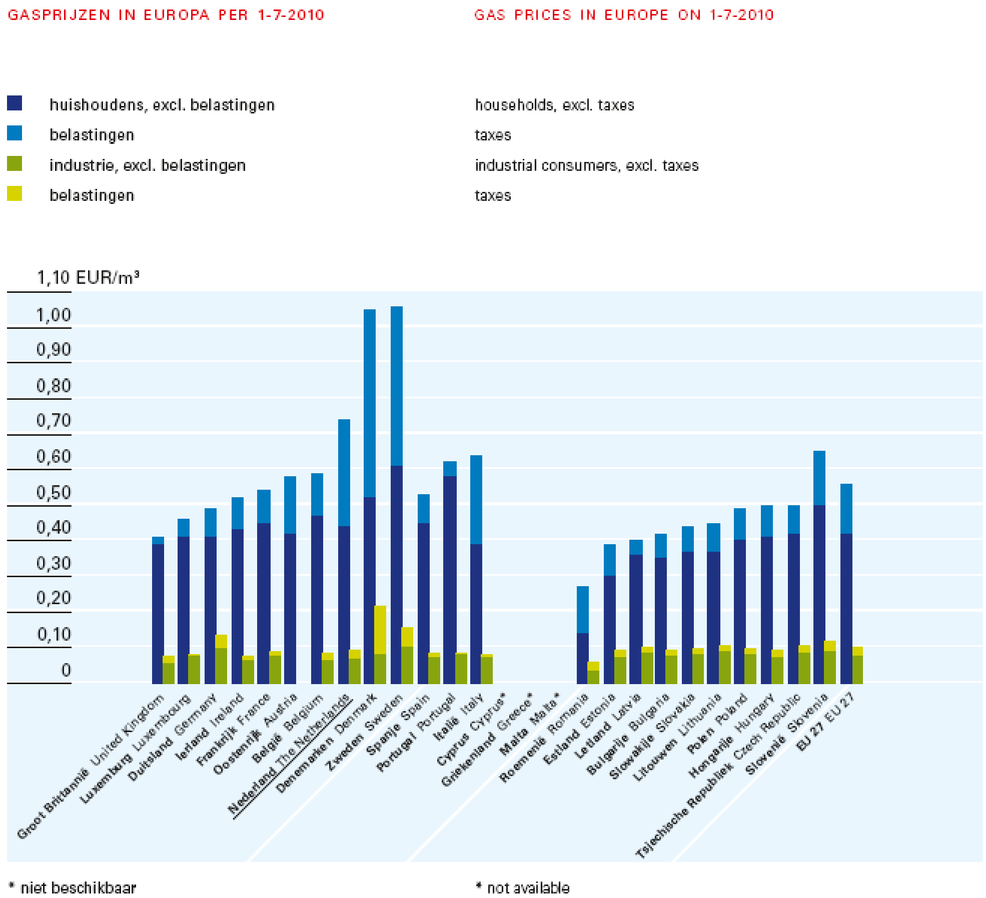


Figure 5.3: gas prices with and without taxes[10].

5.3.5 Costs and revenues network operator

The network operator is the owner of the distribution system and is responsible for the investments and maintenance of the system. His revenues comes from the connection fees due by consumers and there are also electricity cost from pumping power to overcome pressure losses in the pipes.

5.3.5.1 District heating distribution network

<u>Investment costs</u>
In case of a new distribution system or the extension of an existing one, investments are needed. The investments are very dependent on the length and diameter of the distribution pipes and are therefore easier to determine when the layout of the area and its distribution network is known. However when city planners have to decide on the feasibility of a district heating system, these data are mostly not available yet. For this research we used the extensive work of Persson & Werner [14], relating average diameter and length of distribution pipes to area characteristics like size, built area, and heat densities – meaning also that very specific characteristics that could increase the costs (like rivers to be crossed or underground problems) are not taken into account. The analysis was based on a large sample of 83 cities in Belgium, France, Germany and the Netherlands, accounting for more than 1700 district heating systems.

Basically, the investment costs in EUR are determined by the formula:

I= L*(C1+C2*d)

Where L is the network length (m), d the average pipe diameter (m) and C1 and C2 two variables depending on the typology of the area, see Table 5.7, where pr is the plot ratio defined as the ratio (total built area/total land area).

Table 5.7: C1 and C2 variables

	Inner city area (pr ≥0.5)	**Outer city area 0.3≤ pr<0.5**	**Park area (pr≤0.3)**
C1 (EUR/m)	286	214	151
C2 (EUR/m^2)	2022	1725	1378

The network length L [m], can be approached by:
L= total land area/(61.8*pr$^{-0.15}$)
where the build area and the land area are in m^2.

The average pipe diameter d [m] can be calculated by:
d = 0.0486*Ln(3.6*total heat consumption/L) + 0.0007
where L is the network length in m and the total heat consumption is expressed in MWh.
Actual and calculated values are shown in Figure 5.4.

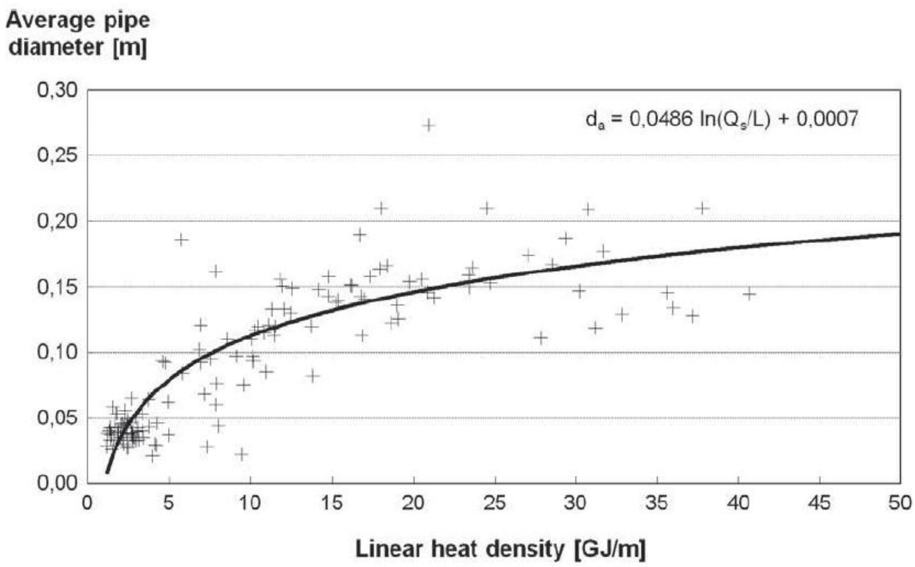


Figure 5.4: average pipe diameter as a function of the linear heat density (total heat consumption/L) for 134 Swedish district heating systems [14].

The investments costs can therefore be calculated very simply as a function of the total heat consumption and the plot ratio (total built area/t total land area).

Maintenance cost
There are estimated to be 2%.

Income Taxes
The corporate income tax is set at 25% of the benefits of the company.

Revenues from connection fees
To catch up the most complex case, we assume that there are two types of connection fees: on single stage fee to be paid once when connection to the network and yearly fees. The assumption for the base case calculation are given in Table 5.8 and fit well with the Dutch situation. The values can be adapted in the Excel calculation tool to each national situation.

Table 5.8: Connection costs/revenues for district heating

	Single stage (EUR)	**Yearly (EUR/year)**
Connection costs consumers	1897	98
VAT (%)	19	19
Revenues Network operator	1537	79

5.3.5.2 Gas distribution network

There is little data on investment costs for gas distribution network. For the length of the network the same data as for the district heating pipes are used (L= total land area/(61.8*pr$^{-0.15}$)) and an average investment of 300 EUR/m is assumed for new gas network [15], assuming there is a main high pressure distribution pipe at an acceptable distance and including lot connections). Maintenance costs are estimated to be 2% of the investment. In case of an existing network the 2% are calculated based on the price of a new network. Connection costs/revenues are given in Table 5.9 and fit well with the Dutch situation.

Table 5.9: Connection costs/revenues for gas

	Single stage (EUR)	Yearly (EUR/year)
Connection costs consumers	697	18
VAT (%)	19	19
Revenues Network operator	566	15

5.3.6 Costs consumers (DHC and individual options)

The calculations are made for one household, under the assumption that one average household needs a total heating capacity of 20 kW (total space and water heating). This assumption can of course be modified in the Excel calculation tool. Electricity costs for non-heating applications are not taken into account. All heating options (DHC, boilers and heat pumps) are assumed to provide space hating as well as water heating.

Investment costs for (condensing) boilers may vary a lot depending on brand name and number of boilers ordered, from 40 to 100 EUR/kW. For the base case 70 EUR/kW was chosen. For heat pumps the price will generally be around 300 EUR/kW.

Also when the household is connected to district heating, investments by the owner are needed, concerning the domestic substation (heat exchanger). The costs of such a substation amount approximately 65-70 EUR/kW, which is quite high in comparison with the price of a boiler. This price may however vary per country and per energy company (who mostly sells the substation to the consumer).

