

Chapter 2

District Heating and Cogeneration in the EU-28: Current Situation, Potential and Proposed Energy Strategy for Its Generalisation

The most common commodity is unrealised potential.
—Calvin Coolidge

Yearly, EU-28 conventional thermal generating plants reject a greater amount of energy than what ultimately is utilised by residential and commercial loads for heating and hot water. If this waste heat were to be used through district heating networks, given a previous energy valorisation, there would be a noticeable decrease in imported fossil fuels for heating. As a consequence, benefits in the form of an energy efficiency increase, an energy security improvement, and a minimisation of emitted greenhouse gases would occur. Given that it is not expected for heat demand to decrease significantly in the medium term, district heating networks show the greatest potential for the development of cogeneration. However, to make this happen, some barriers that are far from being technological but are mostly institutional and financial need to be removed.

The purpose of this chapter is to provide information on the potential of using waste heat from conventional thermal power plants (subsequently converted into cogeneration plants) in district heating networks located in the EU-28. For this, a preliminary assessment is conducted in order to show an estimate of the cost of adopting an energy strategy in which district heating networks are a major player of the energy mix.

From this assessment, it is possible to see that even though the energy strategy proposed in this book, which is based on a dramatic increase in the joint use of district heating networks and cogeneration, is capital-intensive and would require an annual investment of roughly 300 billion euros, its adoption would result in a reduction of yearly fuel expenses in the order of 100 billion euros and a shortening of about 15% of the total final energy consumption, which makes it of paramount interest as an enabler of the legal basis of the “Secure, Clean and Efficient Energy” future enacted by the EU-28 Horizon 2020.

2.1 Introduction

From the simplified energy balances performed annually by EUROSTAT (2013 is the last year for which data is available), conventional thermal power plants located in the EU-28 waste more energy in the form of residual heat than what finally residential and commercial buildings use for heating [1–3]. As is clear from Fig. 2.1, if this residual heat could be used previous energy valorisation from cogeneration in district heating networks, a noticeable decrease in the amount of imported fossil fuels and greenhouse gases emitted into the atmosphere would occur (at Appendix G, additional information on the relation between electricity and heat in a cogeneration plant is included), which would result in economic, environmental, and energy security benefits.

From Fig. 2.1, it is impossible to determine how much heat can be used. Many power plants have to be necessarily located far from the thermal loads of cities (e.g., coal power plants are usually located close to a port to stock). However, in a future scenario, it could be more beneficial, from an economic perspective, to place those plants in the vicinity of the cities. As they are environmentally friendly they can be located closer to them. The old plants should be dismantled when their useful life ends. This supposes an additional expense of transporting coal or lignite in order to be able to use waste heat from power plants [4].

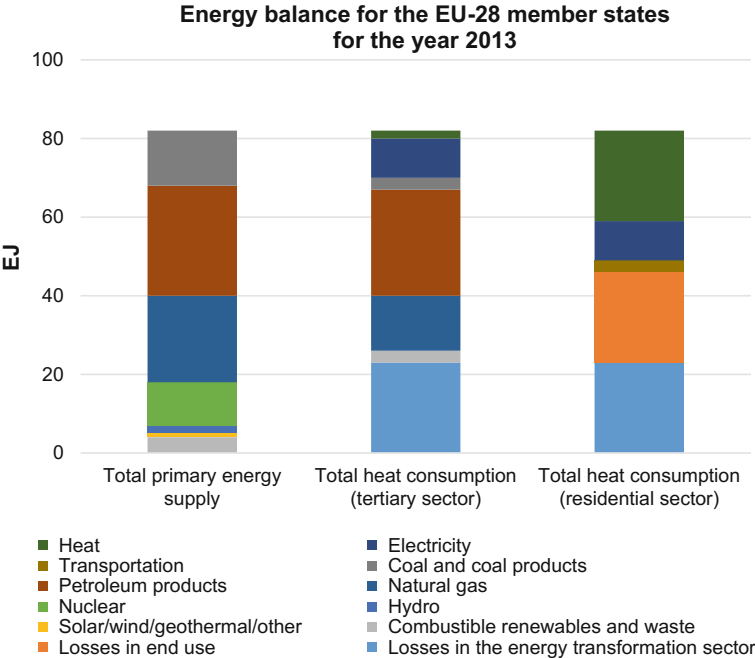


Fig. 2.1 Energy balance for the EU member states for the year 2013 [3]

