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Consumers in district heating and cooling

Background report on how to evaluate the sustainability of district heating and cooling

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Contents

Abstract

Article 24 of the Renewable Energy Directive (RED II) addresses district heating and cooling (DHC) by strengthening the role of consumers (paragraphs 1, 2, 3) and by encouraging an increase of renewable energy sources (RES) in DHC (paragraphs 4, 5, 6). According to paragraph 1 of this Article, Member States shall ensure that information on the energy performance and the share of RES in their DHC systems is provided to final consumers.

The aim of this report is to discuss different calculation methodologies and indicators which quantify energy performance and RES share of the DHC network. We discuss the adequacy of using these different indicators to present how sustainable the heat or cold supply of a particular DHC system is.

The primary energy factor (PEF) for the DHC networks including the assumption on PEF values for different fuels and allocation methods in combined heat and power (CHP) plants are analysed. As the PEF indicator is widely used in different energy system contexts, we assess the accuracy of using PEF as an indicator for sustainability. In addition, we propose to use the following indicators: RES share and waste share, the CO_2-emission factor, efficiency as well as compliance with the definition of EDHC (efficient district heating and cooling). We provide a proposal for a harmonised methodological approach for EU-27 for these indicators.

To communicate this harmonised approach, we develop a guidance document addressing the DHC operator on how to calculate the indicators. And finally, we show how these indicators can be communicated to the final customer of the district heat supply.

Foreword

This work was carried out in the framework of an administrative arrangement between the European Commission's Directorate-General for Energy and the Joint Research Centre (JRC). The JRC provides the Directorate-General for Energy with technical assistance, analysis and inputs to support the implementation of heating and cooling-related provisions of Directive (EU) 2018/2001/EU on energy from renewable energy sources [1] (hereafter referred to as RED II) and support the implementation of Article 14 of Directive 2012/27/EU on energy efficiency [2] (hereafter referred to as EED).

(1) Directive 2018/2001/EU of the European Parliament and the Council on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018, p. 82.

(2) Directive 2012/27/EU of the European Parliament and the Council on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, OJ L 315, 14.11.2012, p. 1.

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1 Introduction

1.1 Motivation, aim and objectives

With the revision of the Renewable Energy Directive ([3]) (RED II) in the framework of the "Fit for 55" package, the Commission has set more ambitious renewables targets for the heating and cooling sector (European Commission, 2021a). One element is to strengthen information provisions for consumers supplied by district heating and cooling systems (DHC). This information could include environmental and efficiency indicators of the DHCs and be communicated to consumer via bills, suppliers/regulators' websites, or/and energy labels (voluntary or mandatory) (European Commission, 2021 (legal proposal elements)). This information should, ultimately, help user make informed decisions on which available heat supply options are best to meet their energy needs.

Such information should contain indicators that measure the performance of the DHCs from a broad perspective rather than focusing on certain features. In addition, these indicators should be easily understood by non-expert users and ensure a fair comparison between different heating supply options.

Given the above, the aim of this report is to prepare a proposal for a guidance document on how to calculate the set of indicators that better measure the energy performance of DHCs. We focus on these main indicators that cover both the sustainability and the energy efficiency dimensions:

- The primary energy factor (PEF).
- The share of renewable sources (RES) and waste heat.
- The CO2 emission factor.
- Criteria for efficient DHC under the Energy Efficiency Directive ([4]) (EED).
- Heating losses.

With this goal, the specific objectives of the report are:

- Discuss the adequacy of using these different indicators for the decarbonisation of the DHC sector and propose harmonised methodologies.
- Analyse different calculation methodologies available in literature for assessing PEF for DHCs including the assumption on PEF values for different fuels and allocation methods in combined heat and power (CHP) plants, and in particular the accuracy of using such PEF methodologies as an indicator for sustainability.
- Provide a guidance document for district heating and cooling operators (DHCO) with simplified calculation approaches on how to derive the indicators (PEF, CO2 emission factor, RES share, waste heat share and heating losses).
- Propose the legal requirement for consumer information in paragraph 1 of Article 24 of RED II focus on the indicators of energy efficiency and renewable shares, so these are studied more in-depth.
- Propose how these indicators could be communicated to the final consumer.

The target audience of this guidance document are existing and potential consumers of DHCs, DHC operators as well as Member States (MSs) responsible for the implementation of provisions set under the framework of the RED.

In our analysis, we devote particular attention to the primary energy factor (PEF) since it is the most prominent indicator and at the same time highly sensitive to the specific assumptions considered for its calculation. The PEF is used in various contexts such as the Energy Performance of Buildings Directive ([5]) (EPBD) to set the energy performance of buildings, and the Energy Efficiency Directive ([6]) (EED) to quantify total primary energy savings. It describes the efficiency of energy systems and, in particular, of district

([3]) 2018/2001/EU and revision of this directive (COM/2021/557 final)
([4]) 2012/27/EU as amended by (EU)2018/2002 and proposal for a revision of the EED 2018/2002 (COM(2021) 558 final)
([5]) 2010/31/EU as amended by 2018/844/EU
([6]) 2012/27/EU as amended by (EU)2018/2002

heating networks. This indicator, however, can be assessed using different approaches: the type of PEF (non-renewable PEF, renewable PEF or total PEF) and energy transformations taking place within the specific boundaries of a system. The adequacy of using PEF as an indicator for sustainability largely depends on these different approaches and assumptions. Moreover, there are other indicators dealing with sustainability aspects, which should be considered in the frame of the RED II as well, such as CO_2 emission factor, and the shares of RES and waste heat.

1.2 Policy framework

According to Article 24(1) of RED II (Directive (EU) 2018/2001), MSs shall ensure that information on the energy performance and the share of renewable energy in their district heating and cooling systems is provided to final consumers in an easily accessible manner, such as on bills or on the suppliers' websites and on request.

The proposal to amend REDII (RED III) reinforces the role of consumers by adding a further requirement specifying the type of information that should be provided for consumers ((Article 1(13a) of the proposal for the amendment of Directive 2018/2001 (RED III) (European Commission, 2021a)). In addition to the requirement already contained in Article 24(1) of REDII, Article 1(13a) of the new proposal states that: The information on the renewable energy share shall be expressed at least as a percentage of gross final consumption of heating and cooling assigned to the customers of a given district heating and cooling system, including information on how much energy was used to deliver one unit of heating to the customer or end-user.

By this additional requirement the proposal to amend REDII (RED III) reinforces the role of consumers by specifying the type of information that should be provided for consumers. The way this information could be expressed include specific RES share/primary energy factor that the district heating/cooling systems operator could provide to consumer (e.g. on bills, suppliers/regulators' websites), or/and it could be an energy label (voluntary or mandatory) for DHC systems. Both REDII's Article 24(1) and REDIII's Article 1(13a) specify that the information shall be provided in an easily accessible manner, such as on the suppliers' websites, on annual bills or upon request. The information required under paragraph 1 of REDII is essential not only for a consumer to know the value versus price ratio of the heating or cooling supply, but is also central for exercising consumers' disconnection right specified under paragraphs 2 and 3 of this Article, as disconnection from a DHC network can be requested if the performance of that network does not satisfy certain minimum energy performance and renewable shares criteria as set out in the "efficient district heating and cooling" definition under Article 2(20) of REDII (referring to Article 2(41) of EED, where this definition is set). Thus, the clarification of the first paragraph (24(1)) could be very useful for the implementation of these two following paragraphs (24(2) and 24(3)) regarding disconnection as well.

1.3 Structure of this report

This reports is structured as follows: section 2 describes relevant provisions from the EED, RED II and EPBD as well as EU standards related to the EPBD. We look at the usage of indicators in the EU Member States, starting with the PEFs presented in the cost-optimal reports of the EPBD and finishing with some concrete examples from three Member States on their legal provisions addressing district heating and cooling systems. The final part of section 2 presents selected studies which look at methodology approaches for the PEFs and other indicators. Section 3 presents methodical approaches to assess the Primary Energy Factor, CO_2 emission factor, renewable energy share and waste heat share as well as the efficiency of the district heating and cooling system and network. In section 4, we provide a proposal for a guidance document showing calculation methods for various indicators. Using the proposed indicators of the guidance document, the district heating operator is meant to inform the final customer (existing or future) about the efficiency and sustainability of the district heating network. In section 5, we show how these indicators can be communicated to the final customer of the district heat supply.

2 Energy indicators used in different context

2.1 EU Legislation and standards

When it comes to energy indicators, the Primary Energy Factor (PEF) plays an important role in the European legislation. In the EED, each Member State shall set an indicative national energy efficiency target based on either primary or final energy consumption (Article 3, EED). Moreover, each Member State shall set up an energy efficiency obligation scheme by expressing the amount of energy savings in terms of either primary or final energy consumption (Article 7, EED). In both cases, the PEF, used to convert the final energy consumption to primary energy consumption, is required. The EPBD ([7]) includes several provisions based on the primary energy use. According to Article 4 and 5 of the EPBD, Member States shall set minimum energy performance requirements expressed in primary energy use for buildings or building units to achieving cost-optimal levels. The calculation of the primary energy use has to be carried out using primary energy factors which may be based on national or regional yearly average values and may take into account relevant European standards (Article 3 and Annex I, EPBD ([8])). Moreover, the EPBD requires Member States to define and apply the standard for nearly zero-energy buildings (Article 9, EPBD). This article asks to use the primary energy consumption. Finally, the third directive referring to the primary energy use relevant for the heating and cooling sector is the Ecodesign Directive and Energy Labelling Regulation. The Ecodesign directive aims at setting design requirements for energy-related products which are compared among others by using primary energy consumption.

In addition to specifically requiring PEF, other indicators are also introduced in the EU legislation to evaluate the performance of the district heating and cooling. According to the RED II, the energy performance and the share of renewable energy in district heating and cooling systems shall be used to inform final customers about the heat they use (Article 24(1), RED II). It is to be noted that PEF can be a key input or even the chosen indicator to define energy performance. The EED defines performance of district heating and cooling by a combination of energy sources and technologies used and sets the following definition for “efficient district heating and cooling”: a district heating or cooling system using at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat (Article 2(41), a revision of this definition was proposed in July 2021 ([9])). Further in this section, we provide more detailed information about the role of the energy indicators from the above mentioned directives and their relation to the district heating and cooling.

2.1.1 RED II

According to Article 24(1) of RED II (2018/2001), Member States shall ensure that information on the energy performance and the share of renewable energy in their district heating and cooling systems is provided to final consumers. The definition of the energy performance of district heating and cooling is not provided in the RED II. However, the proposal to amend REDII (RED III) specifying the type of information that should be provided for consumers ((Article 1(13a) of the proposal for the amendment of Directive 2018/2001 (RED III). In addition to the requirement already contained in Article 24(1) of REDII, Article 1(13a) of the new proposal states that: The information on the renewable energy share shall be expressed at least as a percentage of gross final consumption of heating and cooling assigned to the customers of a given district heating and cooling system, including information on how much energy was used to deliver one unit of heating to the customer or end-user.

2.1.2 EPBD

The calculation of the cost-optimal levels of minimum energy performance requirements for buildings and building elements shall follow guidelines document which accompanies delegated regulation on energy performance in buildings (244/2012 ([10])). The guidelines document recommends that Member States use CEN Standards for their energy performance calculation. Moreover, the EPB ([11]) centre provides a set of standards and accompanying technical reports to support the EPBD by determining the energy performance of a

([7]) 2018/844/EU
([8]) Idem
([9]) Proposal for a revision of the EED 2018/2002 (COM(2021) 558 final)
([10]) Guidelines accompanying Commission Delegated Regulation (European Commission, 2012)
([11]) Consultancy and Services on the Energy Performance of Buildings. https://epb.center/about/

building. The relevant standards related to the primary energy calculation is the standard EN 15603:2008 ([12]) which provides overall scheme for energy calculation and definitions and standard EN 15316-4-5 ([13]) which defines the energy indicators of district energy system as well as standard EN 17423 ([14]) on assumptions to be used to determine PEF or CO_2 emission factors. **Figure 1** shows a schematic illustration of the calculation of energy performance of buildings which starts with the calculation of net energy needs and ends with the calculation of the primary energy use. Calculation of the primary energy from district heating and cooling and decentralised energy supply is carried out using specific primary energy factors. According to EPBD Annex I, Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1 ([15]), 52003-1 ([16]), 52010-1 ([17]), 52016-1 ([18]), and 52018-1 ([19]), developed under mandate M/480 given to the European Committee for Standardisation (CEN). This also includes reporting of PEFs.

(EN) ISO 52000-1 provides a definition for primary energy and gives an example: "Primary energy is the amount of energy which has to be extracted from non-renewable sources or renewable sources for each kWh of energy carrier which is delivered to your building." For example, to deliver 1 kWh gas, 1.1 kWh of gas has to be extracted because some gas was used to power the turbine, to push the gas to the pipeline and something has been lost due to inefficiencies in the pipelines (EPB centre, 2020).

Primary energy includes non-renewable energy and renewable energy. If both are taken into account it can be called total primary energy. For the cost-optimal evaluation, the non-renewable part of primary energy is considered. And, for overall building performance, both the non-renewable part and the total quantity of primary energy related to building operation should be reported (European Commission, 2012).

The proposal to revise the EPBD ([20]) provides definitions for primary energy, non-renewable primary energy, renewable primary energy factor and total primary energy factor (Article 2(9, 10, 11, 12) :

— 'primary energy' means energy from renewable and non-renewable sources which has not undergone any conversion or transformation process;

— 'non-renewable primary energy factor' means non-renewable primary energy for a given energy carrier, including the delivered energy and the calculated energy overheads of delivery to the points of use, divided by the delivered energy;

— 'renewable primary energy factor' means renewable primary energy from an on-site, nearby or distant energy source that is delivered via a given energy carrier, including the delivered energy and the calculated energy overheads of delivery to the points of use, divided by the delivered energy;

— 'total primary energy factor' means the weighted sum of renewable and non-renewable primary energy factors for a given energy carrier.

([12]) EN 15603:2008 Energy performance of buildings. Overall energy use and definition of energy ratings.

([13]) EN 15316-4-5. Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems.

([14]) EN 17423. Energy performance of buildings – determination and reporting of Primary Energy Factors (PEF) and CO2 emission coefficient – General Principles, Module M1-7. (

([15]) ISO 52000-1:2017 Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures.

([16]) ISO 52003-1:2017 Energy performance of buildings — Indicators, requirements, ratings and certificates — Part 1: General aspects and application to the overall energy performance.

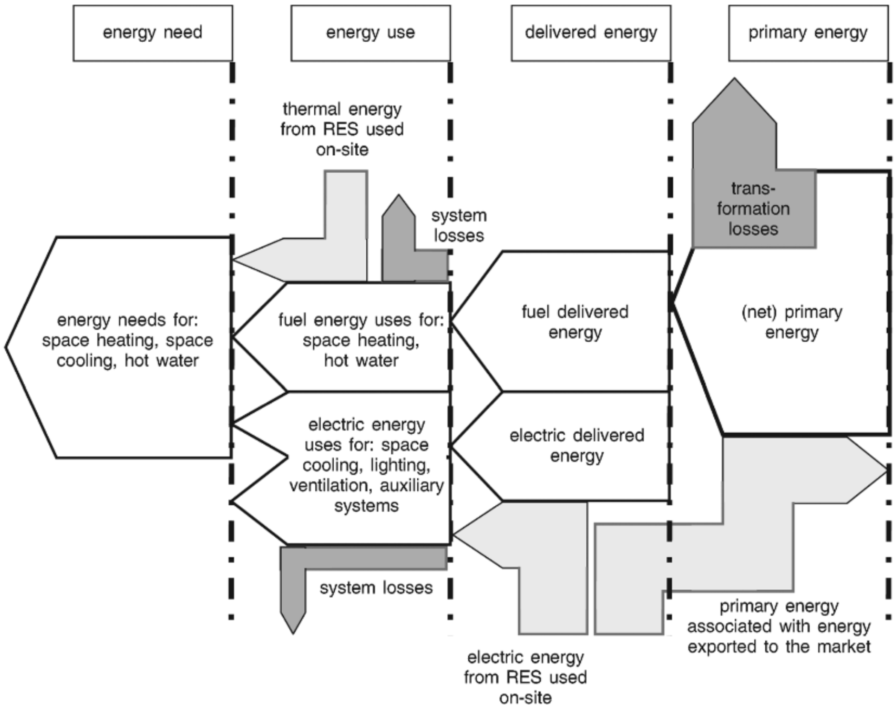
([17]) ISO 52010-1:2017 Energy performance of buildings — External climatic conditions — Part 1: Conversion of climatic data for energy calculations

([18]) ISO 52016-1:2017 Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures

([19]) ISO 52018-1:2017 Energy performance of buildings — Indicators for partial EPB requirements related to thermal energy balance and fabric features — Part 1: Overview of options

([20]) (COM(2021) 802 final

Figure 1. Schematic illustration of the calculation of energy performance of buildings from net energy needs to primary energy use.



Source: European Commission, 2012

Moreover, according to the Commission's proposal to revise the EPBD, district heating or cooling systems should be accounted for in the calculation methodology using primary energy factors (Annex I):

Member States shall take the necessary measures to ensure that, where buildings are supplied by district heating or cooling systems, the benefits of such supply are recognised and accounted for in the calculation methodology through individually certified or recognised primary energy factors.

The calculation of primary energy shall be based on primary energy factors, (distinguishing non-renewable, renewable and total per energy carrier, which have to be recognised by the national authorities. Those primary energy factors may be based on national, regional or local information. Primary energy factors may be set on an annual, seasonal, or monthly, daily or hourly basis or on more specific information made available for individual district systems. Primary energy factors or weighting factors shall be defined by Member States. The choices made and data sources shall be reported according to EN 17423 or any superseding document. Member States may opt for an average EU primary energy factor for electricity established pursuant to Directive (EU) …/… [recast EED] instead of a primary energy factor reflecting the electricity mix in the country.

2.1.3 EED

As mentioned before, the calculation of the national energy efficiency targets and the energy efficiency obligations schemes require the use of PEF in order to quantify and compare in primary energy terms. In addition, the EED sets out a default EU PEF for electricity. This default coefficient for electricity is 2.1 according to the Directive amending the EED. Member States may apply this default value when calculating energy savings in primary energy terms (amendment for Annex IV, footnote 3 EED). Also, the EPBD revision proposed that Member States may opt for the use of a primary energy factor for electricity aligned with the EU average in line with the EED ([21]). Alternatively, Member States can apply a different coefficient established

([21]) From the EPBD revision explanatory memorandum (COM(2021) 802 final): to encourage the swift deployment of heating systems with zero direct emissions, and to avoid that investments in new generations of fossil fuel-based boilers become stranded assets, zero-emission buildings should not generate carbon emissions on-site and Member States may opt for the use of a primary energy factor for electricity aligned with the EU average.

through a transparent methodology on the basis of national circumstances affecting primary energy consumption.