Maintenance costs are estimated to be around 2% for the boiler a, 1% for the DHC substation and 3 % for the heat pumps because a higher risk of failure due to mechanical parts like the compressor. Connection costs and energy costs were already treated in the former sections and are summarized in Table 5.10 to 5.12. It is also possible to introduce a carbon tax for consumers in the calculation.

Table 5.10: Investment and maintenance costs for individual consumers

	Investment costs (EUR/kW)	Yearly maintenance costs (%)
Boiler	55	2
Heat pump	110	3
DHC substation	65	1

Table 5.11: Connection costs for individual consumers

	Single stage (EUR)	Yearly (EUR/year)
Connection costs gas	697	18
Connection costs DHC	1897	98

Table 5.12: Price of energy for consumers, as used in the base case

	(EUR/MWh)
Electricity (heat pump)	130
Heat (DHC))	60
Gas (boiler)	0.58 EUR/m^3

5.3.7 Calculation period, service life and amortization time

Because district heating is a long term investment, it is important to choose a time line for the NPV calculation that is long enough to reflect its possible benefits. All calculations are made for maximum period of 45 year, taking in to account maintenance and replacement when the functional service life is exceeded.

The assumptions for the functional service lives in the bases case can be found in Table 5.13. At the end of the functional service life the whole equipment is replaced by a new one.

For the investment, two extreme possibilities are studied:

- the investment sum is directly available and no loan is necessary (base-case calculation)
- the needed investment sum is entirely loaned and is paid back assuming a certain amortization time, that may differ for the different heating options. This will be studied in the sensitivity analysis.

Table 5.13 Service lives and amortization times

	Functional service life (year)
CHP **Heat Only Boiler**	15 15
Domestic substation **Individual boiler** **Individual heat pump**	15 15 15
Heat distribution network **Gas distribution network**	45 45

Data on inflation, loan rates etc.. can be found in Table 5.1

5.4 Case study and sensitivity analysis

The Excel cost calculation tool developed on the basis of the former sections is used to analyse the main factors influencing the financial feasibility of district heating. The base case is a large natural gas CHP unit, that is compared to a gas heat only boiler and to individual boilers and heat pumps. In section 5.4.1 the data used are summarized. In section 5.4.2 the results are presented, after which an extended sensitivity analysis is presented.

5.4.1 Data for the base case (CHP) en comparison with heat only boiler, individual boiler and individual heat pump

In chapter 1 to 4, the size of the district heating is of no effect on its label performances. However, its size may influence strongly the Net Present Value, since the larger the district heating is, the lower are the investment costs per KWh. For the base case calculation we choose a large size district heating based on CHP using natural gas (mean heat, mean electric) and having a total annual heat delivery of 600 GWh. The characteristics of the district heating are summarized in table 5.14 and 5.15. Calculation are based on Tier 1 and in the Ecoheat4cities calculation tool described in chapter 4.

*Table 5.14: Characteristics of the base case CHP district heating**

Spec. heating consumption space heating	Spec. heating consumption water heating	Total building area	Total ground area	Plot ratio	Distribution efficiency	Fuel	η_{heat}/η_{el}
120 kWh/m^2	30 kWh/m^2	4 km^2	12 km^2	0.33 outer city	90%	100% Natural gas	0.53/0.38
Specific area heat consumption	**Total heat consumption**	**Network losses**	**Heat deli-vered to network**	**Needed Auxiliary electricity**	**Electricity production**	**$f_{P, dh, nren}$**	**$K_{P, dh, nren}$ (kg CO_2/ MWh $_{heat\ consumption}$)**
50 kWh/m^2	600 GWh	67 GWh	667 GWh	27 GWh	478 GWh	0.35 (label Class 7)	155 (label class 6)

*Additionally, the R factor is 1% (label class 1)

*Table 5.15: Additional characteristics needed for NPV calculations**

Number of full load heating hours	Total heating capacity network	Number of connections	Investment costs plant (MEUR/MW$_{th}$)	Maintenance costs plant
1500	444 MW	22222	0.92	2%

*Other data can be found in chapter 5.3

For the comparison with Heat Only Boilers, the following data must be changed in Tables 5.14 and 5.15:

*Table 5.16: Characteristics of the DHC Heat Only boiler**

η_{heat}	Electricity production	$f_{P, dh, nren}$	$K_{P, dh, nren}$ (kg CO_2/ MWh $_{heat\ consumption}$)	Investment costs plant (MEUR/MW$_{th}$)	Maintenance costs plant
1	0	1.34 (label class 4)	274 (label class 5)	0.09	2%

*Additionally, the R factor is 1% (label class 1)

For the comparison with the individual options the following data are used (Tables 5.17 & 5.18):

*Table 5.17: Characteristics of the individual boilers**

$\eta_{heat\ space}$ / $\eta_{heat\ water}$ ($\eta_{heat\ average}$)	Electricity production	$f_{P,,\ nren}$	$K_{P,\ nren}$ (kg CO_2/ MWh)	Investment costs plant EUR/kW_{th})	Maintenance costs plant
1 / 0.76 (0.95)	0	1.2 (label class 5)	244 (label class 5)	70	2%

*Additionally, the R factor is 1% (label class 1)

*Table 5.18: Characteristics of the individual heat pumps(exhaust air)**

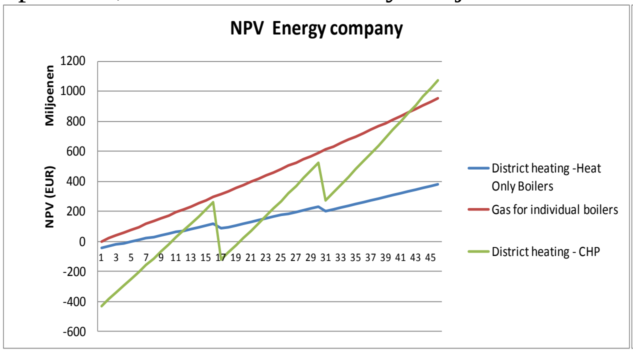
$\eta_{heat\ space}$ / $\eta_{heat\ water}$ ($\eta_{heat\ average}$)	Electricity production	$f_{P,\ dh,\ nren}$	$K_{P,\ dh,\ nren}$ (kg CO_2/ MWh)	Investment costs plant (EUR/kW_{th})	Maintenance costs plant
3/ 3 (3)	0	0.9 (label class 5)	144 (label class 6)	300	2%

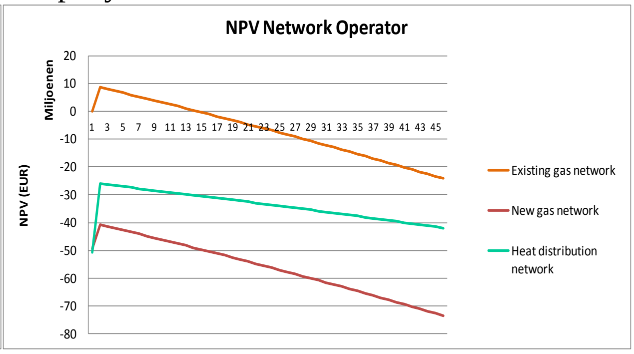
*Additionally, the R factor is 73% (label class 7)

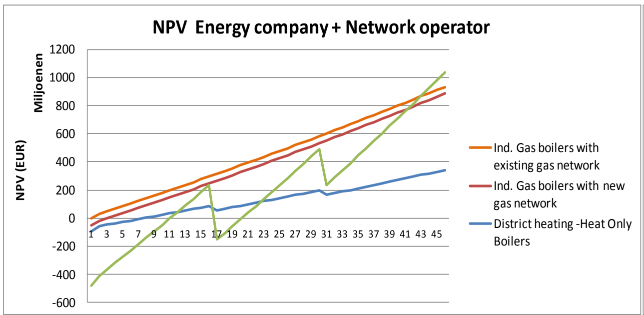
Additionally a rate of return 2 .5% was chosen for the base case and the investment sum is available (no loan). All conversion systems are assumed to have a service life of 15 years.

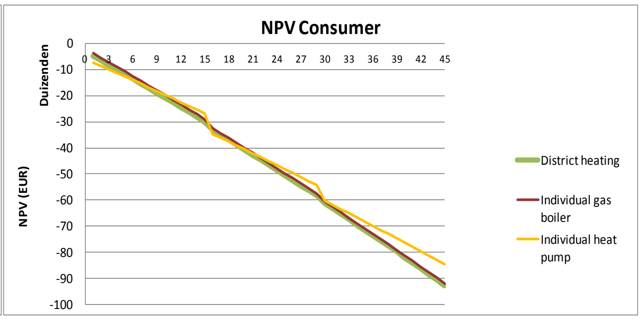
5.4.2 Results for the base case (CHP) and comparison with heat only boiler, individual boiler and individual heat pump.

The results are described by figures 5.5 to 5.8, separately for the energy company, the network operator , both fir the case they are joined in one company and the consumer.