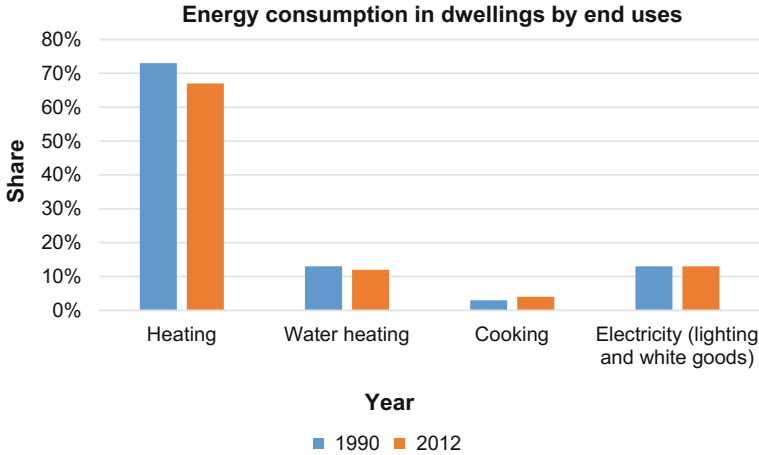


Fig. 2.2 Power consumption for households located in the European Union depending on the energy end-use *Source* Adapted from [38]

In Fig. A-1, Appendix A, it can be seen as another way of representing the energy balance (which again shows the importance of waste heat from power plants) [5].

As seen in Fig. 2.2, about 80% of the energy used in homes has as ultimate goal to provide heating and hot water; this means that, according to Fig. A-1, there would be potentially about 15,000 PJ/year (4100 TWh) to be satisfied through the waste heat from power plants (note that this amount is less than the residual heat emitted by power plants located in the EU-28, 19,608 PJ/year (Fig. A-1).

Finally, Fig. 2.3 shows the energy share for each district heating resource—it is possible to see that, for the EU, most of the heat comes from waste heat from power plants.

Despite these data, it should be noted that, due to the lack of energy matching throughout the year, as well as to the problem of the reject heat temperature (cogeneration can conduct an energy valorisation of this low-temperature heat in an economical way), not all of these thermal loads can be satisfied by the waste heat from thermal power plants. This makes necessary to estimate their real potential including assumptions as close as possible to the reality and to conduct an economic and environmental assessment (reduction of greenhouse gas emissions) that includes a generalised spread of district heating networks using as an energy source waste heat from conventional thermal power plants in the EU-28, which will be conducted in this chapter.

The objective of this chapter is to propose an energy strategy which enables, through the generalisation of the joint use of district heating networks and cogeneration in the EU-28, the fulfillment of the legal basis of the H2020 “Secure, Clean, and Efficient Energy” goals in a feasible, reliable, economically advantageous, and sustainable way. The method proposed here uses a systematic and easy