In the context of DHC, the EED sets out in Article 2(41) the definition of “efficient district heating and cooling” (EDHC) (new definitions for EDHC are proposed in the proposal of the EED (COM(2021) 558 final). In combination with Article 2(42) and 2(43), this definition aims to increase the primary energy efficiency and a progressive integration of renewable energy and waste heat and cold in district heating and cooling. Efficient district heating and cooling is one of the options to provide efficient heating and cooling, which is defined in Article 2(43) as a heating and cooling option that, compared to a baseline scenario reflecting a business-as-usual situation, measurably reduces the input of primary energy needed to supply one unit of delivered energy within a relevant system boundary in a cost-effective way, as assessed in the cost-benefit analysis referred to in this Directive, taking into account the energy required for extraction, conversion, transport and distribution.

Moreover, ‘efficient individual heating and cooling’ means an individual heating and cooling supply option that, compared to efficient district heating and cooling, measurably reduces the input of non-renewable primary energy needed to supply one unit of delivered energy within a relevant system boundary or requires the same input of non-renewable primary energy but at a lower cost, taking into account the energy required for extraction, conversion, transport and distribution.

2.1.4 The European standard EN 15316-4-5

The European standard EN 15316-4-5 specifies the calculation of indicators that characterize district energy systems. The standard provides calculation rules to determine these indicators: primary energy factor, emission factor, renewable energy ratio, waste heat ratio and cogenerated heat ratio.

With regard to the primary energy factor, the standard provides default weighting factors for heat including three primary energy indicators (total primary energy, non-renewable primary energy and renewable primary energy) (see **Table 1**). These weighting factors can be used for a simplified approach where the district heating system is considered as a black box. These weighting factors are determined as a ratio of the weighted energy inputs to the system and energy delivered from the system. These values take into account distribution losses. In addition to the simplified approach, the standard also provides detailed calculation rules. For these calculations additional information about the district energy system is required, i.e. it is not regarded as a black box. For example, the standard provides rules on how to account waste heat from industry, heat from waste-to-energy plants and heat pumps:

- Industrial waste heat: it consists of two components: a process-related component and a district heating component. While the process-related component is the minimum amount of waste heat which is generated in the production process and shall be released to the environment via cooling systems if not used for district heating, the district heating component is the amount of the additional heat needed to meet the requirements of the district heating system if the first component is used. The weighted energy input for generating the district heating component shall be integrated into the numerator to calculate the weighting factor of the district energy system.
- Heat from waste-to-energy plants: the energy input for processes such as ignition, auxiliary firing and flue gas cleaning shall be integrated into the numerator to calculate the weighting factor of the district energy system.
- Heating and cooling from heat pumps: If a heat pump delivers cooling and heating at the same time and energy indicators are required for each of the two products, the energy input shall be divided according to the energy output.

Table 1. Default weighting factors for heat (Table B.2 from The European standard EN 15316-4-5).

Energy carrier		f_{Pnren}	f_{Pren}	f_{Ptot}	f_{co2} (g/kWh)
Heat from boiler	solid fossil fuel	1.7	0	1.7	530
	liquid fossil fuel	1.6	0	1.6	400
	gaseous fossil fuel	1.5	0	1.5	310
	solid bio fuel	0.4	1.4	1.8	70

	liquid bio fuel		0.7	1.4	2.1	110
	gaseous bio fuel		0.6	1.4	2.0	150
Heat from CHP	solid fossil fuel		0.8	0	0.8	500
	liquid fossil fuel		0.7	0	0.7	300
	gaseous fossil fuel		0.7	0	0.7	160
	solid bio fuel		0	2.0	1.8	0
	liquid bio fuel		0	2.4	1.7	0
	gaseous bio fuel		0	2.4	1.4	0
	nuclear power plant		0.6	0	0.6	120
Waste heat from	Industrial process	process-related component	0	0	0	0
		district heating component + process-related component	0.4	0	0.4	90
	Waste-to-energy(*)	incl. CHP	0.1	0	0.1	25
		without CHP	0.2	0	0.2	50

NB: (*) – values are based on conventions.

f_{Pnren} – weighting non-renewable primary energy factor

f_{Pren} - weighting renewable primary energy factor

f_{Ptot} - weighting total primary energy factor

f_{co2} – weighting CO2 emission factor

Source: CEN, 2017

2.2 Member States' approaches

2.2.1 PEFs in cost-optimal reports

In 2018, EU Member States submitted to the Commission the cost-optimal reports requested under the EPBD. In these reports, MSs set cost-optimal minimum energy performance requirements for new buildings, for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls (European Commission 2021). The minimum energy performance requirements should be expressed in primary energy demand using specific primary energy factors. Table 2 shows primary energy and CO_2 emission factors for various fuels, district heating and electricity used by the Member States in their cost-optimal reports. The PEFs for district heating systems vary strongly between MSs. It varies between 0.0-1.6 in case of the total PEF and between 0.0-1.48 for non-renewable PEF (see **Figure 2**). We identified three categories of the PEFs applied:

- Applying one PEF for all district heating networks (Denmark, Estonia, France, Slovakia, Sweden).
- Applying different PEF depending on the generation type and fuel (in most cases, four different values are provided: DH from CHP - fossil, DH from CHP - renewable, DH from boiler - fossil, DH from boiler - renewable). These PEF were found in the cost-optimal reports of Germany, Latvia, Luxembourg, Austria and Poland.
- Applying different PEF depending on the existing district heating grids. Lithuania provided a list of the existing district heating grids and their specific PEFs.

With regard to natural gas and other fossil fuels, two values are used either 1.0 or 1.1 in most countries except Spain, Luxembourg, Austria and Romania. In those countries, the PEF for fossil fuels is higher than 1.1. According to the Fraunhofer study [22], PEF of 1 means that the energy carrier is directly considered as a primary energy source whereas PEF of 1.1 relates to a simplification of energy inputs in

[22] Esser, A., & Sensfuss, F., 2016: "Review of the default primary energy factor (PEF) reflecting the estimated average EU generation efficiency referred to in Annex IV of Directive 2012/27/EU and possible extension of the approach to other energy carriers. Evaluation of primary energy factor calculation options for electricity". We will call this report "Fraunhofer study" in this document.

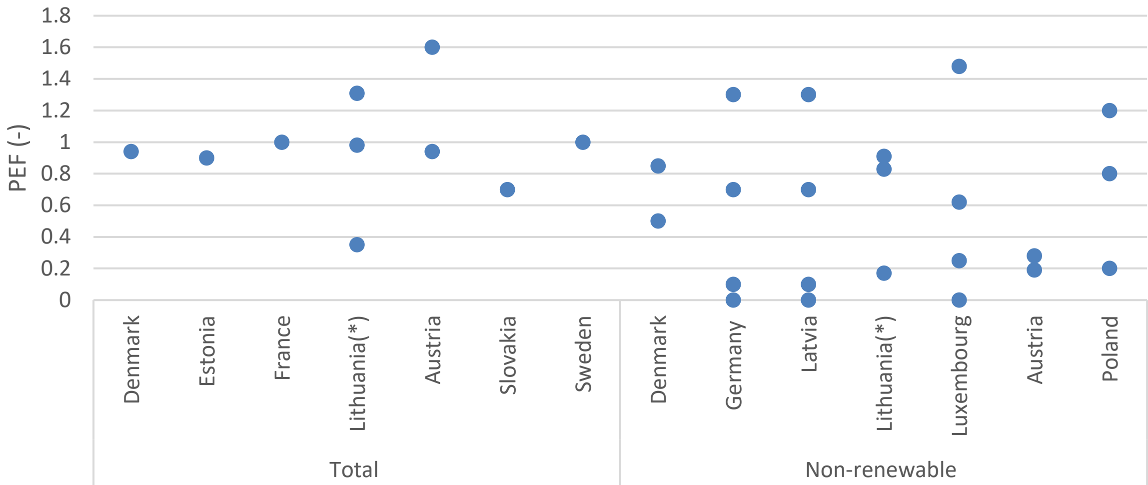
processing and distribution of the primary fuels equalling 10% of the energy delivered by the energy carrier. Values higher than 1.1 mean that more detailed analyses are carried out, considering the energy inputs in different phases of the life cycle.

PEF for biomass varies strongly between MSs. One of the reasons is the large variation of the types of biomass (wood, biogas, pellets, straw and etc.). According to the Fraunhofer study ([23]), there is a lack of harmonised criteria on calculation of biomass. The differences appear also due to life cycle boundaries and indicators used (non-renewable primary energy PEF and total primary energy PEF). In the case of the non-renewable primary energy PEF, bio-based fuels show very low PEF, close to zero while using total primary energy factor, the PEF is above 1. This is due to the renewable energy content of the fuel which is also added to the primary energy inputs of life cycle energy use. The type of heating system use (e.g. simple boiler, cogeneration) could also have an impact.

With regard to the different types of PEF, namely non-renewable PEF, total PEF, renewable PEF, it was often not clear which PEF MSs are referring to. According to the Guidelines accompanying the delegated regulation on energy performance of buildings, the non-renewable part of primary energy is considered for the cost-optimal evaluation (European Commission, 2012). However, for the overall building performance, both the non-renewable part and the total quantity of primary energy related to building operation should be reported.

Next, only few countries provided calculation assumptions.

Figure 2. Primary energy factors for the district heating systems used in the countries' cost-optimal reports 2018.



NB:
Number of values per country (number of dots) depends on the applied approach for PEFs for district heating (see also table 2)
(*) For Lithuania, a range is provided within each DH grid is identified by the individual PEF. 0.91 is the Lithuanian average.

Source: European Commission, 2018.

([23]). Idem

Table 2. Primary energy factors and CO_2 emission factors for various fuels used in the countries' cost-optimal reports 2018.

	Natural Gas		Other fossil fuels		Biomass			District heat			Electricity		
	Total	CO_2kg-CO2/MW	Total	CO_2kg-CO2/MW	Total	Non-ren.	CO_2 kg-CO2/MW	Total	Non-ren.	CO_2 kg-CO2/MW	Total	Non-ren.	CO_2 kg-CO2/MW
Denmark	1.1	225						0.94	0.5 (0.85([1]))	104	2.31	1.29 (2.08([1]))	329
Germany	1.1		1.1		0.2([2]), 0.5([3])			0.7([4]), 0.0([5]), 1.3([6]), 0.1 ([7])			1.8([8]),2.8 ([9])		
Estonia	1.0		1.0		0.75([10])			0.9			2.0		
Spain	1.19 (+0.005 ren. PEF)	252	1.18([11]) (+0.003 ren. PEF) 1.08 ([12])(0.02)	311([11]), 427 ([12])	1.0([13]), 1.03([14]) (ren. PEF)	0.034([13]), 0.085 ([14])	18					2.97-1.95([15])	932-331([15])
France	1.0	270	1.0	314 (oil)	1.0([16]), 0.6 ([17])		32.0	1.0		32.0	2.58		210
Cyprus	1.1		1.1			0.1						2.7	
Latvia	1.1		1.1, 1.2([18])			0.2			0.7([22]) 0([23]) 1.3([24]) 0.1([25])			1.5([19]), 2.0([20]), 0 ([21])	
Lithuania	1.1	200	1.1, 1.2 (coal)	280 (fuel oil), 340 (coal)	1.1([26])	0.1	0	1.31([29]), 0.35-0.98 ([30])	0.91([29]), 0.17-0.83 ([31])	170 ([29])	1.06([27]), 2.8 ([28])	0.06 ([27]), 2.8 ([28])	10([27]), 600 ([28])
Luxembourg	1.12	246	1.1(heating oil), 1.08 (hard coal)	300 (heating oil), 439 (hard coal)		0.06 (wood chips, 0.01 (firewood), 0.07 (wood pellets)	35 (wood chips), 14 (firewood), 21 (wood pellet)		0 ([32]), 0.62 ([33]), 0.25 ([34]), 1.48 ([35])	0, 43, 66,		2.66	651
Netherlands		50.6(kg CO2/GJ)											61.3 (kg CO2/GJ)
Austria	1.17	236			1.08	0.06	4	1.6([36])0.94([37])	0.28, 0.19	51, 28	1.91	1.32	276
Poland	1.1		1.1			0.2			0.8([38])			3([41])0.7([42])	

	Natural Gas		Other fossil fuels		Biomass			District heat			Electricity		
	Total	CO_2kg-CO2/MW	Total	CO_2kg-CO2/MW	Total	Non-ren.	CO_2 kg-CO2/MW	Total	Non-ren.	CO_2 kg-CO2/MW	Total	Non-ren.	CO_2 kg-CO2/MW
									1.2[39] 0.2[40]				
Portugal	1.0	202	1.0 (diesel)	267		1.0 (renewables)	0					2.5	144
Romania	1.17										2.62		
Slovakia	1.1 (1.36)							0.7			2.2 (for deep renovation and nZEB) (2.76)		
Sweden	1.0		1.0		1.0 (Biofuel)			1.0 (1.0 – district cooling)			1.6		

NB:
Countries which provided data are showed in the table (other countries either did not submit their cost-optimal reports or they did not provide data on the PEFs (see comments below).
Belgium: No cost-optimal report.
Bulgaria: No cost-optimal report.
Czechia: PEF are not provided.
Denmark: PEF are calculated using the Danish energy statistics. Inclusive of energy used to extract the fuels. Heating efficiency of 200 % is used to calculate the energy need for heating in relation to CHP production in district heating and power supply systems.
Estonia: Weighting factors for energy carriers.
Greece: No PEF provided.
France: Coefficients for conversion of final energy into primary energy.
Croatia: No cost-optimal report.
Italy: Only source provided, but no PEF. Source: Ministerial Decree of 26June 201.
Cyprus: Heat from waste – 0.05. Primary energy conversion factors.
Latvia: 0 for Wind, solar, aerothermal, hydrothermal and sea energy, hydraulic energy.
Lithuania: Source: Technical Building Regulation STR 2.01.02:2016 'Design and certification of energy performance of buildings'.
Other renewable sources: PV: 1.01, 0.01, wind: 1.01, 0.01, solar: 0.01, 1.
Luxembourg: Not clear what type of PEF is applied (total, non-renewable, renewable). Sources: Ministère de l'Economie, Berechnung kostenoptimaler Niveaus von Mindestanforderungen an die Gesamtenergieeffizienz für neue und bestehende Wohn-und Nichtwohngebäude, Luxemburg: Ministère de l'Economie, 2014.
Hungary: No PEF provided.
Malta: No PEF provided.
Netherlands: Source: NEN 7120:2011. No PEF provided.
Austria: Source: OIB Guideline 6: 2015.
Poland: Source: the annual non-renewable primary energy demand factor EP [kWh/(m2·year)], calculated in accordance with the rules issued on the basis of Article 15 of the Act of 29 August 2014 on the energy performance of buildings (Journal of Laws 2017, item 1498, as amended.).
Portugal: Not clear what type of PEF is applied (total, non-renewable, renewable). Primary energy conversion factor, which reflects the overall performance of the primary energy transport and conversion system). Source: Ministerial Implementing Order (extract) No15793-D/2013.
Romania: Not clear what type of PEF is applied (total, non-renewable, renewable).
Slovenia: No PEF provided.

Slovakia: Not clear what type of PEF is applied (total, non-renewable, renewable). Source: Decree of the Ministry of Transport, Construction and Regional Development No 324/2016
Finland: No PEF provided.
Sweden: Not clear what type of PEF is applied (total, non-renewable, renewable). Source: he National Board of Housing, Building and Planning's building regulations.

([1]) Adjusted primary energy factor by including the fossil fuel used for extraction of the fuel (source: Danish cost-optimal report (European Commission, 2018).
([2]) Wood.
([3]) Biogas, bio-oil (close to the building).
([4]) DH from CHP (fossil fuels).
([5]) DH from CHP (biofuels).
([6]) DH from heating plant (fossil fuel).
([7]) DH from heating plant (biofuels).
([8]) Electricity mix (In accordance with Annex 1 Point 2.1.1 to the Energy Savings Ordinance of 2016).
([9]) Displacement electricity mix (in accordance with DIN V 18599-1: 2011-12; only relevant for determining local primary energy factor for heat from CHP).
([10]) Fuels obtained from renewable raw materials (wood and wood-based fuels and other biofuels, with the exception of peat and peat briquettes.
([11]) Heating gas, oil.
([12]) Coal.
([13]) Non-densified biomass.
([14]) Densified biomass (pellets).
([15]) Varies depending on the region.
([16]) Article 15 of the Order of 26 October 2010 on the thermal characteristics and energy performance requirements of new buildings and new parts of buildings (Th-B-C-E method).
([17]) Article 41 of the Order of 13 June 2008 on the energy performance of existing buildings with a surface area in excess of 1 000 m2, where they are subject to major renovation works (Th-C-E-Ex method).
([18]) Brown coal (lignite).
([19]) From electrical power networks.
([20]) From fossil fuels.
([21]) From renewable energy sources, produced within the boundaries of the technical building systems.
([22]) Thermal energy from boiler rooms, produced in cogeneration (The value corresponds to a heat supply system with 70% output from cogeneration) – fossil fuels.
([23]) Thermal energy from boiler rooms, produced in cogeneration (The value corresponds to a heat supply system with 70% output from cogeneration) – renewable fuels.
([24]) Thermal energy from boiler rooms (without cogeneration) – fossil fuels.
([25]) Thermal energy from boiler rooms (without cogeneration) – renewable fuels.
([26]) Wood, straw, bio-gas, bio-oil, etc.
([27]) Electricity produced in hydroelectric power plants.
([28]) The average of various energy production methods.
([29]) Heat from heat networks (the Lithuanian average).
([30]) Varies depending on the district heating grid. Renewable primary energy factor.
([31]) Varies depending on the district heating grid.
([32]) From CHP with renewable fuel.
([33]) From CHP with fossil fuel).
([34]) From heating plants with renewable fuel.
([35]) From heating plants with fossil fuel.
([36]) District heating from heating plant (renewable).
([37]) District heating from high-efficiency CHP (default value).
([38]) Heat from coal-fired heat plant.
([39]) Heat from gas-/oil-fired heat plant.
([40]) Heat from biomass-fired heat plant.
([41]) Applies to the power supply from the power grid system.
([42]) PV systems.

Source: European Commission, 2018.

2.2.2 Examples from DE, NL and SE

According to Article 24(1) of the RED II, MSs shall ensure that information on the energy performance and the share of renewable energy in their district heating and cooling systems is provided to final consumers. Following the EPBD, MSs have to provide PEFs for district heating networks. In this subchapter, we look at three selected Member States (Germany, the Netherlands and Sweden) and describe how they implement the provisions from these two directives and what kind of indicators they use.

Germany

In Germany, heat suppliers are obligated to provide the PEF to customers showing the non-renewable primary energy demand of the house. Moreover, heat suppliers have to provide the CO_2-emission factor to their customers needed for the building energy certificate (Gebäudeenergieausweis). The information together with a database are published on the AGFW ([24]) website ([25]). **Figure 3** shows a screenshot from the AGFW website indicating the location of the DHC network (city), DHC network, heat supplier, the primary energy factor (f_P) and the validation date.