Figures 5.5, 5.6, 5.7 and 5.8: results of the cost analysis

For an energy company is selling gas the most attractive option as no investment in conversion plants is needed (when there is main high pressure gas infrastructure of course). Because the investments in a CHP are about 10 times higher than the investments in heat only boilers, its costs 22 years before the CHP definitely gets a higher net present value than the heat only boilers. Note however, that already after 10 years the NPV of CHP is positive, meaning that the investment is worth. Note also that after 42 years the CHP is more profitable than selling gas only (Figure 5.5)

Considering the network operator it is clear that with the connection revenues and maintenance costs assumed in the base case, no profitable business can be set up (figure 5.6). To get a profitable business it is necessary to join the network operator and the energy company together, which against actual trends in Europe. Because the NPV values for the energy companies are much higher than the values for the network operator, the results are quite identical for the joint companies as for the energy company only.

As for the consumer, one can see that with the assumed cost structure, it doesn't matter too much what his choice is. However, the apparently small differences between the options on the 5—years scale may influence strongly the consumer's decision as the initial investment for the individual heat pump is 6000 EUR, for the district heating (domestic substation and connection fees) 4967 EUR and for the individual boiler (including connection fees) 3853 EUR. To promote district heating it would important to make sure that the initial investment is no more than the one of the concurring options.

5.4.3 Sensitivity analysis on the rate of return

We described in section 5.2.1 why a low rate of return should be chosen. In the base case a rate of 2.5% was applied.
Figure 5.9 shows the effect of lower and higher rates of return. It is clear that investments in district heating are not recommended to investors wanting quick and high gains (high rate of return) . The lower the rate of return, the higher the profitability of district heating, also in the case where the rate of return id much lower (1%) than the inflation (3%), see left part of Figure 5.9.

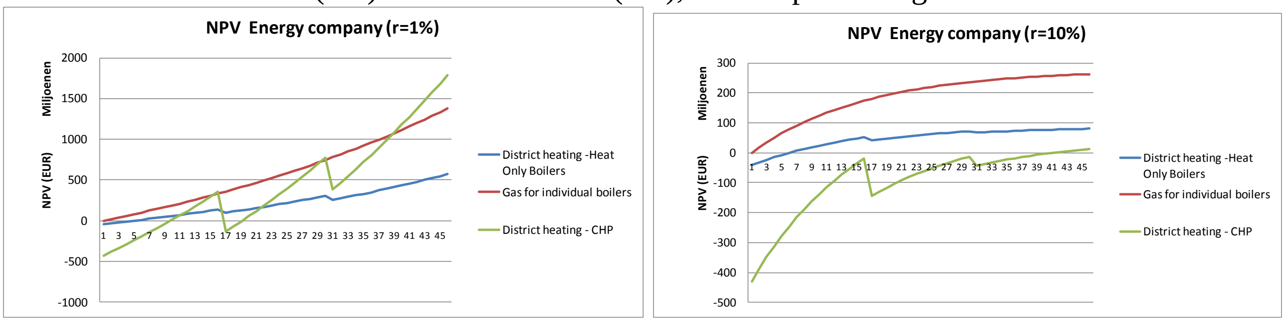


Figure 5.9: Effect of the rate of return on the profitability of district heating for energy companies.

5.4.4 Investing available money or using credit?

In the base case we assumed that the investment sum was available. However, in many cases credit will be needed to be able to invest. In Figure 5.10 the results are presented in case the amortization time is equal to the service life of the conversion plants (15 years) and distribution network (45 years). The interests for loan are set at 5%. The relative performances of the different options do not change very much. However, because the very large initial investment in CHP is now spread out over15 years, the investment becomes already profitable after 5 years and is more profitable than investing in a heat only boiler after 10 years.

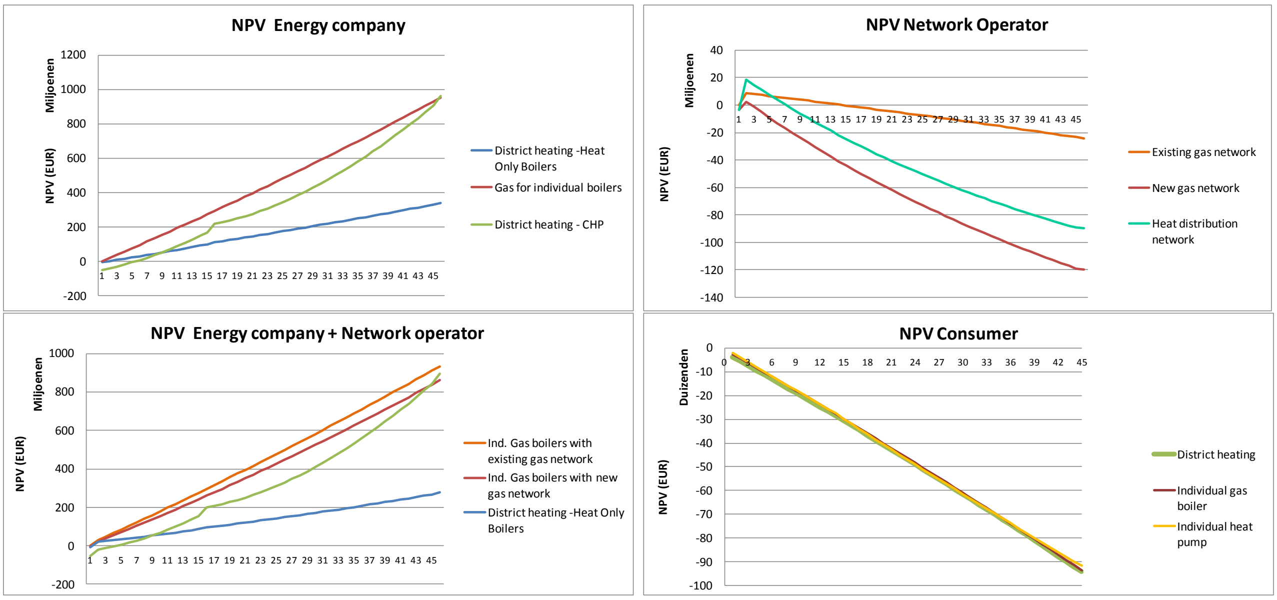


Figure 5.10: effect of using credit (interest 5%)

Figure 5.11 shows the results when the interests are 8%.Obviously, this has a negative impact on the profitability of the option with the highest investment.

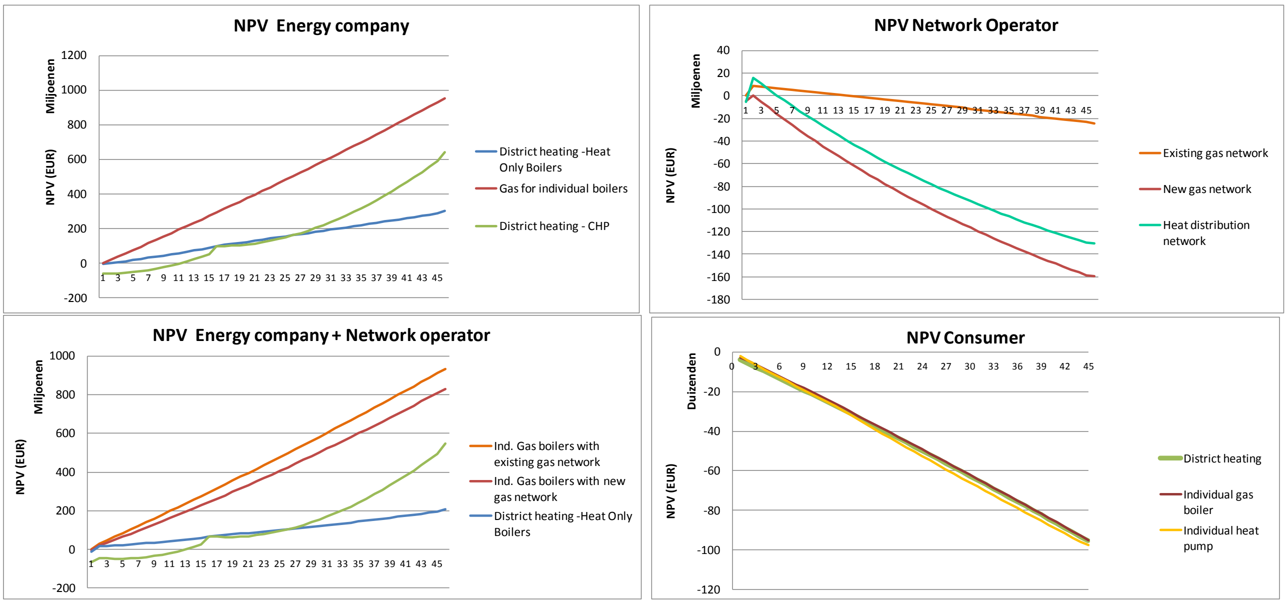


Figure 5.11: effect of using credit (interest 8%)

5.4.5 Sensitivity analysis on functional service life

Increasing the functional service life of the different options will always have a positive influence on the NPV. Figure 5.12 shows the effect of increasing the service life of all options from 15 years to 30 years. The highest the initial investment, the more important it is to increase the service life. With a service life of 30 years, CHP has already after 12 years a higher NPV than heat only boilers and is more profitable than selling gas only after 18 years. Increasing the service life of individual heat pumps to 30 years make them more profitable for the consumer than district heating. It is however not very likely that an individual heat pump achieves a service life of 30 years. This is more likely for a DH domestic substation.