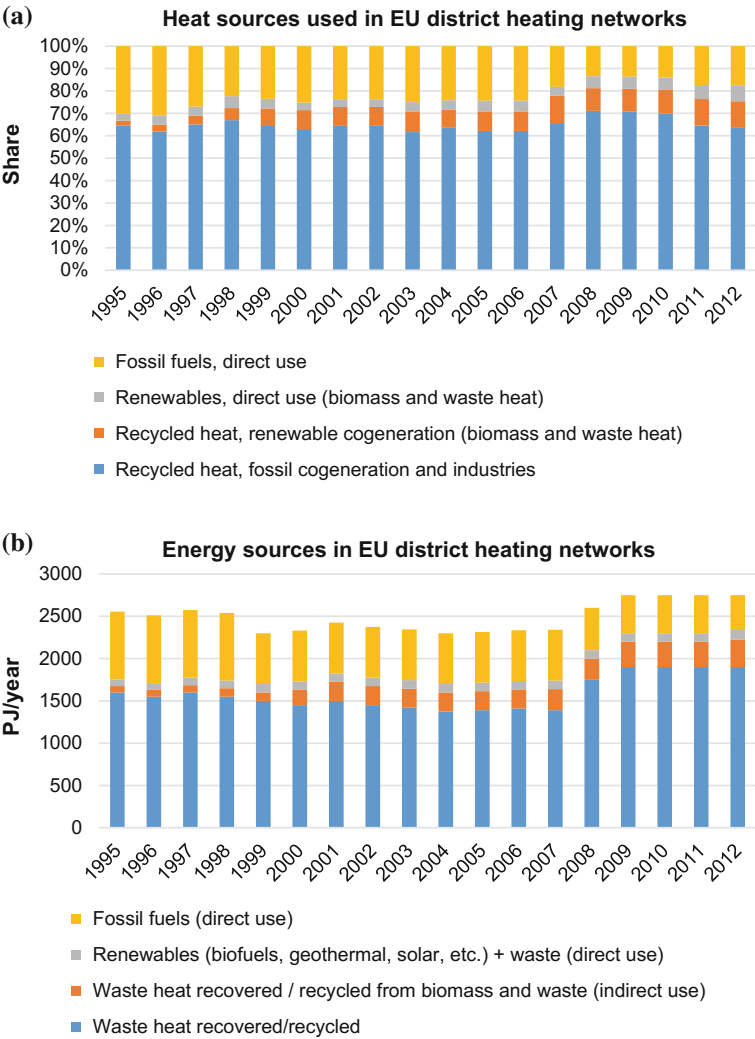


Fig. 2.3 Energy share (a) and generation for each district heating source (b) in the EU-28 [19, 39]

approach (neither strong mathematical skills nor non-widely used software is required) and manages to propose an energy strategy for such a big region as EU-28 based mostly on available public data (with the exception of the plant data obtained through the GESTIS database by using the ArcGIS software).

This is of great importance as other methods are network-oriented (district heating network); lack from massive surface applicability, being inadequate for such a big area as Europe; are limited to industrial sites; or present assessments which need a district heating network taxonomy, information not available in the vast majority of the cases. As a consequence, they are not useful for the purposes of

this book. To our knowledge, there is not a single scientific paper which specifically addresses the potential of the joint use of thermal power plant reject heat into district heating networks across the European Union. Thus, we offer new insights into this matter.

The first section of this second chapter has made a first approximation of the energy balance of EU-28 Member States has been made and mentioned the potential use of reject heat from conventional thermal power plants. Section two will explain the methodology followed to develop the research carried out here; section three will show different studies evaluating the potential joint use of district heating networks and cogeneration for different regions; and section four will present different scenarios on the evolution of district heating networks and estimate the (economically feasible) potential of converting conventional thermal power plants into cogeneration plants.

The fifth section will be reserved for the discussion, and the sixth for the conclusions, which will show the implications (restrictions and benefits) of the generalisation of the joint use of cogeneration and district heating networks in the EU-28.

Finally, as additional information to this second chapter, annexes with information on prices of district heating networks (Annex B), heat transportation (Annex C), heat distribution (Annex D), and thermal storage (Annex E) have been included. Furthermore, the case of Copenhagen as an example of a city that has been able to adequately combine the use of electricity, district heating, natural gas, and waste management (Annex H) has been presented.