Figure 3. List with the DHC network and associated primary energy factors (a screenshot from the AGFW website)

Liste der f_P-Bescheinigungen nach FW 309-1 nach Städten sortiert

Stadt	Versorgungsgebiet / Netz	Versorgungsunternehmen	f_P	gültig bis
Aalen	Wärmenetz Aalen	https://www.district-energy-systems.info/supplysystems/DEBW0077		
Aalen - Fachsenfeld	Wärmenetz Schloßäcker	https://www.district-energy-systems.info/supplysystems/DEBW0078		
Ahrensburg	Bioerdgas-BHKW Ahrensburg Otto Siege Str.	Hansewerk Natur GmbH	0,00	25.04.2026
22926 Ahrensburg	Reeshoop	URBANA Energiedienste GmbH	0,26	18.07.2027
Aichach	Biomasse-HKW Aichach	Biomasse Wärmeverbund Aichach GmbH	0,00	11.08.2024
~~Ainring~~	~~Ainring~~	~~Gemeindewerke Ainring~~	~~0,25~~	~~16.02.2021~~
24161 Altenholz	Gemeinde Altenholz	https://www.district-energy-systems.info/supplysystems/DESH0003		
86450 Altenmünster	Nahwärmeversorgung Altenmünster	Gemeindewerke Altenmünster	0,58	14.08.2027
Altentreptow	Fernwärmenetz Altentreptow	Wärmeversorgung & Dienstleistungsgesellschaft mbH	0,15	17.03.2025
Altötting	Wärmenetz des ESW Energiesparwerk GmbH & Co. Biothermie Altötting KG	ESW Energiesparwerk GmbH & Co. Biothermie Altötting KG Am Huberstadl 1, D-84503 Altötting	0,11	28.02.2023
Ammersbek	Bioerdgas-BHKW Ammersbek	Hansewerk Natur GmbH	0,11	21.12.2026
Arnstadt	Dornheimer Berg in Arnstadt	https://www.district-energy-systems.info/supplysystems/DETH0011		
Arnstadt	Fleischgasse in Arnstadt	https://www.district-energy-systems.info/supplysystems/DETH0012		
Arnstadt	Mitte	https://www.district-energy-systems.info/supplysystems/DETH0013		

Source: AGFW, 2020e

The AGFW defines and provides a methodology on how to calculate the primary energy and emission factors. There are four working documents which provide the methodology for the primary energy factors and CO_2 emission factors applying the Power bonus method (AGFW 2020a), degree of fulfilment and energy source indicators (AGFW 2020b), emission factors according to the Power loss and Carnot method (AGFW 2020c) and Certificate (AGFW 2020d). The methodology and indicators in the working documents are based on the German Buildings Energy Act (Gebäudeenergiegesetz, GEG) (building energy low), DIN EN 15316-4-5: 2017-09, EN 15316-4-5:2017, DIN EN ISO 52000-1:2018-03 and the EED (Energy Efficiency Directive and its definition for the efficient district heating and cooling).

Methodology for the CHP and waste heat:

- Heat supplied by CHP: Applied CHP allocation method is “Stromgutschrift” method (the Power bonus method).
- Waste heat: is a by-product of a (industrial) process.

All data for calculation of the yearly factors have to be from the same time period and cover one, two or three years.

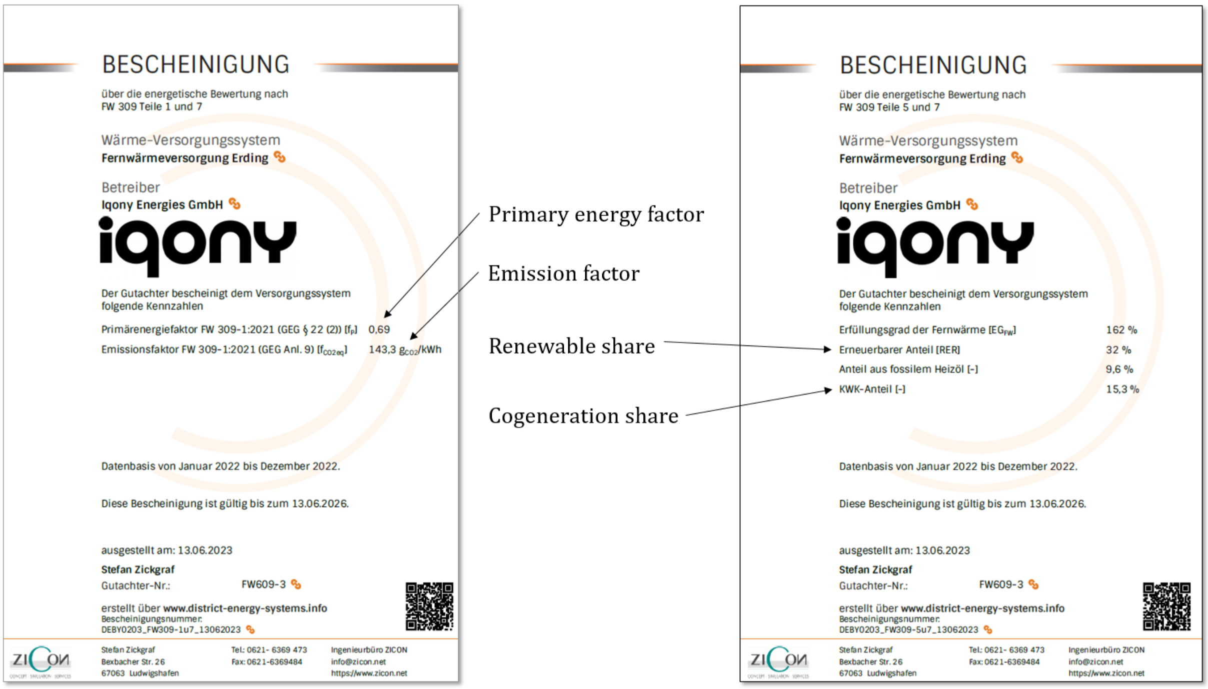
Germany has introduced a certificate for district heating and cooling networks. The calculation of the energy performance and energy source indicators shown in the certificate has to be in line with the above mentioned

([24]) Energy efficiency association for heating, cooling, CHP

([25]) https://www.agfw.de/technik-sicherheit/erzeugung-sektorkopplung-speicher/energetische-bewertung/geg-und-fernwaerme/

documents (AGFW 2020a, AGFW 2020b and AGFW 2020c). Depending on the data used to calculate the indicators, the certificate is valid for 10 years maximum (AGFW 2020d). The certificate is not mandatory. **Figure 4** shows an example of the certificate and explanation of the energy indicators. The certificate shall provide energy performance indicators in accordance with the EPBD including PEFs (non-renewable, renewable and total) and CO_2 emission factor. The certificate also provides energy source indicators in accordance with the EED showing renewable energy ratio, waste heat ratio and cogenerated heat ratio.

Figure 4. Example of a certificate of the district heating and cooling network in Germany



Source: AGFW 2023

The Netherlands

In the Netherlands, there is a reporting obligation for district heating suppliers to report annually on the sustainability of the heat supplied to their customers by providing at least information on: (1) CO_2 emissions per unit of delivered heat, (2) Primary fossil energy use per unit of delivered heat and (3) the share of renewable energy sources (Harmelink 2017). This obligation is part of the Heat Act ([26]).

Moreover, suppliers are obligated to provide the following information in order to calculate the above mentioned information: (i) type and number of customers, (ii) amount of auxiliary energy, (iii) amount of heat produced and supplied and, (iv) volume of heat losses.

A district heating network is defined as follows in the Netherlands: “the complete set of interconnected pipelines, associated installations and other devices capable of transporting heat, except pipelines, installations and utilities that are part of an indoor heating system”.

Heat suppliers are responsible for the reporting on the sustainability. However, heat suppliers are responsible for the entity they operate:

— Heat suppliers operating the transport grid, the distribution grid as well as the heat production installations report on the sustainability of the complete network (currently, this is mostly the case in the NL. These suppliers hold a license under the Heat Act) (Harmelink 2017).

([26]) https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/verduurzaming-warmtevoorziening/publicaties/warmtewet

- There are also DH networks where the transport grid, the distribution grid, the heat production units and heat supply to the consumers are the responsibilities of different entities. In this case, a single supplier is not able to report on the full DH network. The heat supplier reports only for which he/she signed contracts with heat producers that feed into the grid. Consumption of auxiliary energy and heat losses are allocated in proportion to the amount of contracted heat. Heat supplier receives data annually from the operators of the transport grid and the heat producers in order to be able to produce their report (Harmelink 2017).
- The calculation of the energy indicator for the energy sources follows these approaches:
- Electricity: primary fossil energy use and CO_2 emissions associated with the consumption of electricity are calculated using the most recent numbers on the primary fossil energy use and CO_2 emissions of the national electricity production mix applying the "Integral method".
- Heat supplied by heat driven CHP installations: The EMG standard applies the "power bonus method" for this allocation.
- Heat supplied by electricity driven CHP installation: The primary fossil fuel and CO_2 emissions allocated to the produced heat are calculated by applying the specific primary fossil energy factors and CO_2 emissions factors for the fuel used in the installations (see table below)
- Residual heat is defined as heat, which is released as a by-product of a (industrial) process. This means that: (i) this heat otherwise would be discharged and (ii) no additional fuel is required for the production of the residual heat. Electricity that is needed to extract this heat from the production process and deliver to the end-consumer is allocated to the residual heat.

Table 3. Specific primary fossil energy factors and CO_2 emissions factors applied for the heat supplied by electricity driven CHP

	Primary fossil fuel factor	CO2 emission factor (kg/GJprimary)
Coal	1.00	90
Fuel oil	1.00	69
Natural gas	1.00	51
Municipal solid waste	0.46	38
Biomass	0.00	0

Source: Harmelink 2017

Sweden

Following the EU's Energy Efficient Buildings Directive (EPBD) and the guidance for new buildings towards Near-Zero Energy Buildings (NZEB), the Swedish authority Boverket ([27]) proposes a definition for the primary energy factor for district heating and cooling (Gullberg and Ingelhag 2017).

Fixed values for electricity, district heating and other energy sources are defined:

- Electricity is set to the primary energy factor 1.6 (until 2021).
- Heating by either district heating, oil, natural gas or biofuel should initially be assigned the factor 1.0.

Apart from this official approach, different organisations in Sweden have developed alternative approaches on how to define and report the primary energy factor for DHC. These reports disagree with the Swedish official approach to apply the factor of 1.0 for all type of energy carriers (Gullberg and Ingelhag 2017, Gode et al 2013). Moreover, according to an informal discussion with the Swedish Energy Authority, different organisations use different methods on how to set the primary energy factor for waste heat. Waste heat can be accounted as zero (since it is really waste heat and the fuel consumption is accounted on the industry instead) or 1.

([27]) The Swedish National Board of Housing, Building and Planning

2.3 Research and studies

This subchapter provides an insight into some studies which evaluated the application of the primary energy factors and methodological approaches as well as guidance on how to assess the efficiency of DHC systems: "Evaluation of primary energy factor calculation options for electricity" ([28]), EcoHeatCool Project ([29]), EcoHeat4Cities Project ([30]).

Study "Evaluation of primary energy factor calculation options for electricity"

This study showed various ways to define and calculate the PEF of electricity as a uniform PEF for the entire European region (Esser, A., & Sensfuss, F., 2016). This study (hereinafter referred to as "Fraunhofer study") was used to update the PEF for electricity in the EED ([31]). After assessing and comparing different methodological approaches, the Fraunhofer study recommends to base the calculation on a life cycle perspective of the consumption of non-renewable resources.

One of the conclusions of the study is that it is very difficult to propose a consistent PEF of solid, liquid or gas fuels in the EU based on detailed life cycle and supply chain considerations. To calculate PEF for electricity, the study undertook some simplifications. The study developed four different methods which imply, among other criteria, various accounting methods for PEFs for renewable and non-renewable energy sources:

- Calculation method 1: It follows the Eurostat procedure for energy accounting, and therefore does not consider a life cycle approach in the calculations. All fuels have a PEF of 1.
- Calculation method 2: A life cycle approach is considered in this case. Non-renewable primary energy is accounted. For fossil fuels, a PEF value of 1.1 has been chosen as an approximation of life cycle non-renewable primary energy. For the category including biomass and waste fuels, a PEF value of 0.15 has been considered as best approximation.
- Calculation method 3: the same as calculation method 1 (except CHP allocation method).
- Calculation method 4: A life cycle approach is considered for fossil fuels. Total primary energy is accounted. For fossil fuels, a PEF value of 1.1 has been chosen as an approximation of life cycle total primary energy. For the category including biomass and waste fuels, a PEF value of 1 has been considered.

The general principle of the Eurostat approach which is called physical energy content method is that the primary energy form is taken as the first flow in the production process that has a practical energy use. This leads to different situations depending on the energy product:

- For directly combustible energy products (for example coal, natural gas, oil, biogas, bioliquids, solid biomass and combustible municipal/industrial waste) the primary energy is defined as the heat generated during combustion.
- For products that are not directly combustible: the choice of heat as the primary energy form for nuclear, geothermal and solar thermal (in case of nuclear reactor, if amount of heat produced is not known, the primary energy equivalent is calculated assuming efficiency of 33%. In case of geothermal, the primary energy equivalent is calculated assuming an efficiency of 10 % for electricity production and 50 % for derived heat production).

This Eurostat approach does not consider a life cycle perspective, where the entire supply chain is analysed by accounting the processes which involve additional energy inputs. It sets the PEF of the fuels as 1.

In order to incorporate a life cycle perspective, additional energy inputs on the supply chain up to the point the energy carrier should be included. According to the Fraunhofer study, this perspective is used in the standard

([28]) https://ec.europa.eu/energy/sites/ener/files/documents/final_report_pef_eed.pdf

([29]) https://www.euroheat.org/wp-content/uploads/2016/02/Ecoheatcool_WP3_Web.pdf

([30]) https://www.euroheat.org/wp-content/uploads/2016/04/Ecoheat4cities_3.1_Labelling_Guidelines.pdf

([31]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.328.01.0210.01.ENG for building energy performance evaluation EN 15603 ([32]). This standard describes the concept of including the different phases of the supply chain while assessing the primary energy factors (at least those phases):

- Energy to extract the primary energy carrier.
- Energy to transport the energy carrier from the production site to the utilization site.
- Energy used for processing, storage, generation, transmission, distribution, and any other operations.
- Energy necessary for delivery to the building in which the delivered energy is used.

As described above, the Fraunhofer study assessed the PEFs for various energy fuels using the general principle of the Eurostat approach setting the PEF to 1. To incorporate a life cycle perspective, the Fraunhofer study made a simplification by adding 10% of energy needed for processing and distributing the primary fuels (for fossil fuels) (see **Table 4**).

Table 4 shows PEFs for energy carriers by applying different calculation methods. PEF for electricity is the result of the calculation and the PEFs for other energy carriers in the table are input parameters to calculate the PEF for electricity. Apart from the different approaches to assess the PEF for energy carriers (combustible and non-combustible renewable sources, fossil fuels), the study used different type of PEFs (non-renewable primary energy factor and total primary energy factor) and two different CHP allocation methods (the IEA method and the Finnish method).

Table 4. PEFs for various energy carriers by applying different calculation methods

Energy carrier	Calculation method 1 Physical energy content method PEF indicator: Total primary energy System boundaries: Total energy conversion only CHP allocation method: IEA method	Calculation method 2 A life cycle approach is considered PEF indicator: Non-Renewable primary energy only System boundaries: Entire supply chain CHP allocation method: Finnish method	Calculation method 3 Physical energy content method PEF indicator: Total primary energy System boundaries: Total energy conversion only CHP allocation method: Finnish method	Calculation method 4 A life cycle approach is considered PEF indicator: Total primary energy System boundaries: Entire supply chain CHP allocation method: Finnish method
Geothermal	1.0	0.10	1.0	1.0
Hydro	1.0	0.06	1.0	1.0
Wind	1.0	0.03	1.0	1.0
Solar PV	1.0	0.08	1.0	1.0
Biomass	1.0	0.15	1.0	1.0
Fossil fuels	1.0	1.10	1.0	1.10
Nuclear	1.0	1.0	1.0	1.0
Electricity (for 2020)	1.87	1.59	2.01	2.09

Source: Esser, A., & Sensfuss, F., 2016

The EcoHeatCool project

The EcoHeatCool project provided guidelines for assessing the efficiency of district heating and cooling systems. The EcoHeatCool Project assessed the primary resource factor (PRF). The PRF is defined as the ration between the non-regenerative primary resource (i.e. fossil fuels) to the total primary energy supply for a given energy demand. This means that the PRF excludes the renewable energy component of primary energy, thus equivalent to the non-renewable primary energy factor introduced before. In other words, the PRF accounts for those sources that are depleted by extraction (i.e. fossil fuels).

([32]) EN 15603:2008: Energy performance of buildings. Overall energy use and definition of energy ratings

Table 5 shows primary resource factors for various energy fuels and determination of the different PRF for different fuels according to the EcoHeatCool project.

Table 5. Primary resource factor for different energy fuels used in the EcoHeatCool project.

Energy fuels	PRF (non-regenerative resource factor)	Comment
Lignite Coal	1.30	More extensive energy losses for lignite compared to hard coal.
Hard Coal	1.20	NA
Oil	1.10	NA
Natural gas	1.10	Losses occurring from the point of extraction to the delivery to the customers (mainly transport losses, occurring from the energy needed to compress the gas in gas pipelines).
Excess heat e.g. from industrial process	0.05	NA
Renewables (e.g. Wood)	0.10	This value reflects the energy used to harvest the biomass and the transport needed to carry the fuel to the installations.
Waste as Fuel, Landfill Gas	0.00	Burning wastes and landfill gases avoid the use of fossil fuels and make use of energy flows that otherwise would be lost.
Free Cooling	0.00	Free cooling is produced with renewable input such as deep cold sea/lake water. All input additional to free cooling needs to be taken into account
Electrical Power, European average	2.50	The value for electricity is fixed at 2.5 in order to be consistent with European legislation ([33]).

Source: EcoHeatCool 2016

The Ecoheat4cities project

The Ecoheat4cities project promotes awareness and knowledge-based acceptance of DHC systems through the establishment of a voluntary green heating and cooling label. The project developed a guidance and the label which provides information on key energy related parameters of DHC systems. The labelling is built on three criteria: share of renewables, resource efficiency (PEF) and CO_2 emissions.

The EcoHeat4Cities project introduced two energy indicators, the energy performance indicator and energy source indicator. While the energy performance indicator is represented by a primary energy factor and an emission coefficient, the energy source indicators is presented by the renewable and surplus heat fractions (for example, share of cogenerated heat is an energy source indicator).