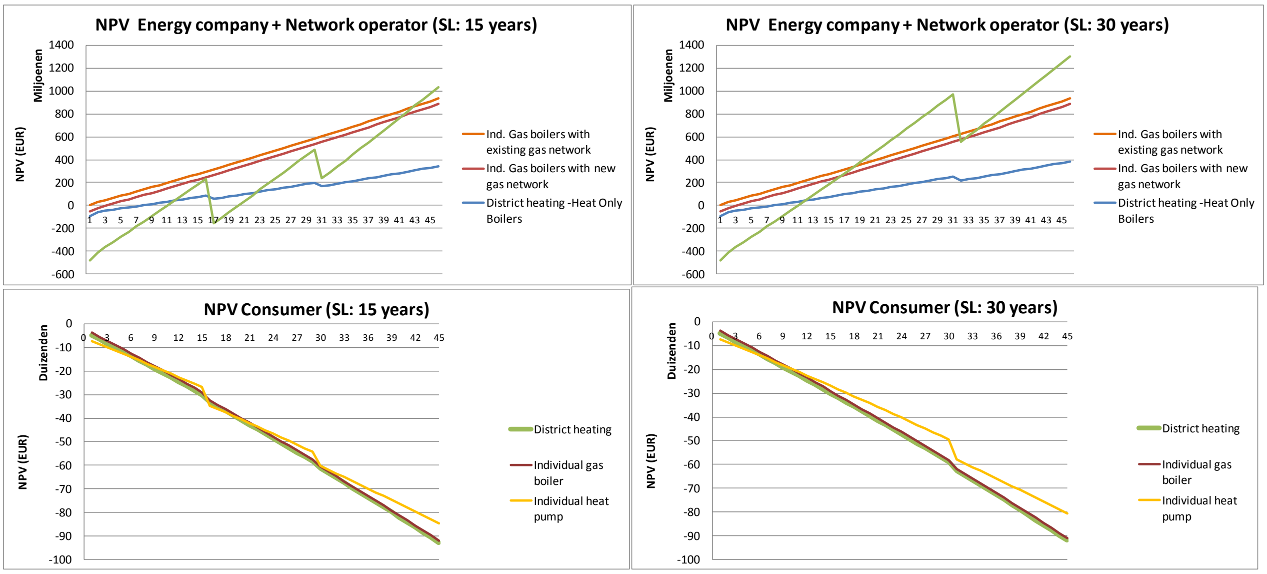


Figure 5.12: Effect of service life on NPV (left: service life of all DH and individual conversion systems and domestic substations is set at 15 years; right at 30 years).

5.4.6 Sensitivity on investment and maintenance costs

In the base case calculations all maintenance costs are set at 2%, except for the individual heat pump (3%) and the domestic substation (1%). Using for both the value of 2% will have a positive effect on the NPV of heat pumps (see figure 5.13).

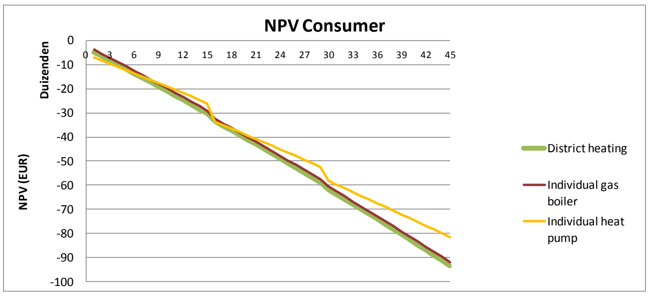


Figure 5.13: NPV for consumers with maintenance costs at 2% for all options.

Of course, an increase of the investment costs will produce a decrease of the NPV. In our study the investment costs were quite well underpinned by actual (Swedish) data, except for the investments in new gas network, in which the uncertainty is higher. In the base case, the investments for the gas network were set at 300 EUR/m (including lot connections). Figure 5.14 shows the NPV when the investments are 140 and 450 EUR/m respectively. The lowest investments are likely to take place when a simple extension of an existing gas network is needed, whereas the highest investments will correspond to a situation where also high pressure pipes must be added. Although it does change considerably the NPV for the network operator, the effects on the profitability of the joint company are not very high.

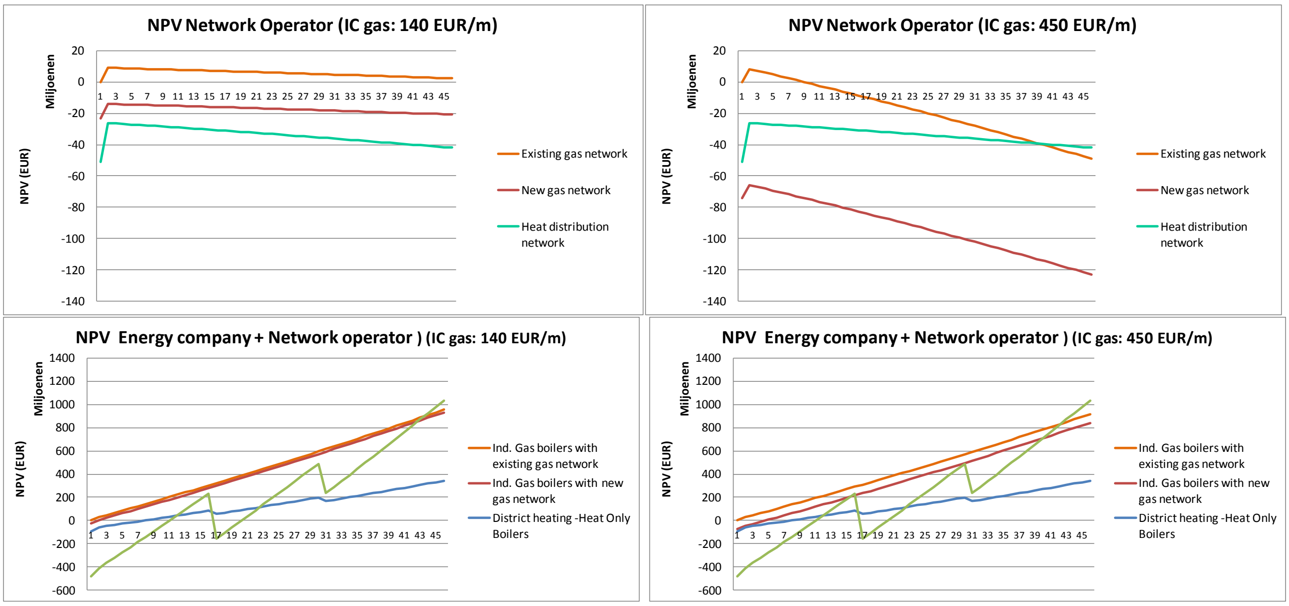


Figure 5.14: Effect of a decrease and increase in investment costs in gas distribution network.

5.4.7 Sensitivity analysis on heat and electricity prices

We saw in section 5.3.4.1 that heat prices varies greatly all over Europe. The percentage of taxes does also varyconsiderably. This of course affect greatly the profitability of district heating. In the base case a heat price of 60 EUR/MWh was used (VAT 19% included). In figure 5.15 the effects of lower (49 Eur/MWh, like in Denmark) and higher (80 Eur/MWh, like in the Netherlands) heat price are shown. It is clear that higher heat prices increases the NPV of district heating for energy companies but is unfavourable to consumers. Low heat prices will increase the acceptation and therefore penetration of district heating. It should be recommended to at least take care that the chosen heat price leads to consumer costs that are not higher than with other options. This means that it will take more time before the investments becomes profitable (NPV>0): 22 years with the lowest heat price against 9 years for the highest heat price.