The primary energy factor is calculated according to EN 15316-4-5. The project used the non-renewable primary energy factor. For the CO_2 emissions criteria, the non-renewable primary CO_2 emission coefficients are used. The renewable and surplus heat fractions are calculated as a ratio of heat from renewable and/or surplus heat carriers to total heat in %. **Table 6** shows primary energy factors and CO_2 coefficients for different energy fuels which have to be used if national values are not available. The energy input from Industrial waste heat is entirely allocated to the product and therefore the PEF and CO_2 emission coefficients are 0. However, the district heating component is the amount of additional energy needed to use the waste heat (e.g. boosting pressure, temperature and flow rate). This energy input shall be integrated in the numerator of the formula to calculate the overall PEF of the district heating network. The same applies to the municipal waste adding the energy input for processes such as ignition, auxiliary firing and flue gas cleaning into the numerator of the formula.

Table 6. Primary energy factor and CO_2 coefficient for various energy fuels used in the EcoHeat4Cities project

Type of fuel	Fuel	non- renewable Primary energy factor	CO_2 coefficient (non-renewable part), g/kWh
Fossil fuels	Natural gas	1.1	230

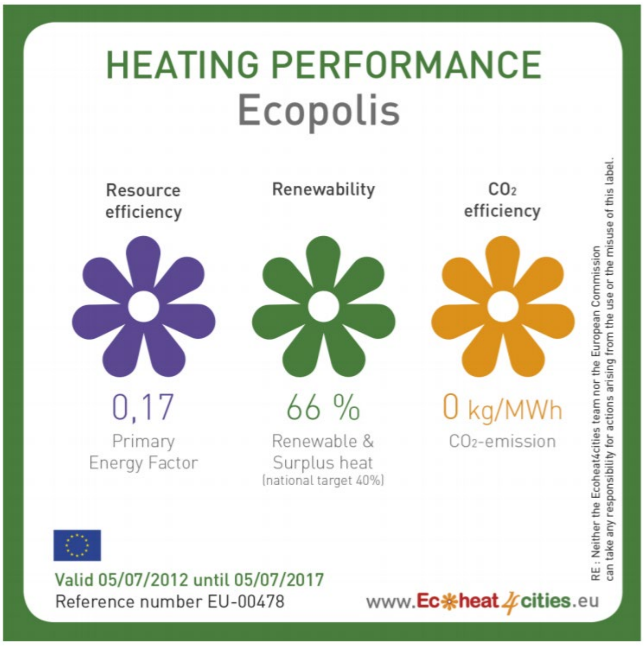
[33] This value is from 2006.

	Liquid gas	1.1	260
	Light oil	1.1	290
	Heavy oil	1.1	300
	Coal	1.1	370
Renewables	Primary bio fuel	0.1	20
	Refined primary bio fuel	0.2	40
Surplus heat	Secondary bio fuel	0.1	20
	Refined secondary bio fuel	0.2	40
	Residual fuel from another process	0.2	40
	Municipal waste as fuel	0	0
	Industrial waste fuel	0	0
	Electricity	2.6	420

Source: EcoHeat4cities 2016

The project developed the energy certificate which shows resource efficiency, renewable share and CO_2 efficiency (see **Figure 5**).

Figure 5. Energy certificate for a district heating system developed in the project Ecoheat4cities project.



Source: EcoHeat4cities 2016

3 Existing calculation methods

In the previous Section we have performed a non-exhaustive review of indicators and methods to determine the energy and environmental performance of DHC systems. To do so, we have checked standards, legal requirements at national and European levels, dedicated studies and research projects.

Based on this review, here, we present in detail the most relevant indicators to assess the efficiency and sustainability of district heating and cooling systems. We pay particular attention to the methods available to calculate the PEF and complement it with other additional indicators namely CO_2 emission factor, renewable energy and waste heat shares as well as the efficiency of both the thermal network and the energy conversion technologies. Even more, we perform a comparison between indicators and discuss their adequacy to characterise thermal networks. By doing so, we set the basis for a guidance document which provides simplified calculation methods of several indicators to inform end users about the sustainability of the heat they use.

3.1 Primary energy factor

The PEF is used for the evaluation of the overall efficiency of energy systems, their sustainability and, thus, as a metric for the compliance of policy requirements. As we presented earlier in the document, the PEF indicator is used in the framework of the EPBD and in the EED to ensure a fair comparison between electricity and other energy fuels (see chapter 2.1).

Focusing on the district heating and cooling domain, the European standard EN 15316-4-5 ([34]), defines the PEF for district heating networks as follows:

$$f_{p,DH} = \frac{\sum_j E_j \cdot f_{P,j} - E_{exp} \cdot f_{P,exp}}{E_{del}} \tag{1}$$

where:

$f_{p,DH}$ – primary energy factor of a district heating system

E_j – energy content of the input fuel to the energy conversion technology j in MWh

$f_{P,j}$ – primary energy factor of the input fuel to the energy conversion technology j in MWh_p / MWh_{input}

E_{exp} - the amount of energy exported outside the system in MWh

$f_{P,exp}$- primary energy factor of the energy exported outside the system in MWh_p / MWh_{input}

E_{del} – Useful delivered energy

This definition, while appearing simple, some decisions or assumptions are needed when it comes to the selection of values for each of the terms included. The main challenges of applying Eq. 1 are:

- The identification of values for the PEF for each energy carrier ($f_{P,j}$). We already observed different PEFs for each input fuel in our review in Section 2.
- The calculation of PEF for secondary fuels such as electricity. This requires a more detailed analysis on their production, involving different methodological approaches and assumptions. Alternatively, default values proposed in the EED can be used — i.e. 2.1 for electricity. Still, many EU countries calculates their own PEF for electricity (see Table 2).
- The allocation of input fuels to power and heat in cogeneration units.

3.1.1 Energy carriers

In order to determine the PEF for energy carriers, two main approaches can be considered: the non-life cycle and the life cycle approaches. The first approach includes a set of methods that are mainly used for statistical

([34]) EN 15316-4-5. Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems.

purposes. These are: the direct equivalent, the zero equivalent, the substitution, the physical energy content and the technical conversion energy efficiency methods. All these methods provide a simplified approach to compare non-combustible RE sources, such as wind and solar with combustion RES and fossil fuels to ensure a fair comparison between fuels and, particularly, between electricity and the rest.

On the other hand, the life cycle approach includes a full analysis of the entire value chain of the energy carrier. By doing so, it distinguishes between renewable and non-renewable primary energy factors depending on the nature of the energy inputs across the value chain. Next, we provide an overview of these alternatives.

3.1.1.1 The non-life cycle vs the life cycle methods

The non-life cycle method

As mentioned before, the non-life cycle methods take specific assumptions in order to simplify the comparison between energy carriers of different nature (i.e. RES against non-RES). They are particularly suitable for statistical purposes as well as for relative comparisons between different energy supply options.

There exists several statistical methods. In particular, the '**physical energy content**' accounting method is used for nuclear electricity and heat generation and the '**technical conversion efficiency**' method is used for electricity and heat generation from fossil fuels and biomass. For non-combustible renewable energy, the method is the '**direct equivalent'** based on the '**total primary energy**' approach.

The **direct equivalent** method distinguishes between combustible and non-combustible electricity generation and assumes that the electricity generated is primary energy, which is equivalent to assume a 100% conversion efficiency. As a result the PEF of the electricity produced by hydro or solar is 3.6 MJ per kWh of electricity. For combustible electricity generation, efficiencies are applied. Then, the electricity produced in a gas-fired power plant with an efficiency of 40% is 9 MJ per kWh of electricity.

The **technical conversion efficiency** method, used in the EED for electricity and heat generation produced from fossil fuels and biomass, takes into account the conversion efficiency of a particular technology to produce electricity and heat. Using this method, the primary energy equivalent of a power plant with an efficiency of 40% is 9MJ of primary energy = 1kWh of electricity. Similarly, the PEF of the electricity produced from a solar PV with an efficiency of 15% has a PEF of 24 MJ (3.6/0.15) per kWh of electricity.

Last, the **physical energy content**, used by Eurostat, assumes that the primary energy is the first flow in the production process that has a practical energy use (i.e. natural gas ready to be burnt in a boiler). It makes distinction between thermal and non-thermal sources of electricity. Thus, it combines the direct equivalent approach for all energy carriers except for those where the primary energy source is heat: nuclear, geothermal and solar thermal. For those, the thermal energy produced is considered as primary energy. Then:

- For directly combustible energy products (for example lignite, natural gas, motor gasoline, biogas, firewood and combustible municipal waste) the primary energy is defined as the heat generated during combustion, which is equivalent to the energy content of the fuel itself.
- For products that are not directly combustible, the physical energy content method adopts the principle that the primary energy form should be the first energy form used down-stream in the production process for which multiple energy uses are practical (Krev et al., 2014; EC, 2019)). The application of this principle leads to:
    - the choice of heat as the primary energy form for nuclear, geothermal, solar thermal and ambient heat; and
    - the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean.
- Choosing these forms of energy, the primary energy equivalent of hydro energy and solar PV, for example, assumes a 100% conversion efficiency to 'primary electricity', so that the gross energy input for the source is 3.6 MJ of primary energy per kWh of electricity. Nuclear energy is calculated from the gross generation by assuming a 33% thermal conversion efficiency, i.e., 1 kWh = (3.6 ÷ 0.33) = 10.9 MJ. For geothermal, if no country-specific information is available, the primary energy equivalent is calculated using 10% conversion efficiency for geothermal electricity (1 kWh = (3.6 ÷ 0.1) = 36 MJ), and 50% for geothermal heat.

In addition to these three, there are two more methods:

— The zero equivalent method that assumes no primary energy for non-combustible RES

— The substitution method that considers that the primary energy for non-combustible RES is the primary energy of the fuel replaced by these RES sources.

Table 7 describes different non-life-cycle PEF methods used by various organisations.

Table 7. Non-life cycle PEF methods

Method	Description	Source / Organisations
Direct equivalent method	Counts one unit of secondary energy provided from non-combustible sources as one unit of primary energy.	long-term scenarios literature, including multiple IPCC reports
Zero equivalent	Assumes no primary energy at all for the use non-combustible RES in electricity or heat generation	n/a
Substitution	Estimates the primary energy from non-combustible sources as being equivalent to the LHV or HHV of combustible fuels that would have been required in conventional thermal power plants to substitute the generated electricity or some other secondary energy form.	U.S Energy Information Administration (EIA)
Physical energy content	Uses the direct equivalent approach (100% conversion efficiency) for all energy sources other than those where primary energy is heat, such as nuclear, solar thermal, and geothermal energy sources - For the case of nuclear, heat is considered the primary energy form. The energy equivalent from electricity is calculated assuming an efficiency of 33%. - For geothermal, if no country-specific information is available, the primary energy equivalent is calculated using 10 % conversion efficiency for geothermal electricity (so 1 kWh = (3.6 / 0.1) = 36 MJ), and 50 % for geothermal heat. - For solar thermal, a 40% efficiency is considered	IEA / OECD / Eurostat, 2005
Technical conversion efficiency	Assumes PEF of the (renewable) fuel as 1 and uses the conversion efficiencies of the technologies to determine the PE demand to generate one kWh of electricity or heat.	n/a

Source: own illustration

The life cycle method

The life cycle approach considers the entire supply chain of the fuels up to the point where the energy carriers are used. This includes processes such as extraction, transformation or transportation to the consumption site. Following this approach, primary energy is defined as the amount of energy required to supply one unit of delivered energy across the entire value chain. This means that the calculation of PEF under the life cycle approach may require the collection of information beyond the conversion process. This method is presented in the EN 15603 ([35]).

To give an idea of the results obtained by the application of the life-cycle method, a PV plant located in South America shows a total PEF of 0.39 MJ per kWh of electricity (EPD, 2017) — and a renewable PEF of 0.0468 MJ per kWh of electricity. Similarly for wind energy, the PEF ranges between 0.17 and 0.07 MJ per kWh of electricity for onshore wind and between 0.5 and 0.07 MJ per kWh for offshore, according to the JRC competitive report (Marschinski et al., 2021).

3.1.1.2 System boundaries

Another decision for the calculation of PEF is the system boundaries. In the non-life cycle methods, or statistical methods, (i.e. the physical energy content method) the first flow (e.g. combustion of biomass) in the production process that has a practical energy use is being considered (the general principle of the Eurostat

([35]) EN 15603:2008 Energy performance of buildings. Overall energy use and definition of energy ratings approach). This means that by definition they do not look into the energy input required to make the energy carrier available.

On the contrary, the life cycle approach expands the system boundaries by adding energy inputs needed along the entire supply chain. This perspective is used in the standard for building energy performance evaluation EN 15603 ([36]). The standard describes the concept of including the different phases of the supply chain while assessing the primary energy factors (at least those phases):

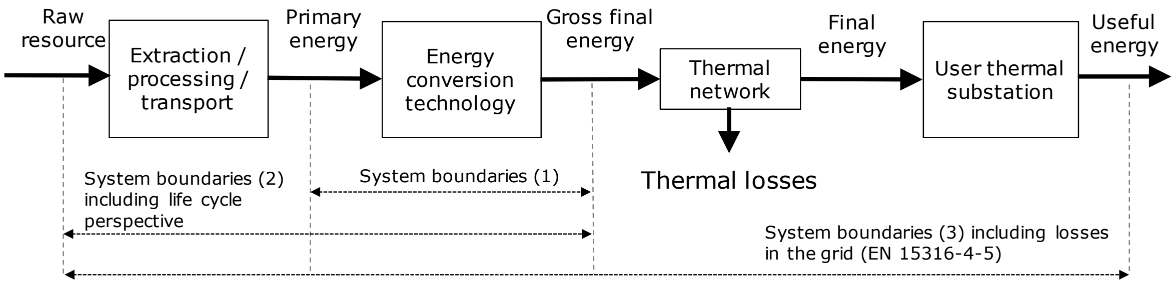
- Energy to extract the primary energy carrier.
- Energy to transport the energy carrier from the production site to the utilization site.
- Energy used for processing, storage, generation, transmission, distribution, and any other operations.
- Energy necessary for delivery to the building in which the delivered energy is used.

The statistical methods can adopt the life cycle approach by incorporating additional quantities to their PEFs. Thus, for example the direct physical energy content method that assumes a ~40% efficiency for the electricity produced from wind can incorporate an additional quantity to the input energy required. Thus, instead of 1/0.4 = 2.5 a factor of 20% is added for the processing of the input fuel: 1.2 • 1/0.4 = 3.

Last in the context of DH, an additional approach regarding system boundaries arises when it comes to the incorporation of thermal losses taking place in the network. The EN Standard 15316-4-5 provides PEF for energy carrier which include the physical energy content, the life cycle perspective and the losses in the grid.

In **Figure 6**, we present the three possible system boundaries.

Figure 6. System boundaries when assessing PEF in DH



Source: own illustration

3.1.1.3 The total and non-renewable primary energy factor

The total primary factor is defined as the renewable and non-renewable energy required to supply one unit of delivered energy. Similarly, the non-renewable primary energy factor is defined as the non-renewable energy required to supply one unit of delivered heat.

The revision proposal of the EPBD ([37]) provides the following definitions:

- 'non-renewable primary energy factor' means non-renewable primary energy for a given energy carrier, including the delivered energy and the calculated energy overheads of delivery to the points of use, divided by the delivered energy;
- 'renewable primary energy factor' means renewable primary energy from an on-site, nearby or distant energy source that is delivered via a given energy carrier, including the delivered energy and the calculated energy overheads of delivery to the points of use, divided by the delivered energy;
- 'total primary energy factor' means the weighted sum of renewable and non-renewable primary energy factors for a given energy carrier.

([36]) EN 15603:2008: Energy performance of buildings. Overall energy use and definition of energy ratings

([37]) COM(2021) 802 final

From the methods presented before, the life cycle approach can adopt both but from the statistical methods only the zero equivalent, which we briefly included in Table 7, is suitable for the non-renewable primary energy factor. The others can only adopt the total primary energy factor mostly because the way they treat non-combustible RES sources.

The difference between the total primary energy factor and non-renewable energy factor is that the non-renewable primary energy factor does not take into account the renewable inputs for the same system boundaries. It should also be noted that the total PEF is always greater than one under the life cycle approach — or at least equal to one under the energy content approach, while the non-renewable PEF can be smaller than one when some processes of the supply chain are performed using renewable sources.

3.1.1.4 The primary energy factor for secondary fuels. The case of electricity

Electricity as a relevant fuel in the provision of heat requires additional considerations for the calculation of the PEF of DH. First, the PEF of electricity should follow the same calculation approach as the other fuels present in a thermal network. Therefore, if we want to calculate the PEF of a DH under the non-renewable primary energy factor approach, electricity should counted under the same considerations.

We have to keep in mind that the PEF for electricity of 2.1 proposed by the Energy Efficiency Directive is calculated under specific assumptions, combining some of the methods presented before (i.e. the physical energy content method). This means that this factor is incorrect if we propose a LCA approach for the calculation of the PEFs.

The Fraunhofer study provided values for the PEF of electricity based on different calculations methods.

3.1.1.5 PEF of energy carriers in the context of DH

In the previous section, we have presented methods to account for PEF, with special attention on the production of electricity. Some additional considerations are needed in the context of heating.

In the current energy system, heat is supplied by:

- Direct combustible fuels, either fossil fuels or biomass
- Non-combustible fuels; geothermal, solar thermal
- Secondary fuels: electricity
- External heat supply including waste heat, heat from waste-to-heat plants and heat from nuclear plants.

We have already covered aspects related to electricity and fossil fuels, but biomass, electricity grid and external heat supply needs further discussion.

First, determining the PEF for biomass is a complex task due to the different value chains (i.e. distance to the consumption site) and the type of biomass itself. In addition, the sustainability of biomass (its capacity to be replenished) will determine its values under the total and non-renewable PEF.

Another important aspect is the generation of heat from power-to-heat technologies. We have presented before how the different methods calculate the associated PEF for the electricity produced from different technologies. However, DH can use electricity from the grid that has been produced by a specific technology mix including renewable and non-renewable sources. For those cases, the calculation of such a mix is required. Alternatively a default value should be selected. Studies such as the Fraunhofer study (referred to in this document) covered different options regarding the calculation of such values. The proposed EED suggests a primary energy factor for electricity of 2.1. In this work, we assume this value unless a specific configuration is design specifically for the supply of heat (i.e. off-grid PV with heat pumps connected to a thermal network).

Last, an additional group of fuels in the context of DH are those incorporated from external heat streams. Within this group we include waste heat, waste-to-heat plants and heat from nuclear. Waste heat is defined as unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a DHC network, where a cogeneration process has been used or will be used or where cogeneration is not feasible (Recast RED Article 2(9); Lyons et al, 2021). As a result, the PEF of such waste streams is zero.

In the case of waste-to-heat plants, i.e. municipal waste, waste products were not meant for the production of energy. This means that only the energy required to the combustion of these products (i.e. ignition or auxiliary firing should be accounted. If no specific information on those energy inputs is available, a default PEF of 0.1 is proposed in (Ecoheat4cities, 2016).

Regarding heat from nuclear, if the heat is extracted in an extracting-condensing unit, the primary energy factor for heat is calculated based on the amount of electricity not produced because of the extraction (Eq. 2). (Ecoheat4cities, 2016).

$$f_{p,\mathrm{h}} \cdot Q_h = f_{p,\mathrm{el}} \cdot \Delta E_{el,ext} \tag{2}$$

where:

$f_{p,h}$ – primary energy factor of heat produced

Q_h – amount of heat

$f_{p,el}$ – primary energy factor of electricity

$\Delta E_{el,ext}$ – reduction of the electricity output due to the heat produced

If no default values are available, a value of 0.25 for $f_{p,h}$ can be assumed (Ecoheat4cities, 2016).

3.1.1.6 Default values in the context of heating supply

Table 8 shows the comparison of PEFs for the three main references used in this work: the Fraunhofer study, EU standard EN 15316-4-5 and national cost optimal reports. The main differences are as follows:

- PEFs from the Fraunhofer study are based on the life cycle non-renewable primary energy and total PEF. For fossil fuels (natural gas, coal), the physical energy content method is used adding 10% of energy needed for processing and distributing of the primary fuels. For biomass, the physical energy content is 0 + 15% addition as an approximation of life cycle component.
- PEFs included in EN 15316-4-5 goes beyond what is included in the transformation required to produce heat (Figure 6). For example, the losses in thermal networks are included. These values are meant to be used for a simplified approach to assess the overall PEF for a DH system (when considering a district heat network as a black box, see chapter 2.1 for more explanation). However, they don't allow comparisons between DHs. Following the same approach, it includes PEFs for CHP plants, which means operating conditions of those plants are assumed fixed (for more information about different allocation approaches, see chapter 3.1.2). For biomass, the standard provides several PEFs depending on the type of fuel: solid, liquid and gaseous. For waste heat from industry, it distinguish between two components: a process-related component and a district heating component. While the process-related component is the minimum amount of waste heat which is generated in the production process and shall be released to the environment via cooling systems if not used for district heating — the unavoidable heat —, the district heating component is the amount of additional heat needed to meet the requirements of the district heating system if the first component is used. The weighted energy input for generating the district heating component shall be integrated into the numerator of the formula to calculate the weighting factor of the district energy system. Default value for the process-related component is 0 and for the district heating component is 0.4. The latter is the amount of additional energy needed to use the waste heat (e.g. boosting pressure, temperature and flow rate) and losses from the grid.
- PEFs from national cost-optimal reports: PEFs for fossil fuels vary from 1.0 to 1.2. Each MS uses different calculation approaches and different types of PEF (non-renewable or total) (see chapter 2.2.1). With regard to biomass, the PEFs vary from 0.2 to 1.08. The reason is the application of different calculation approaches, different boundaries and type of PEF (total, non-renewable or renewable primary energy factor). As we explained before, values above 1 refers to the total PEF — including biomass in the PEF — and low values are the result of using the non-renewable PEF — biomass is excluded under the assumption of a non-depleted source. In addition, a huge variety of fuels play a role. MSs apply different PEFs for biomass depending on the fuel type: wood, biogas, peat, peat briquette, pellets.

Table 8. PEFs for various energy carriers provided by three references: Fraunhofer study, EN 15316-4-5 and national cost-optimal reports.

Energy carrier	Fraunhofer study: non-renewable PEF (with life cycle perspective)	Fraunhofer study: total PEF (with life cycle perspective)	EN 15316-4-5: non-renewable PEF	EN 15316-4-5: total PEF	National cost-optimal reports
Natural gas	1.1	1.1	1.5 (heat boiler) 0.7 (CHP plant)	1.5 (heat boiler) 0.7 (CHP plant)	1.0-1.19
Coal	1.1	1.1	1.7 (heat boiler) 0.8 (CHP plant)	1.7 (heat boiler) 0.8 (CHP plant)	1.0-1.2
Heating oil	1.1	1.1	1.6 (heat boiler) 0.7 (CHP plant)	1.6 (CHP plant) 0.7 (CHP plant)	1.0-1.18
Biomass	0.15	1.0	0.4 (solid), 0.7 (liquid), 0.6 (gaseous) - heat boiler 0 (solid), 0 (liquid), 0 (gaseous) - CHP plant	1.8 (solid), 2.1 (liquid), 2.0 (gaseous) – heat boiler 1.8 (solid), 1.7 (liquid), 1.4 (gaseous) – CHP plant	0.2-1.08
Waste heat from industry	NA	NA	0 (process related component) 0.4 (DH related component)	0 (process related component) 0.4 (DH related component)	NA
Heat from waste-to-energy plants	NA	NA	0.1 (incl. CHP) 0.2 (without CHP)	0.1 (incl. CHP) 0.2 (without CHP)	NA
Ambient heat, geothermal (heat pumps)	0.1	1.0	NA	NA	NA
Electricity	1.59	2.09	NA	NA	1.06-2.8

Source: CEN 2017, Esser, A., & Sensfuss, F., 2016, European Commission, 2018

3.1.1.7 Example

This section presents primary energy calculation using different approaches for three selected generic heat supply systems. The heat supply systems include the following energy carriers:

- Electricity generation sources — solar PV, wind, nuclear and hydro — that combined with heat pumps produce heat. It also includes the electricity from the grid.
- Heating generation sources, including geothermal, gas, biomass and solar thermal.

We assume that all electricity generation sources produce one unit of electricity that is converted into three units of heat via a heat pump with a COP of 3 and that all heating generation sources produce one unit of heat.

Based on these assumptions, we calculate the primary energy factor using three calculation approaches:

- The physical energy content method under a non-life cycle approach and for the total PEF.
- The life-cycle approach for the non-RES PEF (LCA).
- The hybrid approach that incorporate the life cycle approach to the energy content method.

To calculate the PEF for each case we have made the following assumptions:

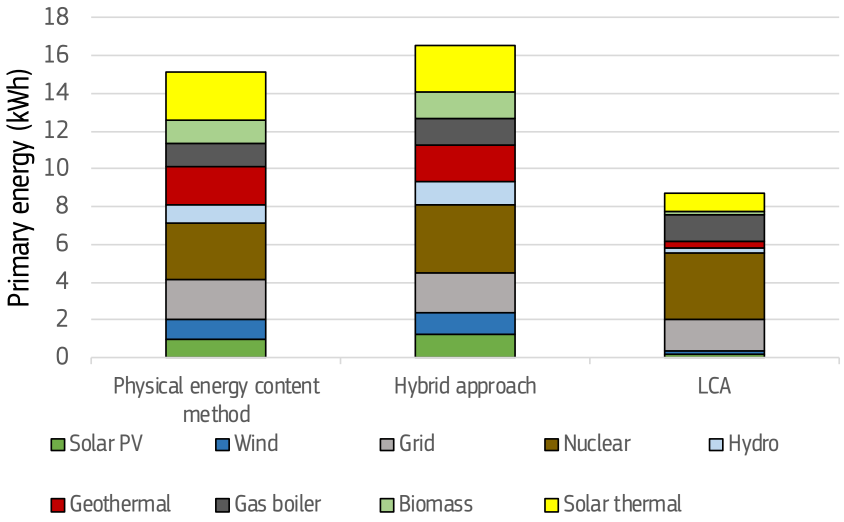
- The PEF for the electricity grid is 2.1 under the total PEF option and 1.59 under the non-RES PEF option (see Table 8).
- Gas and biomass boilers have an efficiency of 80%.
- Solar thermal has an efficiency of 40% and heat from geothermal 50%.

— The additional energy inputs across the value chain for the LCA approach are assumed 20% of the energy output for solar PV, wind, hydro and nuclear, 10% for natural gas and biomass.

— The non-RES PEF for biomass. 0.15 is assumed (see Table 7).

Figure 7 and **Figure 8** present the primary energy for selected heat supply system using three different approaches. The first aspect that should be noted is that the system boundaries for the physical energy content method stays within the energy conversion while the LCA and hybrid method include all the transformations required to obtain the input fuel.

Figure 7. Calculated primary energy



Source: own illustration

The LCA (non-renewable PEF) approach is the option that leads to the lowest PEF (0.461 kWh per unit of heat supplied). The main reason for that is that the renewable sources that cannot be depleted are not considered. The physical energy content, on the contrary, counts the renewable sources (non-combustible renewable sources) for statistical purposes. This leads to higher PEF. Last, the hybrid method builds on the physical energy content assumption and adds the energy inputs across the value chain, thus, leading to the highest PEF.

Coming back to the main goal of this work, our aim is to provide robust indicators for DH that are easy to calculate all allow comparison between thermal networks as well as with other heating and cooling supply options. Along these lines, the LCA method requires a complete analysis for each energy asset (thermal network). On the other hand, the physical energy content method is easy to apply as it only requires some assumptions. In addition to that, the major drawback of this method is that the relative different between renewable and non- renewable sources is small or non-existent in some cases. For example, a condensing gas boiler with 100% efficiency leads to the similar PE as a solar PV installation connected to a resistive heater. This fact can be corrected by the hybrid approach.

At the end of Section 3, we discuss on which set of indicators and methods are more convenient in the context of DH.

Figure 8. Calculation of the primary energy for a heating supply case under three different calculation methods. Left: physical energy content method, centre: LCA method and right: hybrid method

Physical energy content method
Total PEF
No life cycle

	PE	FE	UE
Solar PV	1	1	
Wind	1	1	
Grid	2.1	1	15
Nuclear	3	1	
Hydro	1	1	
Geothermal	2	1	1
Gas boiler	1.25	1	1
Biomass	2.86	1	1
Solar thermal	2.5	1	1
	16.71		**19**
			0.879

LCA
non-RES PEF
Life cycle

	PE	FE	UE
Solar PV	0.2	1	
Wind	0.2	1	15
Grid	1.59	1	
Nuclear	3.6	1	
Hydro	0.2	1	
Geothermal	0.4	1	1
Gas boiler	1.38	1	1
Biomass	0.19	1	1
Solar thermal	1	1	1
	8.75		**19**
			0.461

Hybrid approach
Total PEF
Life cycle

	PE	FE	UE
Solar PV	1.2	1	
Wind	1.2	1	
Grid	2.1	1	15
Nuclear	3.6	1	
Hydro	1.2	1	
Geothermal	2	1	1
Gas boiler	1.38	1	1
Biomass	1.38	1	1
Solar thermal	2.5	1	1
	16.55		**19**
			0.871

NB: PE - Primary energy, FE – Final energy, UE – useful energy

Source: own illustration

3.1.2 CHP: allocation of heat and power

Combined heat and power technologies imply the simultaneous generation of heat and power from a single input fuel. To characterise the primary energy factor for each sub-product — heat and power — an allocation method is required. In other words, we have to determine which fraction of the input fuel is used for the production of electricity and which for the production of heat.

The literature contains several methods on the allocation of the input fuel into the two by-products. Here, we have selected the most common ones:

- Power bonus method (presented in EN Standard (EN 15316-4-5))
- Carnot method (presented in EN Standard (EN 15316-4-5) and Annex VI of RED II)
- Finnish method (or reference system method) (presented in EN 15316-4-5 as alternative production method).

In the next Sections, we present these methods and discuss the implications of using one of them.

3.1.2.1 Power bonus method

The power bonus method assumes heat as the main product while the power is considered as a bonus. This means that the total primary energy used by the CHP plant, including all energy used in the production of heat and electricity and the energy losses, is allocated to the heat produced in the CHP and the electricity produced in primary energy terms is subtracted as a bonus (Eq. 3). This method can lead to low primary energy factors for heat when the power to heat ratio is high. In other words, a large electricity generation increases the bonus and, as a result, reduces the PEF for the heat produced. This effect increases in the case of large PEF for electricity. As a result, district heating networks with a large share of heat produced from CHP units show, under this method, low PEFs.

$$f_{p,DH} = \frac{\sum_j E_{CHP,j} \cdot f_{P,j} - E_{el,chp} \cdot f_{P,el,chp}}{Q_{del}} \qquad (3)$$

where:

$f_{p,DH}$ – primary energy factor of a district heating system

$E_{CHP,j}$ – energy content of the input fuel to the energy conversion technology (CHP plant) j in MWh

$f_{P,j}$ – primary energy factor of the input fuel to the CHP plant j in MWh_p / MWh_{input}

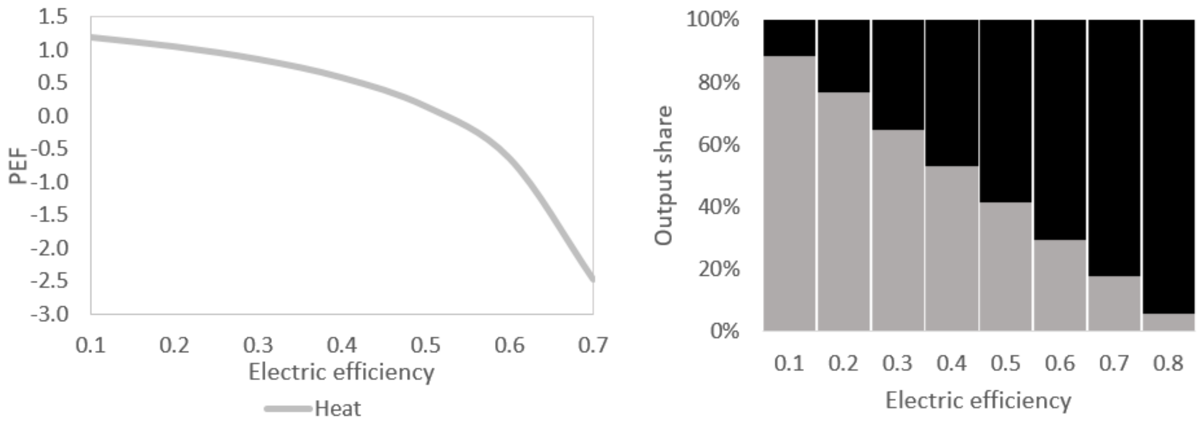
$E_{el,CHP}$ - the amount of produced electricity in MWh

$f_{P,el,CHP}$- primary energy factor of the displaced electricity in MWh_p / MWh_{input}

Q_{del} – Useful delivered energy

In Figure 9 left, we present the PEF for heat (grey line) and the electricity power bonus (black line) expressed in primary energy terms for different electricity efficiencies in a CHP unit with an overall efficiency of 85%. As it can be observed, the PEF for heat decreases rapidly with high electric efficiencies, which implies low heat generation and, therefore, high power bonus. For an electric efficiency of 40%, the PEF for heat is 0.58 and it reaches negative values, which makes no sense from a physical point of view, if the power efficiency is above 50%. Therefore, this allocation method leads to low PEF for heat when the generation of electricity is significant and it only provides reasonable results in CHP units that mostly produce heat. Yet, it leads lo low primary energy factors for heat.

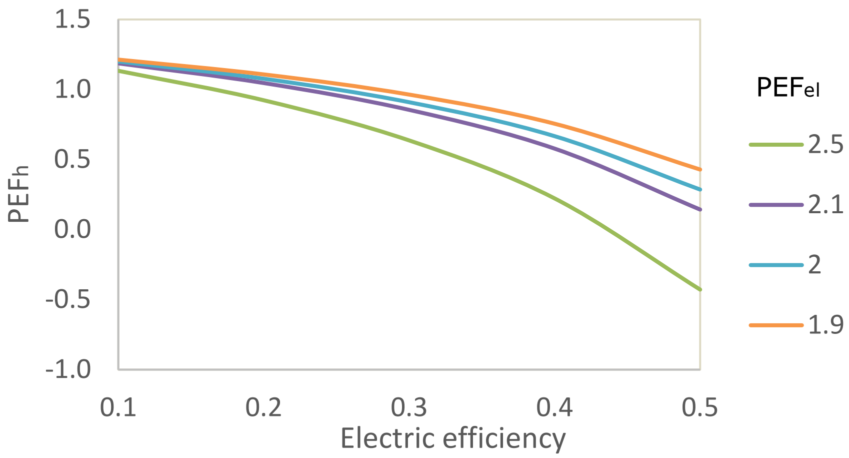
Figure 9. Primary energy factors for the combined production of heat and electricity for different electric efficiencies assuming an overall CHP efficiency of 85% and a PEF for the input fuel (gas) and electricity of 1.1 and 2.1 respectively. Power bonus method



Source: own illustration

One important aspect of this method is that it depends on the assumption for the PEF of electricity. This is, the lower the PEF_{el}, the lower the bonus and the higher the PEF_H (**Figure 10**).

Figure 10. PEFh for different PEFel under the power bonus method



Source: own illustration

3.1.2.2 Carnot method

The Carnot method (also known as the Exergetic method) takes into account the quality of the heat supplied to allocate the input fuel to the heat and power outputs. The heat quality is determined by its temperature. The higher the temperature (or exergy) of the heat streams the more applications it can cover and, thus, the higher its quality. To do so, the Carnot method uses the equivalence of heat and power that can be transformed into each other by using the Carnot's efficiency. The Carnot factor for electricity is set to one, the highest possible quality —assumption adopted from REDII Annex VI —, while the Carnot factor for heat is calculated as follows:

$$f_{p,DH} = \frac{\sum_j E_{CHP,j} \cdot f_{P,j}}{Q_{del}} \cdot \frac{\eta_{c,h} \cdot Q_{prod}}{\eta_{c,h} \cdot Q_{del} + \eta_{c,e} \cdot P_{del}} \qquad (4)$$

$$\eta_{c,h} = 1 - \frac{T_{amb}}{T_h} \tag{5}$$

Where:

$f_{P,DH}$ – primary energy factor of the district heat system

$E_{CHP,j}$ – energy content of the input fuel to the energy conversion technology (CHP plant) j in MWh

$f_{P,j}$ – primary energy factor of the input fuel to the CHP plant j in MWh_p / MWh_{input}

T_h – mean temperature of heat supply, K

T_{amb} – ambient temperature, K

$\eta_{c,h}$ – Carnot efficiency for heat

$\eta_{c,e}$ – Carnot efficiency for electricity

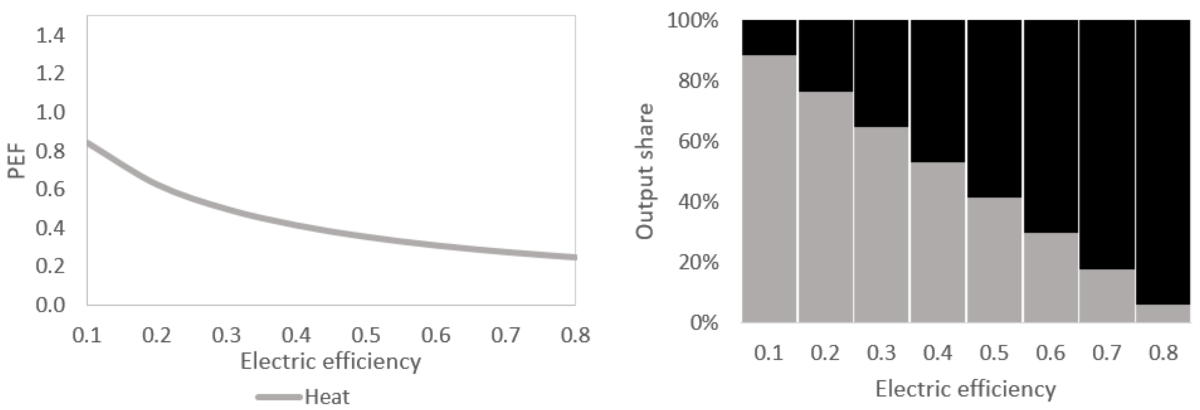
P_{del} – Cogenerated electricity

Q_{del} – Useful delivered energy

Q_{prod} – Produced heat from cogeneration

The same way we did for the Power bonus method, in **Figure 11**, we present the PEF for heat and electricity for different electric efficiencies assuming an overall CHP efficiency of 85% and a heat supply temperature of 80 °C. The PEF for heat varies from 0.89 for the maximum heat production to 0.29 for the minimum (grey line in **Figure 11** left). In the case of electricity, PEF values ranges from 3.91 (minimum electricity production) to 1.28 (maximum electricity production) (grey line in **Figure 11** right).