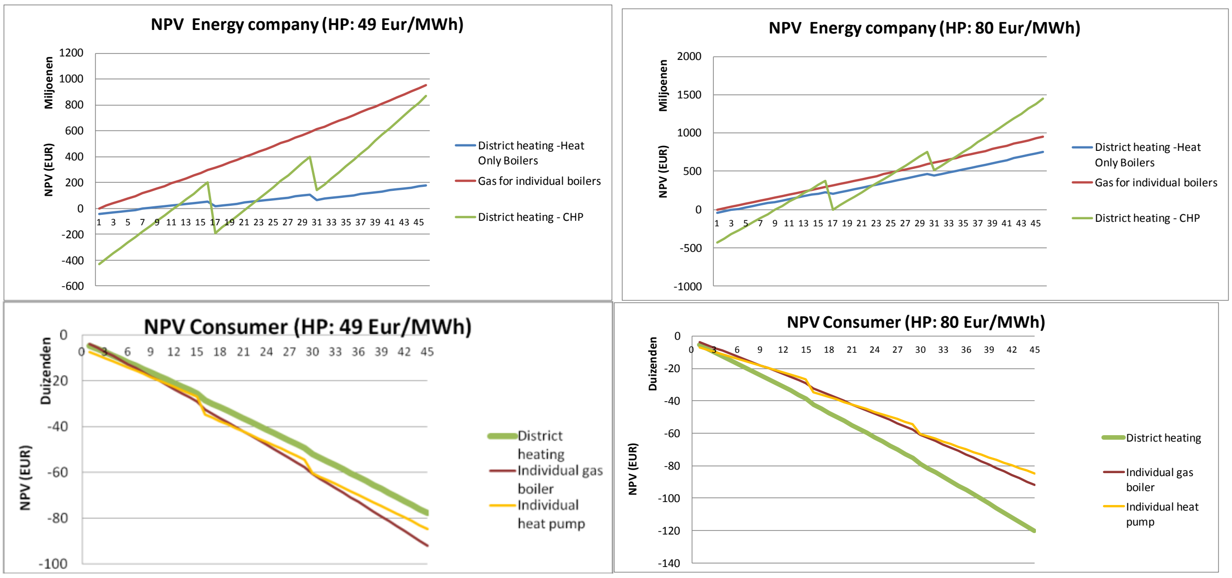
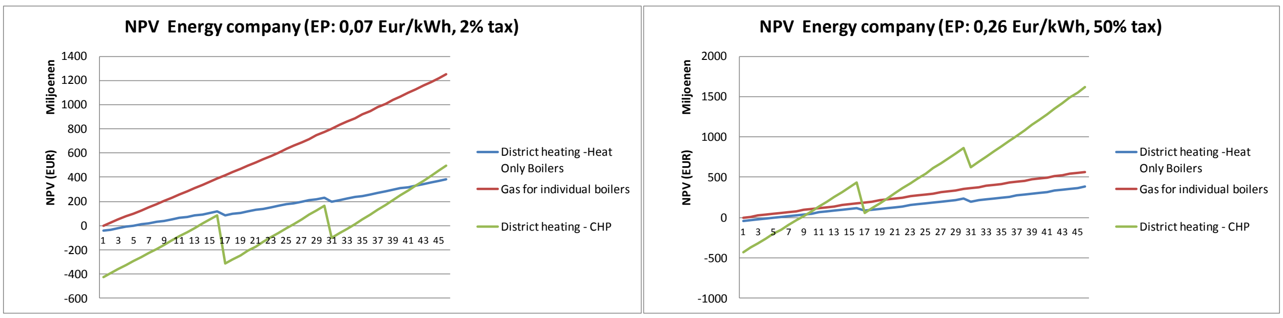


Figure 5.15: Effect of heat price on NPV

Figure 5.16 shows the effect of varying electricity prices on the NPV. In the base case a value of 0.13 Eur/kWh was used, but prices as low as 0.07 and as high as 0.26 Eur/kWh can be found (in Bulgaria and Denmark respectively). Generally these prices arise from the combination with different VAT rates. In Bulgaria the taxes (VAT and other energy taxes) rate for energy is ~2% whereas it is 50% in Denmark. In the base case we used the average value of 23%. Since generally the tax rates are identical for gas and electricity, both rates were equal in the calculations shown in Figure 5.16. The gas price was kept identical as in the base case.

Low electricity prices will of course be unfavourable to CHP, leading to the decision of not investing in it. High electricity prices lead to much shorter pay back times. With the highest electricity price, the NPV of a CHP is higher than the NPV of heat only boilers already after 10 years. Additionally, the highest the electricity price, the less favourable the individual heat pumps. This shows the wide bandwidth national governments can play with to make CHP more or less attractive to energy companies and consumers.



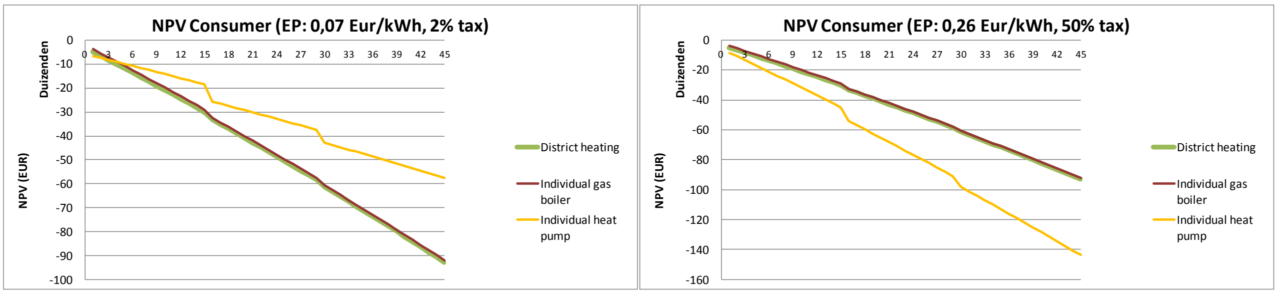


Figure 5.16: Effect of electricity price on NPV.

5.4.8 What are the effect of the carbon tax?

In the base case a carbon tax of 15 EUR per ton CO_2 was assumed. Figure 5.17 shows what happens when no carbon tax is applied and when a carbon tax of 100 EUR/ton CO_2 is applied.

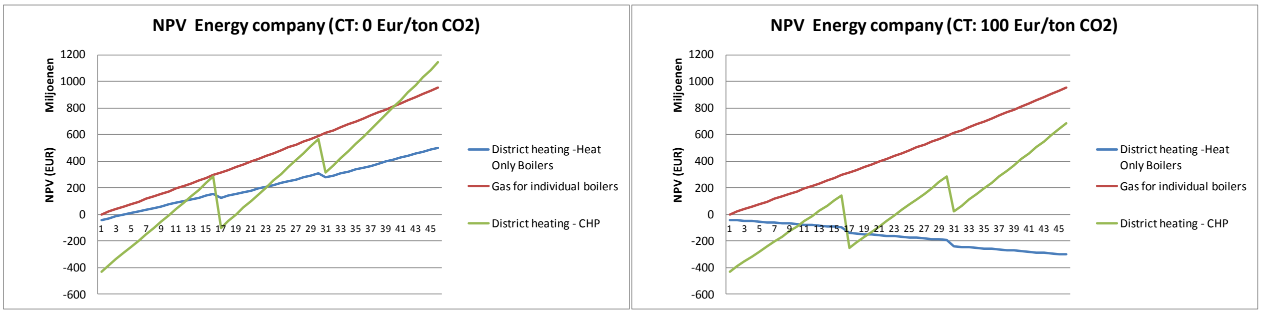


Figure 5.17: Effect of Carbon Tax

In the present case a low carbon tax increase the NPV and therefore the profitability of district heating systems (both CHP and heat only boilers). This is because in the base case natural gas is used as fuel for both CHP and boilers. The gas company is not submitted to CO_2 tax, as there is no combustion taking place. The CO_2 tax will not help to implement district heating based on fossil fuels but will helpful when changing to renewable sources (see section 5.4.12).

5.4.9 Effects of lower heat demand than expected

In a free market it may be difficult to make sure all consumers will finally connect to the district heating. This may have huge consequences on the exploitability of the district heating, as the revenues may decrease strongly. The costs of energy purchase by the energy company will also decrease, but this does not compensate for the lost of incomes. Additionally, in case the district heating is ready before completion of the area, the energy company may be confronted with the risk of making a major investment without getting enough customers in the first years, or without getting enough customers at all if the construction is stopped earlier or if the customers can't be forced to connect. To avoid these major risks, a tight collaboration between energy company, network operators, urban planners and constructors is necessary. Figure 5.18 shows the dramatic effects of 50% disconnecting consumers.