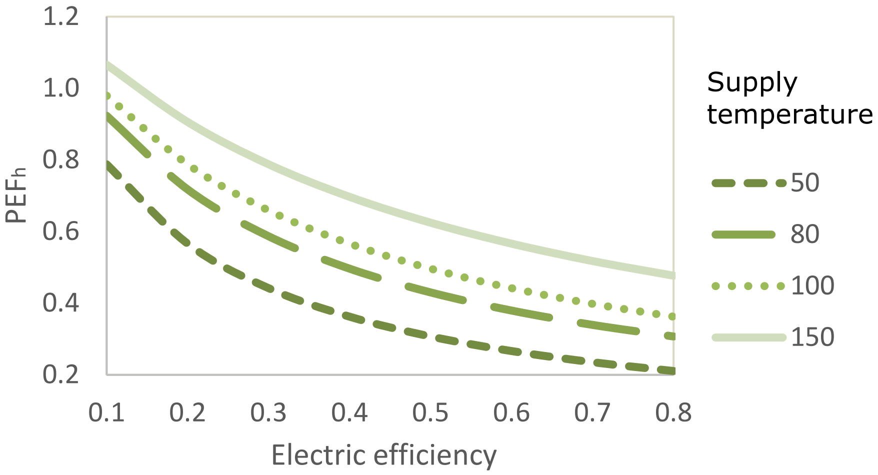
Figure 11. Primary energy factors for the combined production of heat and electricity for different electric efficiencies assuming an overall CHP efficiency of 90% and a PEF for the input fuel (gas) of 1.1. Carnot method



Source: own illustration

As we said, the Carnot method takes into account the quality of the energy outputs. To put it differently, it considers the temperature of the heat supply. As a result, the higher the temperature the larger the PEF associated to heat. In **Figure 12**, we present the heat PEF for different temperatures of supply. If we compare the two extreme temperatures depicted, 50 °C in the range of 4GDH and 150 °C, the PEF increases between 34% (minimum electric efficiency) and 124% (maximum electric efficiency). This result is relevant to ensure a fair comparison of PEF in district heating systems operating at different temperatures.

Figure 12. Heat Primary energy factors for different temperatures of supply and electric efficiencies assuming an overall CHP efficiency of 90% and a PEF for the input fuel of 1.1. Carnot method



Source: own illustration

3.1.2.3 *Finnish method*

The Finnish method uses reference energy systems to separate the production of heat and power. These reference systems are defined by reference efficiency for electricity ($n_{e,ref}$) and heat ($n_{h,ref}$). Then, the corresponding PEFs for heat and electricity are calculated as follows:

$$f_{P,DH} = \frac{f_{P,j} \cdot E_{CHP,j} - P_{discount}}{Q_{del}} \tag{6}$$

Where:

$f_{P,DH}$ − primary energy factor of the district heat system

$E_{CHP,j}$ − energy content of the input fuel to the energy conversion technology (CHP plant) j in MWh

$f_{P,j}$ − primary energy factor of the input fuel to the CHP plant j in MWh_p / MWh_{input}

Q_{del} − Cogenerated heat

$$P_{discount} = f_{P,j} \cdot E_{CHP,j} \cdot \frac{\frac{\eta_e}{\eta_{e,ref}}}{\frac{\eta_e}{\eta_{e,ref}} + \frac{\eta_h}{\eta_{h,ref}}} \tag{7}$$

Where:

$\eta_{e,ref}$ – reference efficiency for electricity

η_e – efficiency for electricity

$\eta_{h,ref}$ – reference efficiency for heat

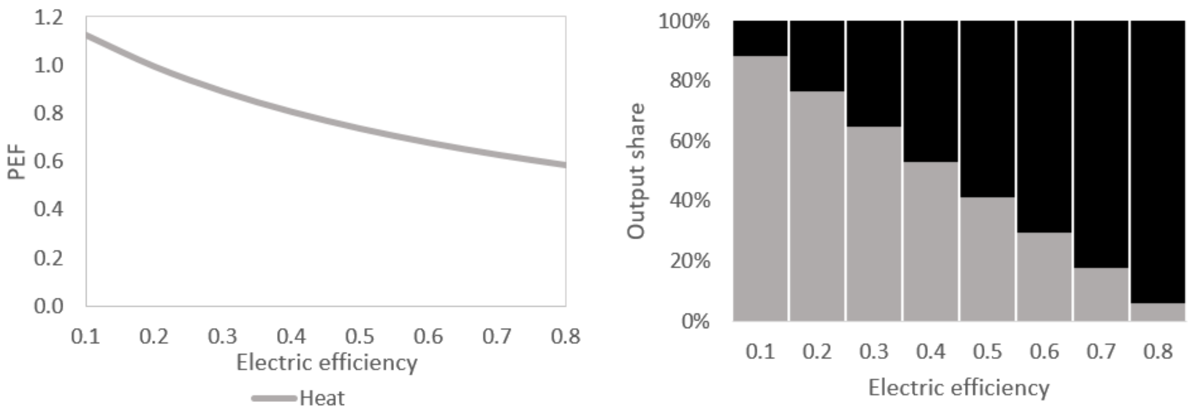
η_h – efficiency for heat

Figure 13 presents the PEFs provided by the Finnish method for different electric efficiencies assuming and overall CHP efficiency of 85% and a primary energy factor for the input fuel (PEF_f) of 1.1 (typical value for natural gas). For the reference efficiencies of the separate production of heat and power, we have assumed 80% for heat ($n_{h,ref}$) and 35% for power ($n_{e,ref}$).

As we can observe, the PEF for heat ranges from 1.07, when the heat production is around 90%, to 0.55, heat production 12% of the total (see the grey line on the left figure). For comparison purposes, a gas boiler with a thermal efficiency of 80% will provide a PEF for heat of 1.38. In the case of electricity values for PEF vary from 2.45 to 1.26.

The Finnish method provides reasonable PEF both for heat and power. The variations observed for both indicators are the result of the different outputs shares of heat and electricity. In both cases, the larger the electricity production, the smaller both PEFs. In all cases, electricity shows larger values of PEF. This is due to the ration between the reference efficiencies. In our case the ration between PEFe and PEFh is equal to the ration $n_{h,ref}$ to $n_{e,ref}$ (0.8 / 0.35 = 2.28). As a result the selection of the reference efficiencies should be determine in a robust manner, considering the general characteristics of the entire energy system, in order to provide a fair allocation of PEFs. We will discuss these aspects in the coming sections.

Figure 13. Primary energy factors for the combined production of heat and electricity for different electric efficiencies assuming an overall CHP efficiency of 85% and a PEF for the input fuel of 1.1. Finish method

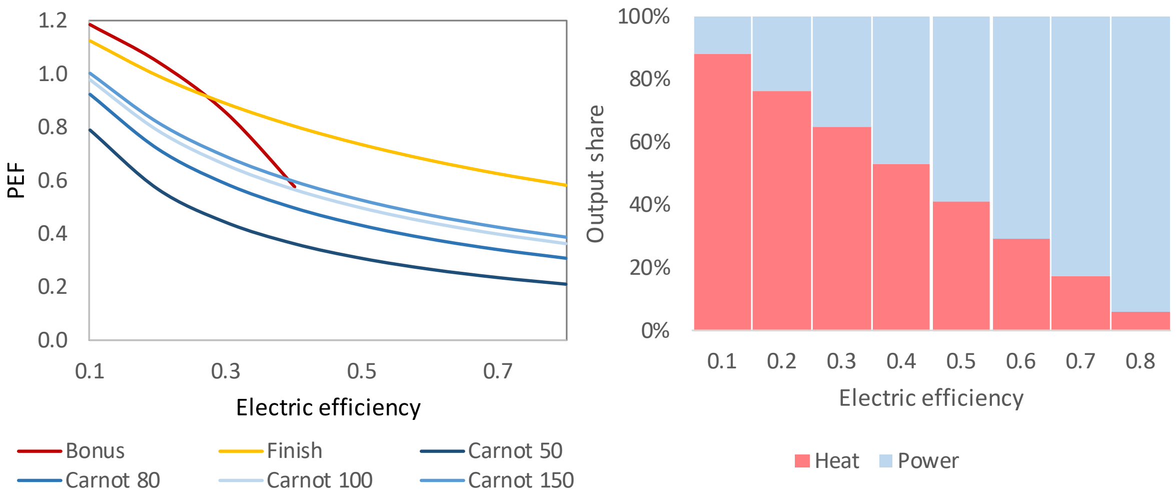


Source: own illustration

3.1.2.4 Comparison of CHP allocation methods

To understand the implication of choosing one of these methods, here we compare their PEF for heat for different electric efficiencies and assuming an overall CHP efficiency of 90% supplied by natural gas.

Figure 14. Comparison of the natural gas CHP allocation methods for different electric efficiencies assuming a global efficiency of 90% and a PEF_{el} of 2.1 (NB: Carnot factor refers to the temperature of the heat supply)



Source: own illustration

As we can observe the Power bonus (Bonus) method provides the highest PEF for heat when the production of electricity (electric efficiency) is small (low bonus). The finish method leads to the highest PEF for heat starting with the electricity production of 30%. Regarding the Carnot method, the PEF for heat depends on the values of the supply temperature: the lower the supply temperature, the lower is the calculated primary energy factor for heat.

Advantages and disadvantages of using these three methods:

Bonus method: primary energy factor for heat can reach negative values when the electric efficiency is above 50% (the output share of CHP is 50% of electricity).

Carnot method: the Carnot method addresses temperatures of the operation. The lower supply temperature the lower is the overall PEF for heat. In the context of the new generation of DH networks, characterised by low temperatures of operation, the Carnot method can address this important energy efficiency aspect of the district heating networks. Moreover, the Carnot method allocates losses proportionally between the two energy outputs: heat and power. Thus, it avoids low PEF for heat as is the case with some methods that allocate all losses to electricity.

Finish method: the reference efficiencies should be determine in a robust manner, considering the general characteristics of the entire energy system, in order to provide a fair allocation of PEFs.

3.2 CO_2 emission factor

The CO_2 emission factor provides the estimation of CO_2 emissions per unit of energy supply, providing an indication of how clean the energy sources are. The CO_2 emission factor is widely used as it quantifies the amount of CO_2 emitted for the provision of useful energy. In the context of energy policy, it allows, among others, assessing if energy systems comply with the decarbonisation goals.

The calculation of CO_2 emission is formulated as follows:

$$f_{CO2,DH} = \frac{\sum_j E_j \cdot f_{CO2,j} - \sum_i E_{exp,i} \cdot f_{CO2,i}}{Q_{del}} \tag{8}$$

where:

$f_{CO2,DH}$ – CO_2 emission factor of a district heating system in tCO_2 / MWh_{heat}

E_j – energy content of the input fuel to the energy conversion technology j in MWh

$f_{CO2,j}$ – CO_2 emission factor of the input fuel per energy content in primary energy terms tCO_2 / MWh_{input}

E_{exp} - the amount of energy exported outside the system in MWh

Q_{del} – Useful delivered energy in MWh_{heat}

As it can be observed, its definition is similar to the one for the PEF that we presented in Eq.-1. The difference lays with the f-factors that in this case reflects the emissions of the corresponding fuels. Next we detail how to calculate the CO_2 emission factors similarly to the case of the PEFs.

3.2.1 Energy carriers

As in the case of PEFs, the calculation of the CO_2 emission factors can follow two approaches: the direct emissions approach that only takes into account the emissions derived from the stationary combustion of fuels to produce heat (or cold), and the life cycle approach that includes CO_2 emissions that take place across the entire value chain of the energy carrier including extraction processing or transmission.

These two approaches tie with the definition of emissions described in (Allwood et al., 2014):

- Direct emissions: Emissions that physically arise from activities within well-defined boundaries of, for instance, a region, an economic sector, a company, or a process.
- Embodied emissions: Emissions that arise from the production and delivery of a good or service or the build-up of infrastructure. Depending on the chosen system boundaries, upstream emissions are often included (e.g., emissions resulting from the extraction of raw materials). See also chapter 3.2.1.2 on lifecycle assessment (LCA).
- Indirect emissions: Emissions that are a consequence of the activities within well-defined boundaries of, for instance, a region, an economic sector, a company or process, but which occur outside the specified boundaries. For example, emissions are described as indirect if they relate to the use of heat but physically arise outside the boundaries of the heat user, or to electricity production but physically arise outside of the boundaries of the power supply sector.

Here we stay with the direct emissions (i.e. those emissions occurring while burning natural gas in a boiler) and the embodied emissions (i.e. including in addition to the direct emissions those taking place in the extraction, processing and distribution of the natural gas). The indirect emissions relate to activities taking place as a result of the provision of the heat. Boundaries for those are not easy to set and are out of the scope of our analysis.

Contrary to the case of PEFs, where energy statistics required certain assumptions to ensure completeness in the construction of the energy balances, the evaluation of the CO_2 emissions only requires the decision on the approach: direct or LCA. In other words, RE sources can take emission factor values of zero.

In the next subsections, we provide typical values under the two approaches for the most common energy fuels used in the heating domain.

3.2.1.1 Direct emission factors

For the direct emissions approach, well-stablished emission factors have been defined by the IPCC (IPCC, 2006), which are also presented in Annex VI of the Regulation EU 601/2012. The emission factor of the most common fuels used in the heating sector are presented in **Table 9**.

Table 9. CO_2 emission factor for the most common heating fuels except for biofuels and electricity

	Emission factor (g CO_2/kWh)	Source
Renewable	0	
Waste	0	
Natural gas	201.9	IPCC 2006 GL
Gas/Diesel oil	266.8	IPCC 2006 GL
Natural gas Liquids	231.1	IPCC 2006 GL
Crude oil	263.9	IPCC 2006 GL

Source: IPCC 2006

Within the direct combustible (or primary) fuels, we should pay particular attention to the characterisation of biofuels. Two options are possible here; first, biofuels are assumed carbon neutral, second, they are not considered carbon neutral and, as a result, their associated carbon factors reflect the carbon content potentially further corrected by the carbon assimilation.

Here, our aim is not to cover a detailed analysis on which should be the specific values to be used for biofuels, but to provide an overview of values that are currently considered and use them in the context of DHs. In **Table 10**, we present the CO_2 emission factors for some selected biofuels. These values are extracted from Annex V of REDII.

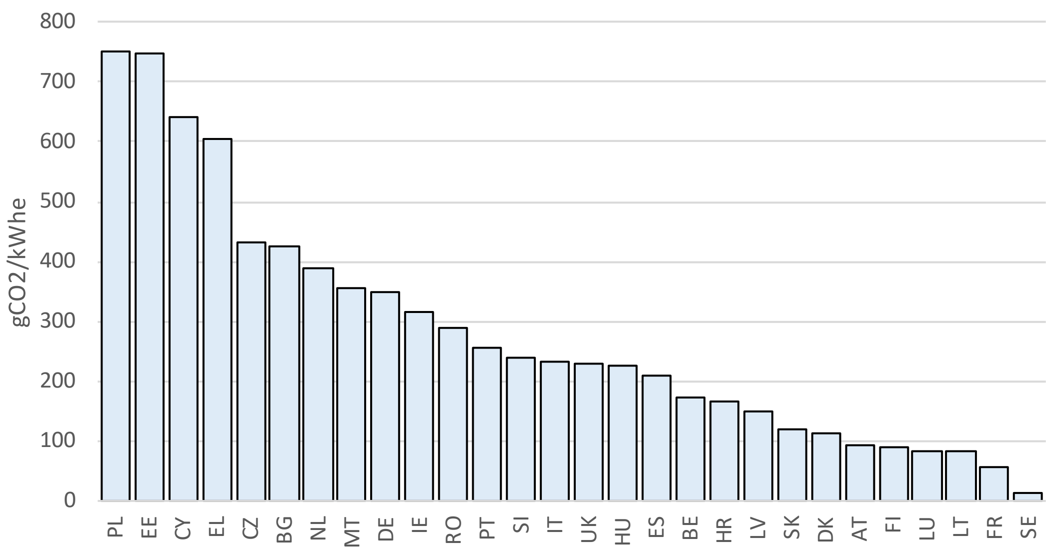
Table 10. CO_2 emission factor for selected biomass fuels ([38])

Type of biomass	Emission factor (t CO_2/TJ)	Source
Woodchips from forest residues	54	Annex V REDII
Woodchips from industry residues	46.8	Annex V REDII
Wood briquettes or pellets from forest residues	75.6	Annex V REDII
Wood briquettes or pellets from wood industry residues	46.8	Annex V REDII
Agricultural Residues with density < 0,2 t/m3 (1)	54	Annex V REDII
Straw pellets	46.8	Annex V REDII

Source: European Commission 2018

Last, for secondary fuels, mainly electricity, CO_2 emission factors should reflect the conditions under which the specific fuels have been produced. For our discussion, we use national emission factors provided by the European Environmental Agency for the year 2019 (**Figure 15**).

Figure 15. CO_2 emission intensity of electricity generation in the EU. 2019



Source: EEA 2019

([38]) Assumed transport distance: 2,500 to 10,000 km

3.2.1.2 LCA-CO_2 emission factors

As in the case of the PEF, the application of the LCA approach, including direct and indirect emissions, could be a complex exercise depending on the specific fuel and the complexity of its supply chain. In addition to the direct emission approach, the LCA includes the emissions produced along the supply chain.

In **Table 11** and **Table 12** we present the default values provided by (IPCC, 2006; Koffi, 2017) for the two methods, direct emission factor and LCA-CO_2 emission factors.