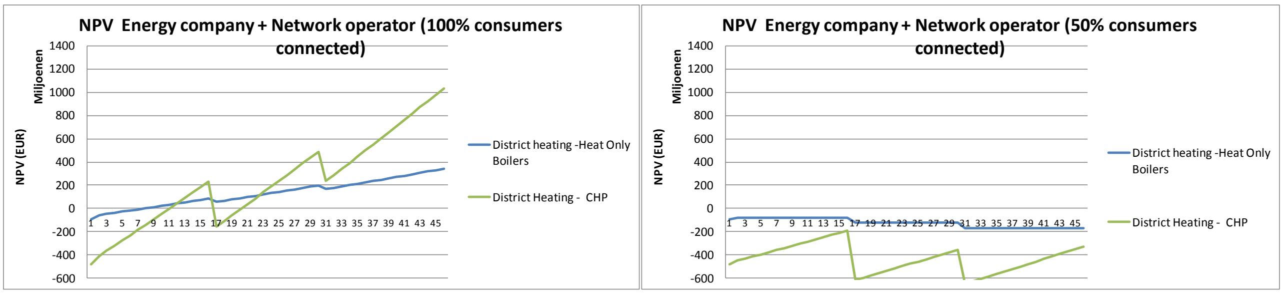


Figure 5.18: Effect of disconnecting consumers

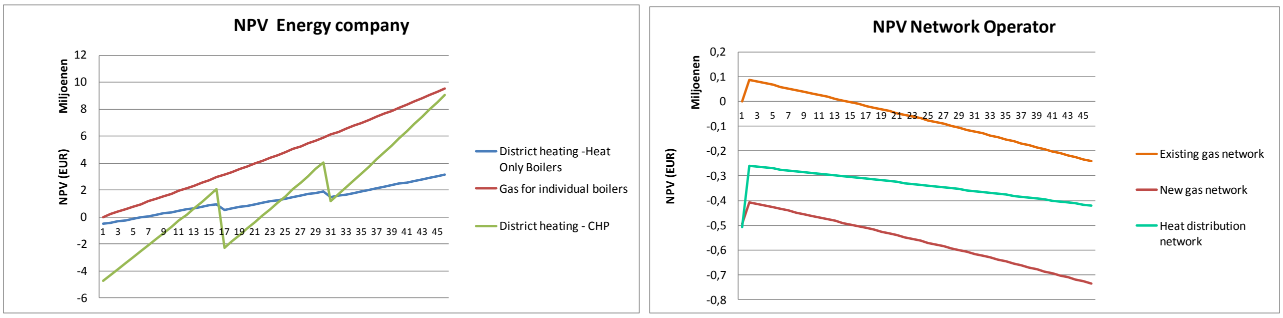
5.4.10 Effects of district heating size and plot ratio on NPV

When the size of the district is smaller or larger, it doesn’t influence the performances on the label’ criteria, but the quantity of heat consumed are changed and the investment costs varies according to the data in Table 5.4. In the base case the total area of the district was 4x3 km with 22222 connections, now it is 400x300 m with 222 connections (see Table 5.19)

Table 5.19: Characteristics of the small location

Total building area	Total ground area	Total heat consumption	Network losses	Heat delivered to network
0.04 km^2	0.12 km^2	6000 MWh	667 MWh	6667 MWh
Needed Auxiliary electricity	Electricity production	Total heating capacity network	Number of connections	Investment costs plant ($MEUR/MW_{th}$)
267 MWh	4780MWh	4444 KW	222	1.02

Additionally, the investment in heat only boilers will be 0.11 MEUR/MWth. The results are shown in Figure 5.19. Except for the absolute value of the NPV, the results are quite similar (see for comparison Figures 5.5 to 5.8). There is a small size effect as the NPV of district heating options becomes positive a few years later than for the large size district.



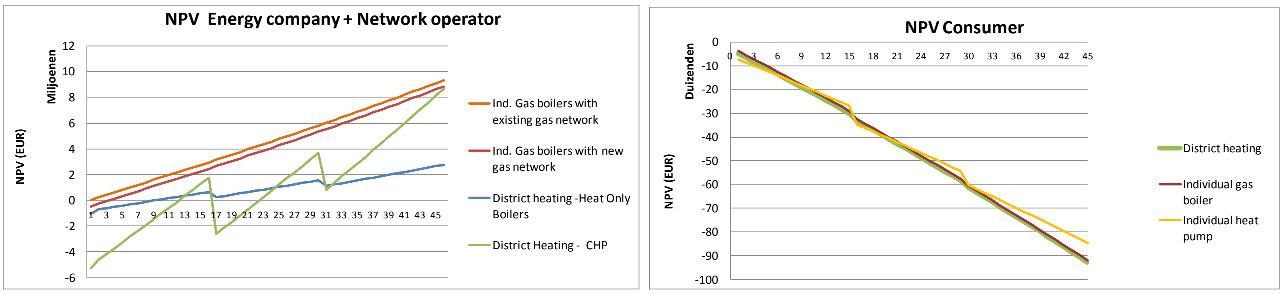


Figure 5.19: Results for a small size district heating

In the base case, a plot ratio of 0.33 was taken (outer city area). The results are presented for a plot ration of 1 (dense inner city area) and 0.1 (park area) in Figure 5.20. The plot ratio affects strongly the profitability for the network operator, dense area being more interesting. However, as the investments in the distribution network are much smaller than the investment in the conversion plant itself, the profitability for the joint company is not influenced very much. In the dense area with the plot ratio 1, the NPV of heat only boilers becomes positive after 6 years and the NPV of CHP after 20 years. In low density park areas, this will be 12 years and 22 years respectively.

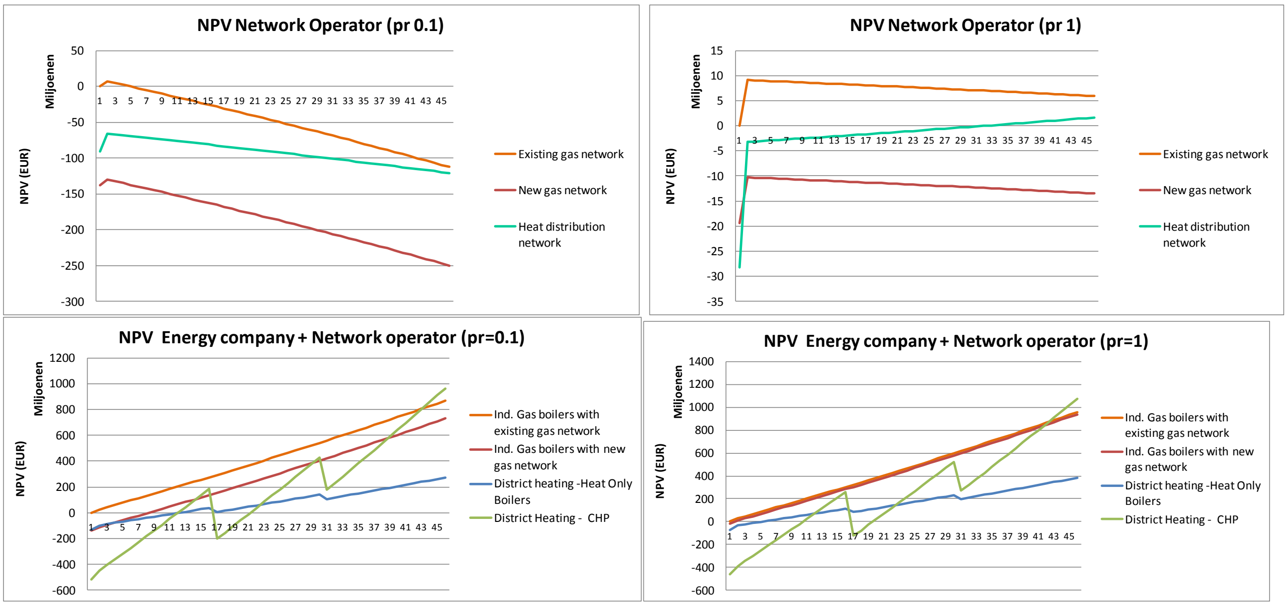


Figure 5.20: Effect of plot ratio on the profitability of district heating .

5.4.11 Effect of different heat/electricity ratio's for the CHP

In the base case calculation a mean heat mean electric production was assumed (η_{heat}=0.53; η_{el}=0.38). Table 5.20 summarize the input data when a low heat/ high electric or a high heat /low electric production are assumed. For the sake of simplicity we assumed in all calculations that natural gas boilers and CHP are used. The results are shown in Figure 5.21. As expected, a high electricity production causes higher NPV and is very important for the profitability of CHP plants. With a high electrical efficiency, the NPV of CHP is better than that of heat only boilers after 8 year already instead of 21 years with mean heat mean electric. With a low electrical efficiency the CHP may never be profitable. Note that with a high efficiency the CHP performs financially better than the gas company after 9 years.

Table 5.20: input data for different heat/electricity ratio's

CHP low heat, high electric	η_{heat}/η_{el}	Electricity production	$f_{P,\,dh,\,nren}$	$K_{P,\,dh,\,nren}$ (kg CO_2/ MWh $_{heat\ consumption}$)
	0.38/0.47	825 GWh	0.0 (label Class 7)	95 (label class 7)
CHP high heat, low electric	η_{heat}/η_{el}	Electricity production	$f_{P,\,dh,\,nren}$	$K_{P,\,dh,\,nren}$ (kg CO_2/ MWh $_{heat\ consumption}$)
	0.68/0.30	294 GWh	0.64 (label Class 6)	182 (label class 6)

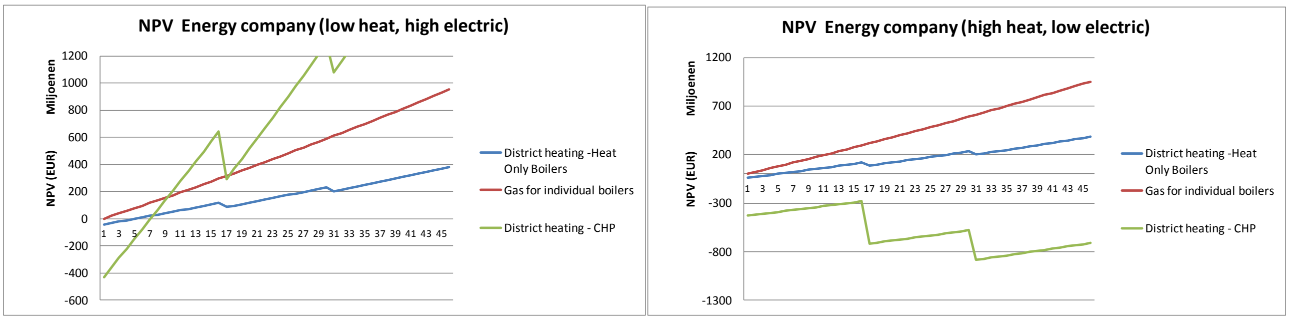


Figure 5.21: Effect of different heat/electricity ratio's on the NPV.