Table 11. Default emission factors for fossil fuels and municipal wastes

Energy carriers		Standard (IPCC,2006)	LCA up to 2007	LCA 2008-2015 (current update)
SECAP* Template	IPCC denomination	tCO2-eq/MWh	tCO2-eq/MWh	tCO2-eq/MWh
Natural gas	Natural gas	0.202	0.237	0.24
Liquid gas	Liquefied Petroleum Gases	0.227	n.a.	0.281
	Natural Gas Liquids	0.231	n.a.	0.272
Heating Oil	Gas/Diesel oil	0.268	0.305	0.306
Diesel	Gas/Diesel oil	0.268	0.305	0.306
Gasoline	Motor gasoline	0.25	0.307	0.314
Lignite	Lignite	0.365	0.375	0.375
Coal	Anthracite	0.356	0.393	0.37
	Other Bituminous Coal	0.342	0.38	0.358
	Sub-Bituminous Coal	0.348	0.385	0.363
Other non-renewable fuels	Peat	0.392	0.39	
	Municipal Wastes (non-biomass fraction)	0.337	0.174	0.295

*NB: * Sustainable Energy and Climate Plans*

Source: IPCC 2006; Koffi 2017

Table 12. Default emission factors for renewable energy sources

Renewable energy			Standard (IPCC,2006)	LCA up to 2007	LCA 2008-2015 (current update)
Energy classes	IPCC denomination	Carbon neutrality	tCO_2-eq/MWh	tCO_2-eq/MWh	tCO_2-eq/MWh
Plant oil	Other Liquid Biofuels	cn	0.001	0.182	0.182
		ncn	0.302	0.484	0.484
Biofuel	Bio-gasoline	cn	0.001	0.207	0.207
		ncn	0.256	0.462	0.462
	Biodiesels	cn	0.001	0.156	0.156
		ncn	0.256	0.411	0.411
Other biomass	Biogas	ncn	0.197	n.a.	0.284
	Municipal wastes (biom. fraction)	cn	0.007	0.106	0.106
	Wood (/Wood waste)	cn	0.007	0.013	0.017
		ncn	0.41	0.416	0.42
	(Wood/) Wood waste	ncn	0.41	0.184	0.184
	Other primary solid biomass	ncn	0.367	n.a.	n.a.
Solar thermal			0	n.a.	0.04

Geothermal	0	n.a.	0.05

Source: IPCC 2006; Koffi 2017

As we can observe, renewable sources such as solar thermal or geothermal have emissions factors equal to zero for the direct emission approach — they do not emit any gas during the heat delivery — and for the LCA approach is slightly higher than zero due to use of materials for the installation, maintenance, etc. It is also worth noting that for the case of biofuels two additional alternatives can be considered: the carbon neutrality (cn) and the non-carbon neutrality (ncn). The choice of one of them ties with the assumption that the carbon emitted can be assimilated by the biofuel and, thus, it is not depleted.

3.3 Renewables and waste heat shares

The renewable share of DHC refers to the ration between the total heat supplied from renewable sources to the total heat supply. The renewable sources are sustainable biofuels and bioliquids, ambient heat (air, water), solar heat, and geothermal energy.

Similarly the share of waste heat in a DHC refers to the amount of waste heat incorporated in a thermal network to the total energy provided into the network, where the waste heat and cold is defined as the unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible (Article 2(9) REDII) (Jimenez Navarro, J.P. et al, 2022).

These two indicators — provide information on the composition of the fuel mix supplying a network. However, it does not offer information on the efficiency of the generation of heat nor the thermal losses occurring in the networks. Both, the renewable and waste heat share are relevant in the context of Article 24 of the RED II and for the identification of efficient district heating and cooling (EDHC) as defined in Article 2 of the EED. In the next section we explain the concept of efficient district heating and cooling as an additional indicator of the DHC energy performance.

3.4 Efficient district heating and cooling

According to Article 2(41) of the EED 'efficient district heating and cooling' (EDHC) means a district heating or cooling system using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat. In the proposal of the EED (COM(2021) 558 final), this definition is valid until 31 December 2025. From 1 January 2026, this definition will be replaced with other definitions increasing the share of renewables and efficiency of cogenerated heat (Article 24 of the EED (proposal)):

- b. from 1 January 2026, a system using at least 50% renewable energy, 50% waste heat, 80% of high-efficiency cogenerated heat or at least a combination of such thermal energy going into the network where the share of renewable energy is at least 5% and the total share of renewable energy, waste heat or high-efficiency cogenerated heat is at least 50%;
- c. from 1 January 2035, a system using at least 50% renewable energy and waste heat, where the share of renewable energy is at least 20%;
- d. from 1 January 2045, a system using at least 75 % renewable energy and waste heat, where the share of renewable energy is at least 40%;
- e. from 1 January 2050, a system using only renewable energy and waste heat, where the share of renewable energy is at least 60%.

The way an efficient district heating and cooling is defined explains the convenience of quantifying both renewable and waste heat shares. Even though the compliance with efficient district heating cooling requirements may be more relevant for district heating and cooling operators, it is also relevant for final user. Even more when, according to Article 24(2) of the RED II, Member States should lay down the measures and conditions required to allow costumers of DHC which are not efficient to disconnect by terminating or modifying their contract in order to produce heating or cooling from renewable sources themselves.

3.5 Thermal losses

Thermal losses have a relevant impact on the PEF of the heat supply via district heating. For a given amount of heat produced in the generation units, thermal losses will decrease the net heat delivered and, thus, increase the overall PEF. Therefore, thermal losses are directly correlated to the primary energy factor (see Eq-9) (the European standard EN 15316-4-5). The larger the losses, the smaller the energy delivered and the higher the PEF. Thus, the quantification of E_{del} implicitly includes the effect of thermal losses. (Eqs. (9)-(10))

$$f_{p,DH} = \frac{\sum_j E_j \cdot f_{P,j} - E_{exp} \cdot f_{P,exp}}{E_{del}} \tag{9}$$

$$E_{del} = E_{gen} - E_{loss} \tag{10}$$

where:

$f_{p,DH}$ – primary energy factor of a district heating system

E_j – energy content of the input fuel to the energy conversion technology j in MWh

$f_{P,j}$ – primary energy factor of the input fuel to the energy conversion technology j in MWh_p / MWh_{input}

E_{exp} - the amount of energy exported outside the system in MWh

$f_{P,exp}$- primary energy factor of the energy exported outside the system in MWh_p / MWh_{input}

E_{del} – useful delivered energy

E_{loss} - thermal losses

E_{gen}- heat generated

From the end user point of view, having information on the PEF of the DH supplying the heat requirements is useful to understand the efficiency of the complete heat value chain and the share of fossil fuels as well. However, the user cannot from this indicator understand if the high or low PEF is due to an inefficient heating generation, a high share of fossil fuels or to an inefficient thermal network. Therefore, information on how much losses occur in the network could be complementary to the PEF.

3.6 Discussion on the adequacy of different indicators

In the previous sections, we have covered the relevant indicators that can allow consumers taking informed decisions about their heating supply. Here, we aim to briefly discuss the interaction among them and the possibility of using a combination of interrelated metrics.

To recap, the list of indicators covered in previous sections are:

- Various types of PEF (primary energy factor);
- CO2 emission factor;
- Thermal losses;
- Share of renewable sources and waste heat;
- Criteria for efficient DHC under the Energy Efficiency Directive ([39]) (EED).

According to Article 24(1) of RED II (2018/2001), Member States shall ensure that information on the energy performance and the share of renewable energy in their district heating and cooling systems is provided to final consumers. As we described above in this document, the PEF plays an important role in different pieces of the European legislation (chapter 2). We suggest using the PEF to assess the energy performance of the district heating systems (next paragraph supports our suggestion with concrete arguments). We also showed that there are different approaches to assess the PEF having impact on the value of the calculated PEF of the district heating supply. In this chapter, we show how the PEF reflects other indicators such as thermal losses and CO_2 emissions.

([39]) 2012/27/EU as amended by (EU)2018/2002 and proposal for a revision of the EED 2018/2002 (COM(2021) 558 final)

The PEF, calculated by any of the approaches presented in previous chapters, includes both the efficiency of the heat generation and the thermal losses. Thus, in the case of thermal losses and for a fixed heat generation, the higher the losses the lower the heat delivered and, consequently, the higher the PEF as this is inversely proportional to the heat supply. The same argument applies for the efficiency of the heat generation. For a fixed mix of input fuels, the lower the efficiency the lower the heat supply and, as a result, the higher the PEF. Even though embedded in the PEF, they cannot be deducted from the PEF separately. However, the District Heating Operator (DHO) has this information available as a result of the monitoring of its operation, so it can be provided with limited additional effort.

At this point the remaining question is how the PEF and the CO_2 emission factor correlate. Additionally, the approach to calculating the PEF should be determined. To answer this question, we are going to take four simplified cases presented in a previous JRC report (Jimenez Navarro, J.P. et al, 2022). These four examples comply with the definition of efficient district heating and cooling under the four options: 75%COGEN (Cogeneration), 50%RES (Renewable energy), 50%WASTE (waste heat and cold) and 50%COMBI (combination of the above). Annex I includes the configuration of these examples.

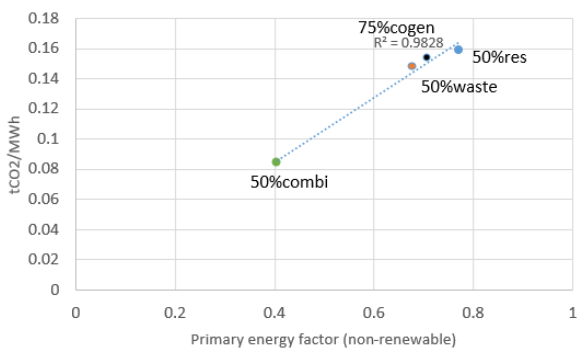
To calculate the PEF for each case we have made the following assumptions:

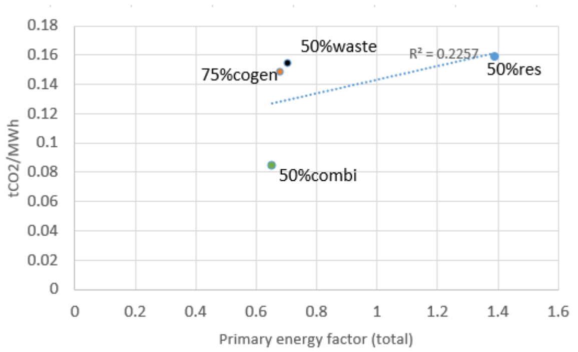
- Gas and biomass boilers have an efficiency of 90%.
- The additional energy inputs across the value chain for the LCA approach for gas and biomass are assumed 10% and 15% respectively.
- The non-RES PEF (LCA) for gas and biomass is 0.15 and 1.1 respectively, the PEF (total LCA) is 1.15 and 1.1 respectively.
- CHP: 40% (for the heat production).

For these four cases we have applied the calculation approaches introduced in chapters 3.1 and 3.2. **Figure 16** presents PEF and CO_2 emission factor for the four district heating cases (75%COGEN (Cogeneration), 50%RES (Renewable energy), 50%WASTE (waste heat and cold) and 50%COMBI (combination of the above)). For the PEF, we applied the total PEF (Figure 18, right side) and the non-renewable PEF (Figure 18, left side). As can be observed, there is no close correlation between the PEF (total) (Figure 18, right side) CO_2. The reason for this is the approach to define the PEF for renewables. A case in point is 50RES, with a large amount of renewable inputs resulting in a high PEF. On the other hand, there is a high correlation between the non-renewable PEF and CO2 emission factor.

To allocate input fuels between electricity and heat, we applied the Carnot method. Even though the district heating network called 75cogen consists of 75% of CHP (gas), it has a relatively low PEF. This is due to the allocation approach which calculates low inputs of heat. A high share of input fuels to a CHP is allocated to electricity.

Figure 16. CO_2 emission factor vs PEF for different district heating systems





Source: own calculation

Therefore, we can conclude that the approach of the non-renewable PEF is sufficient to describe the efficiency and sustainability of a district heat system. It provides a close correlation to the LCA CO_2 emissions. This indicator together with the share or renewables and waste heat that are required under Article 24 of the REDII, are the indicators that we propose to provide to users.

It is important to note that from the point of view of communication, the CO_2 emission factor could be a meaningful indicator. However, here, we aim to provide the essential information required from a technical and environmental perspective.

Similarly, from the point of view of policy makers, it could be relevant to report the efficiency of the heat generators and of the network separately rather than embedded in the PEF. Here again, this information may not be so interesting for end users.

As conclusion, we propose as the main indicators the following:

- Primary energy factor expressed as a ratio of input fuel to the energy conversion technology and the useful delivered energy calculated following the non-renewable PEF approach.
- Renewable and waste heat shares.

4 Proposal for a guidance document

This proposal for a guidance document addresses district heating suppliers by providing calculation methods on how to assess the sustainability of their district heating networks. Using the proposed indicators, the district heating operator could effectively inform final customers (existing or future) about the efficiency and sustainability of the district heating network. The results could be communicated through the website of the DH operator, heating bill or a label. The communication options are presented in chapter 5 of this report.

To inform the final user of the sustainability characteristics of a specific thermal network, we suggest, as concluded in the previous section, using the non-renewable primary energy factor. This factor will give a good indicator of both, reflecting well the positive impact of renewables and efficiency of the district heating network.

It is recognised that a single indicator cannot provide the complete picture, e.g. the efficiency of the heat generators or the amount of thermal losses. However, we consider that the amount of information provided should remain concise and easily understandable by a non-expert audience. The non-renewable PEF, following this analysis, appears to be the best indicator in that respect.

In addition, following the requirements of Article 1(13a) of RED III (proposal to amend REDII (2018/2001)), the shares of RES and waste heat should be provided to the consumers as well.

Therefore, we suggest that the district heating operator provide, at least, these three indicators:

- Primary energy factor (non-renewable primary energy factor) per unit of heat delivered,
- Share of renewable energy sources (%),
- Share of waste heat (%).
- In addition to these indicators, we suggest showing the CO2 emission factor, efficiency and compliance with the definition of efficient district heating and cooling from Article 2 of the EED.

4.1 Non-renewable primary energy factor

To calculate the non-renewable primary energy factor, the following equation is applied (EN 15316-4-5):

$$f_{p,DH} = \frac{\sum_j E_j \cdot f_{P,j} - E_{exp} \cdot f_{P,exp}}{Q_{del}} \tag{11}$$

where:

$f_{p,DH}$ – non-renewable primary energy factor of a district heating system

E_j – energy content of the input fuel to the energy conversion technology j in MWh

$f_{P,j}$ – non-renewable primary energy factor of the input fuel to the energy conversion technology j in MWh_p / MWh_{input}

E_{exp} - the amount of energy exported outside the system in MWh

$f_{P,exp}$- non-renewable primary energy factor of the energy exported outside the system in MWh_p / MWh_{input}

Q_{del} – Useful delivered energy in MWh

E_j, E_{exp} and E_{del} are measured data. Non-renewable primary energy factors can either be taken from the table below (**Table 13**) or from national sources. If countries choose the second option, they should ensure that the non-renewable primary energy factor is calculated following a life cycle approach according to the standard EN ISO 52000-1.

Table 13. Default values for non-renewable primary factor of energy carriers

Energy carrier	Non-renewable primary factor	Explanation and source of reference
Fossil fuels (gas, heating oil, coal)	1.1	Primary energy form is taken as the first flow in the production process that has a practical energy use (physical energy content method used by Eurostat) + 10% of energy needed for processing and distributing of the primary fuels is added to take

		entire life cycle into account (Fraunhofer study).
Biomass (sustainable) (*)	0.15	Approximation of life cycle non-renewable primary energy (Fraunhofer study).
Biomass (not sustainable)	1.15	Idem to fossil fuels.
Waste heat from industry	0 (process-related component) 0.05 (district heating component)	Industrial waste heat consists of two components: a process-related component and a district heating component. District heating component is the amount of additional energy needed to use the waste heat (e.g. boosting pressure, temperature and flow rate). Calculation rules from the standard EN 15316-4-5 are applied. PEF (non-renewable) of 0.05 is taken from the EcoHeatCool project.
Heat from waste-to-energy plants	0.15	Approximation of life cycle non-renewable primary energy (Fraunhofer study).
Ambient, geothermal (**)	0	Calculation depends on the SPF (seasonal performance factor) of heat pumps (see explanation below).
Electricity	1.59	EU mix calculated in the Fraunhofer study.

Source: own illustration

(*) Biomass (sustainable): Biomass needs to fulfil sustainability criteria in order to apply the non-renewable primary energy factor of 0.15 (sustainability criteria in line with the recast Renewable Energy Directive 2018/2001 and a revision of the Renewable Energy Directive). If biomass does not fulfil sustainability criteria, it applies the PEF of 1.15.

(**) PEF for ambient and geothermal is 0 for heat pumps fulfilling the criteria referred to in Annex VII of RED II (2018/2001) of SPF > 1,15 * 1/ŋ.

SPF - Seasonal Performance Factor

ŋ - the ratio between total gross production of electricity and the primary energy consumption for the production of electricity and shall be calculated as an EU average based on Eurostat data (the calculated value for EU27 for 2019 is 0.49 (Eurostat 2021)).

If heat pumps do not fulfil the efficiency criterion, the PEF is calculated as follows:

$$f_{hp*} = \frac{f_{elect.}}{SPF} \tag{12}$$

where:

f_{hp*} – non-renewable primary energy factor of heat pump which does not fulfil the efficiency criteria.

where:

$f_{elect.}$ – non-renewable primary energy factor of electricity

An additional aspect required for the calculation of the PEF is the allocation of fuels for the combined production of heat and power in CHP units. To do so, we recommend using the Carnot method, which is presented in Annex VI of RED II (2018/2001). The input fuel for heat ($E_{CHP,heat}$) is calculated as follows:

$$\alpha_{CHP,h} = \frac{\eta_{c,h} \cdot Q_{del}}{\eta_{c,h} \cdot Q_{del} + \eta_{c,e} \cdot P_{del}} \tag{13}$$

$$\alpha_{CHP,e} = \frac{\eta_{c,e} \cdot Q_{del}}{\eta_{c,h} \cdot Q_{del} + \eta_{c,e} \cdot P_{del}} \tag{14}$$

$$\eta_{c,h} = 1 - \frac{T_{amb}}{T_h} \, and \, \eta_{c,e} = 1 \quad (15)$$

$$E_{CHP,heat} = E_{CHP,h} \cdot E_{CHP,input\ total} \cdot f_{p,j} \quad (16)$$

where:

$\alpha_{CHP,h}$ – the allocation factor for heat based on Carnot efficiencies (value between 0 and 1)

$\alpha_{CHP,heat}$ - the input fuel for heat

$E_{CHP,e}$ – the allocation factor for electricity based on Carnot efficiencies (value between 0 and 1)

$\eta_{c,h}$ – the Carnot factor for heat (REDII Annex VI)

$\eta_{c,e}$ – the Carnot factor for electricity (REDII Annex VI)

$E_{CHP,input\ total}$ – total input energy to CHP

$f_{p,j}$ – primary energy factor of the input fuel

Q_{del} – total heat delivered in the CHP

P_{del} – total power delivered in the CHP

T_h – Mean temperature of heat supply, K

T_{amb} – Ambient temperature, K

If the Carnot method is selected, formula 11 for a cogeneration unit has to be replaced with the following formula (for the terms, see formulas above):

$$f_{p,DH} = \frac{\sum_j E_{CHP,j} \cdot E_{aux} \cdot f_{P,j}}{Q_{del}} \cdot \frac{\eta_{c,h} \cdot Q_{del}}{\eta_{c,h} \cdot Q_{del} + \eta_{c,e} \cdot P_{del}} \quad (17)$$

4.2 Share of renewables and waste heat

The share or renewable sources is calculated as follows:

$$sRES = \frac{\sum_i^{RES} Q_i}{\sum_j^{N} Q_j} \quad (18)$$

Where:

sRES - share of renewables

Q_i – gross final energy by renewable sources

Q_j – gross final energy by all energy sources

The renewable sources are sustainable biomass, ambient heat (air, water), solar heat, and geothermal energy.

Accounting of heat pumps: ambient energy or geothermal added to numerator and denominator.

Only the heat pumps fulfilling the criterion referred to in Article 7(4) of RED II (2018/2001) (SPF > 1,15 * 1/η) are accounted as renewables.

The share of waste heat is accounted as follows:

$$sWH = \frac{\sum_i^{WH} Q_i}{\sum_j^{N} Q_j} \quad (19)$$

Where:

sWH – share of waste heat

Q_i – gross final waste heat

Q_j – gross final energy by all energy sources

The share of waste heat in a DHC refers to the amount of waste heat incorporated in a thermal network to the total energy provided into the network, where the waste heat and cold is defined as the unavoidable heat or cold. It must be a by-product of power generation, or an industrial or services activity. For cogeneration, all reasonable efficiency measures must have been implemented and in general only the heat from the condenser can be counted (Lyons, L. et al. 2021 and Jimenez Navarro, J.P. et al. 2022).

4.3 Optional indicators

In this section, we include the list of indicators that can complement the mandatory ones. It may be the choice of the Member States or district heating operator to ask for and provide them to end users. These indicators are:

- CO2 emission factor,
- Efficiency (global efficiency covering losses from both, the network and energy conversion technology),
- Compliance with the definition of EDHC (Efficient district heating and cooling) from the EED and EED (proposal).

4.3.1 CO_2 emission factor

The following equation applied to calculate the CO_2 emission factor:

$$f_{CO2,DH} = \frac{\sum_j E_j \cdot f_{CO2,j} - \sum_i E_{exp,i} \cdot f_{CO2,i}}{Q_{del}} \qquad (20)$$

Where ([40]):

$f_{CO2,DH}$ – CO_2 emission factor of a district heating system in tCO_2 / MWh_{heat}

E_j – energy content of the input fuel to the energy conversion technology j in MWh

$f_{CO2,j}$ – CO_2 emission factor of the input fuel per energy content in primary energy terms tCO_2 / MWh_{input}

E_{exp} - the amount of energy exported outside the system in MWh

Q_{del} – Useful delivered energy in MWh_{heat}

The CO_2 emission factor of the input fuel can be either taken from this document (see **Table 14** and **Table 15**), or from the national documents ensuring the usage of the life cycle approach (LCA) that includes CO_2 emissions that take place across the entire value chain of the energy carrier including extraction processing or transmission.

Table 14. CO_2 emission factors for fossil fuels and municipal wastes

Energy carriers		LCA 2008-2015
SECAP Template	IPCC denomination	tCO2-eq/MWh
Natural gas	Natural gas	0.24
Liquid gas	Liquefied Petroleum Gases	0.281
	Natural Gas Liquids	0.272

([40]) All terms in the equation except for $f_{co2,j}$ have been already introduced before in this guidance section.

Heating Oil	Gas/Diesel oil	0.306
Diesel	Gas/Diesel oil	0.306
Gasoline	Motor gasoline	0.314
Lignite	Lignite	0.375
Coal	Anthracite	0.37
	Other Bituminous Coal	0.358
	Sub-Bituminous Coal	0.363
Other non-renewable fuels	Peat	
	Municipal Wastes (non-biomass fraction)	0.295

Source: Koffi, B. 2017

Table 15. CO_2 emission factors for renewable sources

Renewable energy		LCA 2008-2015 (current update)
Energy classes(1)	IPCC denomination	tCO_2-eq/MWh
Plant oil	Other Liquid Biofuels	0.182
		0.484
Biofuel	Bio-gasoline	0.207
		0.462
	Biodiesels	0.156
		0.411
Other biomass	Biogas	0.284
	Municipal wastes (biom. fraction)	0.106
	Wood (/Wood waste)	0.017
		0.42
	(Wood/) Wood waste	0.184
	Other primary solid biomass	n.a.
Solar thermal		0.04
Geothermal		0.05

Source: Koffi, B. 2017

4.3.2 District heating efficiency

The district heating global efficiency covers losses from both, the network and energy conversion technology, and is calculated as follows:

$$\eta_{DH} = \frac{E_{del}}{\sum_j E_j + E_{aux}} \tag{21}$$

Where:

η_{DH} – district heating global efficiency

E_j – energy content of the input fuel to the energy conversion technology j in MWh

E_{del} – useful delivered energy in MWh

E_{aux} – auxiliary and pumping electric consumptions in MWh

E_j, E_{aux} and E_{del} are measured data

4.4 Summary of all parameters

The list of indicators proposed to communicate the efficiency and sustainability of DH networks are summarised in **Table 16**.

All indicators, required or optional, shall be determined over a year time period and for the same system boundary and time resolution. They should be provided together with the values of the previous five years ([41]) to show the evolution of the thermal network over time.

Table 16. Information on energy performance and sustainability indicators calculated by district heat supplier following the calculation rules from this report

Indicator	Value	Unit	Calculation year	Calculation approaches	Required / Optional
Primary energy factor	Calculated value	(-)	Year of calculation	Life-cycle non-renewable primary energy factor. The choice between the national values for PEFs for energy carriers and values provided by this guideline should be specified. The allocation of the input fuel for CHP plants should follow the Carnot method .	R
CO_2 emission factor	Calculated value	(-)	Year of calculation	Life-cycle CO_2 emission factors. The choice between the national values for PEFs for energy carriers and values provided by this guideline should be specified.	O
RES-share and waste heat share	Calculated value	(%)	Year of calculation	The renewable share refers to the ration between the total heat supplied from renewable sources to the total heat supply. The share of waste heat refers to the amount of waste heat incorporated in a thermal network to the total energy provided into the network.	R
Efficiency	Calculated value	(%)	Year of calculation	The district heating global efficiency covering losses from the network and energy conversion technology.	O
Efficient district heating and cooling	Yes/no	(-)		Definition from Article 2(41) of the EED which gradually changes with the years according to the EED (proposal).	O

([41]) Five years period corresponds to the periods sets under Article 24 of the REDII.

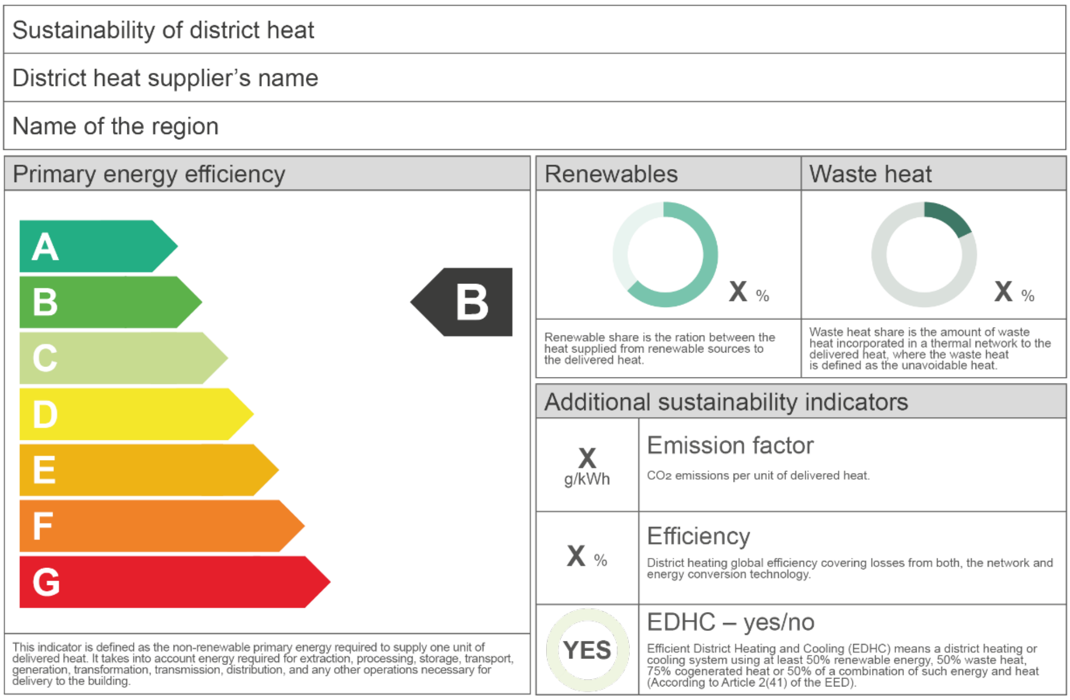
5 Communication to the customer

According to Article 24(I) of the RED II, the information about the energy performance and the share of renewable energy of the district heating and cooling system shall be presented to final consumers in an easily accessible manner, such as on the suppliers' websites, annual bills or upon request.

In chapter 4, we developed a guidance document for district heating operators on how to calculate the following main indicators: the primary energy factor and the shares of renewable energy and waste heat, as well as three optional ones: CO_2 emission factor, district heating efficiency, and compliance with the efficient district heating and cooling definition. In this chapter, we discuss how these indicators could be communicated to final consumers.

Figure 17 shows an example of a certificate for a district heating supply that includes all indicators mentioned above. The main indicator, called "Primary energy efficiency," is shown as a 7-color label. This indicator is based on the non-renewable primary energy factor of the heat supply and is shown on a scale from the highest class A (most sustainable) to the lowest class G (least sustainable). The shares of renewables and waste heat are presented in a pie chart. Finally, three additional indicators (CO_2 emission factor, efficiency, and compliance with the definition of EDHC) are listed on the bottom of the certificate.

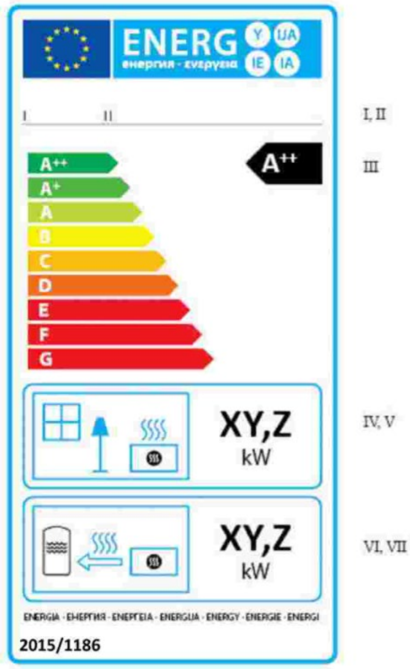
Figure 17. Certificate example showing different indicators on sustainability of district heat



Source: own illustration

Our proposed primary energy efficiency label for a district heating system looks similar to the EU energy label for individual space heaters (regulation (EU 2015/1186)) (**Figure 18**). However, the EU energy label requirements are compared within their own product group with their own methods, whereas a district heating system usually comprises several different types of heat sources. Moreover, while the EU energy label informs customers about the energy efficiency of a product, our proposed label reflects primary energy efficiency of non-renewable energy sources (reflecting both the efficiency and renewability of a district heating system). In order to set the scale for the classes from A to G, we propose to use the non-renewable PEF values of reference heat supply technologies (see ***Table 17***). These comparable heating systems could possibly be shown to end users to compare performance of their heat supply with other energy systems such as individual systems in buildings.

Figure 18. The EU energy label for a local space heater



Source: European Commission 2021

Table 17. Thresholds of a possible labelling system and comparable reference heating systems

Label	PEF (non-renewable primary energy factor of heat production)	Comparable reference heating system*
A	<0.1	Heat pump (efficient), sustainable biomass cogeneration
B	<0.2	Sustainable biomass boiler (pellets)
C	<0.3	Sustainable biomass boiler (firewood)
D	<0.5	Biomass (not sustainable) cogeneration
E	<0.7	Heat pump (low SPF)
F	<1.2	Fossil fuel condensing boiler
G	>1.3	Fossil fuel boiler, electric heater

NB: * This label is different to the EU energy label and its scale. It cannot be directly compared with e.g. Energy Labelling regulation for space heaters (Space heating regulation 811/2013).

Source: own illustration

To calculate the thresholds for the reference technologies, we applied the above mentioned methods and the non-renewable primary energy factors for the energy carriers (chapter 4). In addition to assumptions for the efficiency of energy systems, we assumed distribution losses of the network of 13% for all cases. Other assumptions for calculation are as follows:

- A class:
  - Heat pump (efficient): PEF (non-renewable) for ambient heat is 0 for heat pumps fulfilling the criteria referred to in Annex VII of RED II (2018/2001).
  - Sustainable biomass cogeneration: biomass needs to fulfil sustainability criteria from RED II (2018/2001) and RED III (revision of RED II (COM/2021/557 final)). Other assumptions: PEF for sustainable biomass is 0.15, CHP efficiency is 90%, power to heat ratio: 0.9, temperature of supply 80 °C.
- B class: sustainable biomass boiler (pellets). PEF (non-renewable): 0.15, 84% boiler efficiency. Biomass needs to fulfil sustainability criteria (see above).
- C class: sustainable biomass boiler (firewood). PEF (non-renewable): 0.15, 75% boiler efficiency. Biomass needs to fulfil sustainability criteria (see above).
- D class: biomass (not sustainable). PEF (non-renewable) for biomass is 1.0, CHP efficiency is 90%, power to heat ratio: 0.9, temperature of supply 80 C. This biomass does not fulfil sustainability criteria from RED II and RED III.
- E class: heat pump (low SPF). Heat pump does not fulfil efficiency criteria from RED II. It applies the PEF (non-renewable) of electricity 1.59 and SPF of 2.6.
- F class: fossil fuel condensing boiler. PEF (non-renewable) for gas and oil is 1.1, Heating system efficiency (95(%)).
- G class:
  - Fossil fuel boil: PEF (non-renewable) for gas and oil is 1.1, heating system efficiency (90%).
  - Electric heater: PEF (non-renewable) for electricity is 1.59 (EU mix calculated in the Fraunhofer study), heating system efficiency (100%).

6 Conclusions

We prepared a proposal for a guidance document on how the energy performance of district heating and cooling (DH&C) systems and their shares of renewable sources (RES) are calculated. This guidance document addresses district heating suppliers by providing calculation methods on how to assess the following five indicators: (1) Primary energy factor, (2) CO_2 emission factor, (3) the share of renewable energy sources and (4) district heating global efficiency and (5) in compliance with efficient district heating and cooling (according to the EED). Since this report aims at supporting Article 24 of RED II which addresses final customers of the DHC system, we provided communication options to present these indicators in an accessible manner to the final customer. To inform the final user of district heat, we suggest an example for a certificate with all above mentioned indicators. The main indicator called “Primary energy efficiency” is shown as a 7-color label. Based on the non-renewable primary energy factor of the heat supply, this indicator is shown on a scale from the highest class A (most sustainable) to the lowest class G (least sustainable). We selected a comparable heating system for each class which could accompany the certificate in order to compare the performance of their heat supply with other energy systems such as individual systems in buildings.

The review of energy indicators used in different contexts such as EU legislation and research studies has showed that the PEF is a widely used indicator to assess energy performance of DH networks. However, there exist several methodological approaches to define the PEF for DH networks. The total PEF can vary depending on the specific assumed PEF for energy carriers and on the allocation method for the CHP plants. Regarding the specific PEF for energy carriers, the calculation boundary (across the energy value chain) and the primary energy indicator (total primary energy or non-renewable primary energy only) play an important role. With regard to the energy allocation of the input fuel for CHP plants, there exist several methods leading to different results. The analysis of the PEF for DHC systems applied by the EU Member States in their cost-optimal reports (following the requirements from the EPBD) has showed that the primary energy factor for district heating systems vary strongly between the EU Member States (it varies between 0.0-1.6). One of the reasons of this large differences between Member States is the approach followed to calculate the PEFs for various energy carriers used within the DHC system and the allocation of heat and power generated by CHP plants. So, the PEFs cannot be compared among the Member States. Moreover, the methodologies to determine PEFs are not always transparent.

We propose an harmonised methodology to assess the PEF for the DH&C systems with the main rules to be followed by the Member States:

— Use the life-cycle non-renewable primary energy factor for various energy carriers. The values can either be calculated using national approaches or taken from the guidance document developed in this report. We suggested the PEF for various energy carriers using EU srtandards and other souces of reference.

— The allocation of the input fuel for CHP plants should follow the Carnot method which is presented in Annex VI of RED II. Unlike other allocation methods, the Carnot method addresses temperatures of the operation. The lower supply temperature the lower is the overall PEF for heat. In the context of the new generation of DH networks, characterised by low temperatures of operation, the Carnot method can nicely address this important energy efficiency aspect of the district heating networks. Moreover, the Carnot method allocates losses proportionally between the two energy outputs: heat and power. Thus, it avoids low PEF for heat as is the case with some methods that allocate all losses to electricity.

The PEF should not be the only indicator, especially in the frame of the RED II Directive. This factor reflects the efficiency of the district heating network and the sustainability, but it does not show these indicators explicitly. They are hidden behind one number in which the primary energy factor is expressed. This indicator does not directly reflect the type of energy carrier. The share of RES and waste heat in district heating and cooling networks and CO_2 emission should be taken into account as well. Finally, the global efficiency indicator showing both losses in the network and generators is an important indicator as well. These latter indicators would deliver valuable information to policymakers and customers of district heat about the efficiency and renewables in the district heating networks to help designing policies and measures.

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List of abbreviations and definitions

CHP	combined heat and power
DHC	district heating and cooling
DHCO	district heating and cooling operators
EED	Energy Efficiency Directive (2018/2002 amending 2012/27/EU)
EED (proposal)	Proposal for a revision of the EED 2018/2002 (COM(2021) 558 final)
EDHC	Efficient district heating and cooling (according to Article 2(41) of the EED)
EPBD recast	Energy Performance of Buildings Directive (2018/844/EU amending 2010/31/EU)
EPBD (proposal)	Proposal for a revision of the EPBD recast (COM(2021) 802 final)
EU	European Union EU-27 27 Member States of the EU
FEC	final energy consumption
H & C	heating and cooling
HECHP	high-efficiency combined heat and power
JRC	Joint Research Centre
MSs	EU Member States
NZEB	nearly zero-energy building
PEF	Primary Energy Factor
RED II	Renewable Energy Directive (2018/2001)
RED III	proposal to amend the RED II (2018/2001) (COM/2021/557 final)
RES	renewable energy source
SECAP	Sustainable Energy and Climate Action Plans
TFEC	total final energy consumption
COP	Coefficient of performance

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