5.4.12 Effect of production type on NPV

Referring to Chapter 4, were the f, K en R factors of different types of CHP and heat only boilers were studied, we will analyse their economical feasibility. The data are given in Table 5.21. The results are shown in Figure 5.22 for CHP with a carbon tax of 15 EUR and 100 EUR en in Figure 5.23 for Heat Only Boilers.

Figure 5.22 shows clearly that CHP based on biofuels and waste combustion are not profitable. This is of course only true under the costs assumptions described in former sections. We can see from the figure that the problem with biofuels lies in too low gains after investments (the green line is almost horizontal). This comes mainly from the high biomass prices used (see table 5.4): 0.014 Eur/MJ, which is more than 10 times the price of gas. As already mentioned, the price may be much lower, and even be negative if the biomass is wasted. The results obtained for biomass here can therefore not be generalized and it would be easy to find biomass CHP plants that are profitable.

Considering waste CHP the lack of profitability arises from the very high investment costs. The chosen functional service life of 15 years is also quite short and a service life of 30 years would make the waste CHP profitable after 17 years (see also analysis in section 5.4.5).

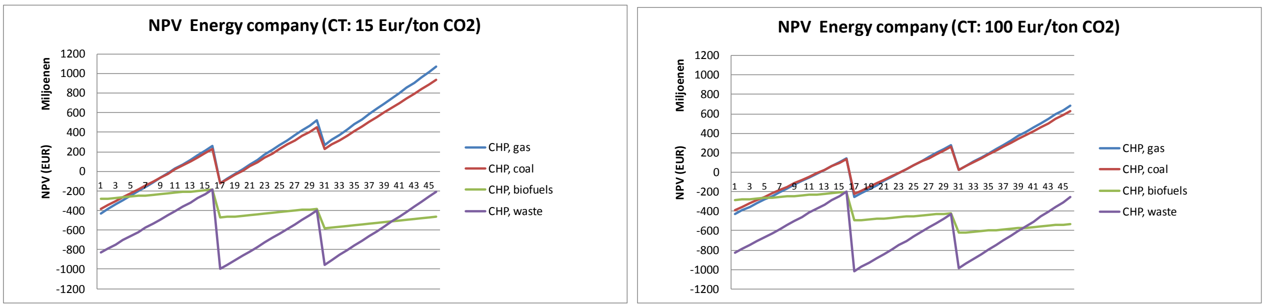


Figure 5.22: Effect of production type on NPV for CHP plants

Table 5.21: input data for the different production types

Production type	Fuel type	$f_{P,dh,nren}$	$K_{P,dh,nren}$ (kg/MWh)	Rdh (%)	Investment costs (MEUR/MWth)	Maintenance costs (% per year)	η_{heat}/η_{el}	Electricity production
CHP mean heat, mean electric (Base case, type 3)	Fossil fuel: gas	0.4	155	1	0.92	2	0.53/0.38	478 GWh
CHP mean heat, mean electric (type 5)	Fossil fuel, solid: coal	0.4	124	1	0.83	2.5	0.53/0.38	478 GWh
CHP mean heat, mean electric (type 6)	Biofuels, gas & liquid	0	26	97	0.61	2	0.53/0.38	478 GWh
CHP high heat, low electric (type 8)	Waste as fuel*	0	19	97	1.78	3	*0.68/0.30*	*294 GWh*
HOB (base case, type 10)	Fossil fuel, gas	1.3	274	1	0.09	2	100% /-	-
HOB (type 12)	Fossil fuel, solid: coal	1.3	430	1	0.2	2.5	100% /-	-
HOB (type 13)	Biofuels, gas & liquid	0.3	52	97	0.33	2	100% /-	-
HOB (type 15)	Waste as fuel*	0.1	19	97	1	3	100% /-	-
Heat pump, electric (type 16)	Electricity	1	165	73	0.6	0.5	*320% /-*	-

*For the processing of waste, revenues of 22 EUR/MWh_{waste} are taken into account.

A high Carbon tax affect as expected only the fossil fuels CHP. However, because of the large difference between the NPV of the fossil fuels CHP and the renewable CHP, this doesn't influence strongly the results. In case of longer service lives and lower biomass prices, the effect would be more visible.

Figure 5.23 shows the NPV for the heat only boilers. The same conclusions can be drawn as for the CHP. Increasing the carbon tax seems to have a much stronger effect by reducing the profitability of fossil options to the same level or far below the profitability of biofuels heat only boilers.
The low NPV of heat pumps arises from the relatively high price of electricity purchase in comparison with the price of heat.

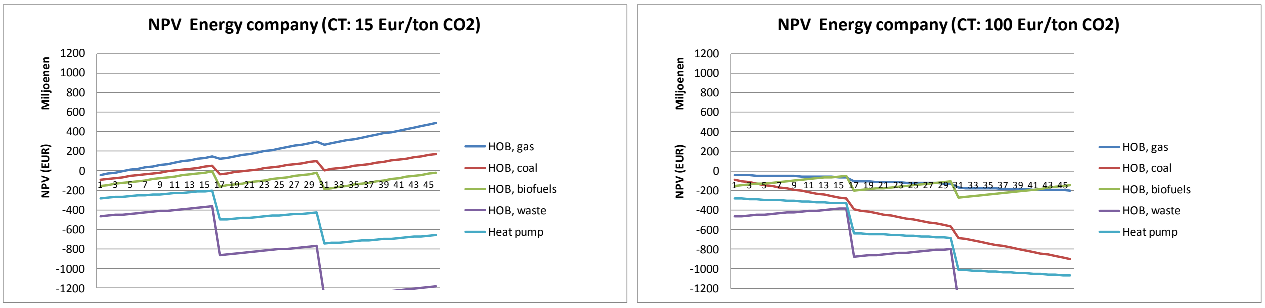


Figure 5.23: Effect of production type on NPV for Heat Only Boilers

5.5 Conclusions and recommendations

The main findings/point of attention are summarized below:

- To get a profitable business it is necessary to join the network operator and the energy company together, which may be against actual trends in Europe. With actual connection cost structure the business is not profitable or stand-alone network operator.
- As for the consumer, it doesn't matter too much what his choice is. However, the apparently small differences between the options on the 5-years scale may influence strongly the consumer's decision as the initial investment for the individual heat pump is 6000 EUR, for the district heating (domestic substation and connection fees) 4967 EUR and for the individual boiler (including connection fees) 3853 EUR. To promote district heating it would important to make sure that the initial investment is no more than the one of the concurring options.
- On the long term the profitability of district heating (in terms of Net Present Value) is high. But long term means rather 20-30 years than 10 and means the use low rates of return (~2.5%), reflecting the low investments risks on the long term.
- Low heat prices and high electricity prices are favourable to district heating, and more specifically to the exploitation of CHP.
- CHP with a high electrical efficiency is more profitable than CHP with low electrical efficiency.

- The plot ratio affects strongly the profitability for the network operator, dense area being more interesting. However, as the investments in the distribution network are much smaller than the investment in the conversion plant itself, the profitability for a joint company is not influenced very much.
- The effects of the carbon tax in DHC implementation seem to be rather limited at actual rates (~ 15 EUR/ton CO2). Higher rates may be much more effective, but still not sufficient to compensate for the high investment prices for waste-based CHP and the high prices of biofuels (although this is not always the case as the price of biofuels varies a lot depending on location). In both cases, direct subsidies may be more effective.
- Disconnecting customers may affect pretty much the profitability of district heating. In the case study we assumed that the whole district area can be heated from year 1 by the district heating system. In practice this happens only seldom as the district heating will be implemented gradually. Depending on the planning it may be that a part of the district must first be equipped with temporary boilers that will be removed when the (extension of) district heating plant is ready. This means that revenues for energy company and network operator are delayed and that additional investments costs for the boilers are needed, reducing the NPV of the district heating case. A detailed cost analyse should therefore account for the construction planning of the area and for the construction (or extension) planning of the district heating plant. In the case (parts of) the buildings are constructed before completion of the district heating plant, temporary boilers will be needed. In case the district heating is ready before completion of the area, the energy company may be confronted with the risk of making a major investment without getting enough customers in the first years, or without getting enough customers at all if the construction is stopped earlier or if the customers can't be forced to connect. To avoid these major risks, a tight collaboration between energy company, network operators, urban planners and constructors is necessary.

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6 OTHER CRITERIA

When comparing district heating and cooling to individual options, additional criteria (next to label, primary energy, CO2 emissions, renewability and costs) may be useful. In this chapter we gathered additional criteria on emissions, pollution control and air quality, advantages (and possible drawbacks) of DHC for cities and local communities as well as for the end consumer.

6.1 Emissions, pollution control and air quality

Generally speaking, when Combined Heat and Power or waste heat from industrial processes is used to replace district heating Heat Only Boilers or individual boilers, a huge reduction of primary resources and emissions is achieved – as demonstrated in the Ecoheat4cities project, because the heat used is then a by-product of another process with no additional use of resources and no additional emissions.

Main emissions from combustion systems are- beside CO_2, Nitrogen oxides (NOx), Sulphur dioxide (SO_2) and Carbon monoxide (CO) and particulate matter. Detailed information can be found in [1] and [2].

- NOx, particulate matter and hydrocarbon vapours are mainly responsible for urban smog (photochemical oxidation leading to ozone production), causing head-aches, eye irritation and long diseases. However, most NOx emissions arise from traffic and not from energy conversion plants.
- SO_2 (and alos NOx) are causing acidification, damaging forests and corroding materials like stone. SO_2 emissions are limited by the Sulphur Emissions Reduction Protocol and desulphurisation equipment in flue gases is compulsory in many countries for large plants.
- CO emissions are produced by incomplete combustion and are highly toxic in air-tight environment (like a house) leading to a rapid death. High CO levels in an urban area contributes to a poor air quality.

Better dilution with DHC

Because the stacks of a centralized district hating plant are much higher than the stacks of individual boilers, emissions like NOx, SO_2 and CO are much more diluted above the city, contributing to a better air quality at city level. This is of course only true when district heating is compared to boilers and not to individual electrical heat pumps. However, increased dispersion in the city doesn't change the concentration of SO_2 at regional level- and therefore doesn't change potential acidification impact.

More easy to install emission reduction equipment and to control emissions

However, one the main advantages of a district heating plant is that it is much more easy and cost effective to install desulphurisation equipment to decrease the SO_2 concentration in flue gases. These are compulsory now for large plants but not for small boilers, where the cost would become too high. Therefore replacing individual boilers by DHC may lead to a decrease in local SO_2 concentration. On the same way, efficient equipment for separation of particulate matter from flue gases in much too expensive to be applied in individual boilers and can only be afforded for large conversion plants. Furthermore emissions are continuously controlled in district heating plants, which is not the case with individual boilers.

This is important especially when biomass is used. Consumers using individual biomass boiler may use uncontrolled fuels like timber treated with pesticides or wooden fences causing local health damages. Burning wood in small boilers may also lead to the creation of poly-cyclical aromatic carbon-hydrates (PAH) when the boiler is not operating in the right way, which is difficult to control when individual boilers are used. PAH causes cancer.

However, district heating based on biomass or waste incineration have been criticized a lot for potentially leading to a strong increase in emissions. However, these problems are solved when modern combustion technologies are used. Furthermore, environmental regulations are much more stringent for large plants than for individual boilers –and can be more easily strengthened.

Noise
Noise nuisances may cause stress and strongly influence the health of building occupants. Noise may arise from the domestic substation, from the network (hydronic system) by propagation into the building and from the CHP itself, which is often located closer to buildings than a conventional power plant. In this case, silencing equipment should be considered. However, there is no literature showing that noise annoyance would be higher in houses with district heating than in houses with a boiler.

6.2 Cities and local communities

District heating and Cooling may have specific advantages and drawbacks for the local urban community. There are listed below, see also [1].

Security of supply and safety
As district heating plants often use local fuels, dependence on fossil fuels and on the countries producing these fossil fuels may be decreased strongly. This especially the case when local biomass (when available), (domestic) waste, geothermal heat or solar collectors are used.
However, in case of failure of the district heating plant or network, a large number of buildings will have no access to heat. This may be the case during war or because of accidents. Outage times may be high in old systems (like in Russian district heating) but in modern systems in Western Europe, very low outage times of about 1 hour per 12 years are reported. Fuel explosions and fuel fire did happen in the past but are currently almost eliminated because of the compulsory presence of fire protection equipment. The combination of different conversion plants within one district heating network (smart heating network, possibly combining several CHP plants and geothermal heat or heat pumps) may offer a solution to increase the security of supply to consumers.

When biomass fuels are used, a lot of logistic activities for transport and storage are involved, leading to additional space use. These activities may also lead to an increased risk of accidents.

Economic considerations

District heating may create a new local market, especially when biomass is used. Logistic activities nay create new job opportunities in the area. The production of liquid or solid biofuels from local biomass may create a new industry. It is difficult to estimate whether the presence of a fossil fuel CHP will help increasing job opportunities. At one side, new jobs will be created around the plant and the network. At the other side jobs will disappear at the side of local installers and plumbers, except if they are involved in installing and maintaining the domestic substations.

New jobs may also be created if residual products from CHP plants can be processed to useful products in a new industrial process. For instance scrubber technology for desulphurisation produces gypsum as by-product that could be processed to plates for the building industry. Also ashes removed from coal or biomass through fluidized beds can be processed to ballast for roads.

Urban planning considerations
When a new CHP plant is to be built, a suitable site must be found, which may be difficult, especially in densely populated areas. Furthermore, a long term time planning is needed, especially for the implementation of the network and in case of a complex DHC system involving several conversion plants and when the construction activities for buildings will take place concurrently with the construction of the DHC. Long term planning may also be an opportunity to set up and achieve local energy and environmental targets. It is recommended to start up such a project with making an energy map, showing all potential needs and sources of heat in the city or the region. If the know-how and technical skills needed to set up a DHC system are not available, collaboration with more experimented partners is needed.

Finally, DHC system may result in a monopolistic situation where one energy company delivers heat to a whole city. This could lead to too high prices for consumers. This may possibly be avoided when the municipality and other stakeholders form together with the energy company a joint-venture. Stakeholders must then ensure that they own together a high enough share of the company to influence the decisions.

More easy to achieve local and national environmental targets
Conversion from fossil fuels to renewable is more easy and cost-effective with a centralized energy conversion plant than with a lot of individual boilers, the owners of which have to be persuaded to switch to more sustainable options. Especially in areas already having a district heating network covering the whole city, this may be a huge opportunity to achieve environmental targets at once. When biomass is available this may be relatively easy to realize. However, awareness of the differences between primary and secondary biomass is important. Secondary biomass is much more sustainable than primary, because it is a waste product. Primary biomass for energy conversion may compete with its use as food resource, which should be its first aim. Especially in regions with little biomass, the use of primary biomass is not recommended and the use of secondary biomass will be limited by its availability. Therefore the use of biomass, which appeared in our study to be a powerful way to sustainable heat production will be possible everywhere. Connecting the district heating to a combination of other renewable sources will then be necessary. These renewable sources may be deep geothermal heat, heat from ground or aquifers in combination with heat pumps, solar panels and photovoltaic cells, wind or hydropower for electricity production.

An argument often used against district heating is the high level of heat losses in the distribution network. These losses can be high, up to 50%, especially in old non insulated networks. In modern distribution systems in city areas, a distribution efficiency of 90% seems to be realistic. Large heat losses are a major item when Heat Only Boilers are used. On the contrary, when CHP is used, it has no particular disadvantage, as the heat is already a by-product (waste heat). However, from the view point of rational energy use and in order to increase the revenues of the energy company, it is recommended to reduce the network heat losses up to an acceptable level.

Another argument against district heating is that it is often applied to avoid investments in energy savings at building level. A given threshold in primary energy consumption, energy label or CO_2 emissions may be achieved by switching to a high efficiency DHC plant (possibly using renewables) or by taking insulation and air-tightness measures at building level (or by a combination of both). From the long term point of view, reducing the energy demand (therefore applying insulation) is a necessary step as it will also reduce the secondary environmental effects of using renewable energy (less surface area collectors, smaller plants, less use of biomass etc...). However the reduction of the energy demand may also reduce strongly the profitability of the DHC for energy companies (see chapter 6). However for the end consumer, it is important that the buildings are well insulated, otherwise their bill from the energy company may be much higher than for insulated buildings with individual heating options, which is certainly not a good publicity for district heating. In the case of old city centres with a lot of protected monuments district heating may however offers a great opportunity to achieve energy and environmental targets while letting the monuments untouched.

6.3 End consumer

Although consumers may have a negative perception of DHC because of poor past experience with old DHC technologies or because of too high heat prices due to monopoly, DHC has clear advantages. First it is safe (no combustion emissions in house, no combustion devices), highly reliable (very low outage times) and as comfortable as other options. The maintenance of the domestic substation is less than maintenance of an individual boiler or a heat pump. The substation is also much smaller; therefore, space is saved inside the building. The investments are generally lower than for individual options, but as seen in chapter 5, they may be higher than for a cheap boiler. Finally it may be that knowledge about heating techniques and sustainability in general decreases very much at the level of consumer, as he is just a consumer of heat produced elsewhere, and not an owner that must take decisions.

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