2.2 Materials and Methods

To give documentary strength to this chapter, it was necessary in the first instance to consult more than 100 scientific publications and/or gray literature in the field of cogeneration and district heating networks. While not absolute, it is a representative sample of the state of the art of the subject under study.

Subsequently, and to determine the degree of matching between the above publications and the perception of experts from various members of the EU-28, a total of nine experts from seven countries of the European Union (see section “Acknowledgements”) were consulted through questionnaires, email correspondence and/or telephone conversations.

Once the scientific/gray literature and the experts were consulted, the third step taken was to use various databases to estimate the potential for the joint utilisation of district heating networks and cogeneration. Among these databases, the most notable were EUROSTAT, GESTIS database based on Platts, and The European Pollutant Release and Transfer Register (European Environment Agency). The latter was essential for selecting those conventional ones potentially convertible in an economical way.

The fourth step taken was to introduce some restrictions on the type of plant and the distance from it to the thermal load (nearest town). To estimate the cost related to the heat demand, member states of the EU-28 were firstly divided into zones, with the countries of central and southern Europe assigned a cost on energy demand different from the one used only for the countries of southern Europe. This discrimination is based on the fact that, obviously, the costs of providing heat to the thermal loads decrease as demand increases.

Finally, and in order to know the cost of providing heat through district heating networks for different typical climatic zones of the EU-28, [6] was consulted, which constitutes a supporting feature to the review presented here. To the heat demand for each consumption located in Northern and Central Europe, a value of 2000 GWh/year was assigned, having been established the distance from the heat load at 75 km. Meanwhile, for those loads located in the Southern European countries, a type value of 750 GWh/year of heat and 400 GWh/year for cooling was established, being the distance in this case also 75 km. Note that these conditions are much more restrictive than those described in [6]; we have proceeded in this way because such cases, although based on real plants, have better characteristics for the conversion to cogeneration plants than those that would be considered as “typical”.

Due to the fact that DHNs and DCNs lack a symmetrical end-use purpose (DHNs are usually aimed at areas where there are residential buildings within a city, while DCNs tend to be focused only on the central areas of the cities) and its proximity-to-load requirement, it is not possible to distribute cold appropriately from an economic perspective. District cooling is based on a difference of temperatures much smaller than district heating; see respectively in Appendix D and Appendix F additional information on the distribution of heat and cold in modern heating/cooling systems) [7]. It would be impractical to transmit the cold at a distance of 75 km, so for the countries of Southern Europe, it has been supposed the use of absorption heat units that use the heat from district heating networks for cooling, not being, therefore, necessary to use pipes for transporting cold at a large scale.

Some restrictions have been imposed, e.g. only those thermal power plants with a rated power of over 300 MW located within 75 km of urban centers of more than 100,000 inhabitants are considered as valid for conversion, and some data such as the following was found out:

- total installed capacity of thermal power plants using fossil fuels,
- total installed capacity of cogeneration,
- CHP generation percentage,
- CHP maximum installable capacity from thermal plants.

From this data, a feasible CHP capacity that would comply with the aforementioned restrictions is obtained and presented in the Results section. From these feasible convertible thermal power plants and from data obtained from the literature,

usable heat, the investment needed, and fuel savings are obtained and shown in the Results section.

A summary of every stage of study and its relationship with the Results section would be as follows:

- (1) Scientific publications and/or gray literature review.
- (2) Experts in the field of cogeneration and district heating networks consultation.
- (3) Databases (EUROSTAT, GESTIS, and The European Pollutant Release and Transfer Register) consultation.
 - The obtainment of conventional thermal combustion capacity, CHP electrical capacity, share of CHP electricity production, electricity generation from generation plants, heat generation from CHP plants, final total energy consumption, total district heating network sales, and percentage of citizens served by district heating, is immediate from EUROSTAT databases.
 - The methodology to assemble the data obtained from GESTIS and EPRTTR was as follows:
 - a. Plant data: GESTIS database based on Platts
 - i. This data was accessed through the GESTIS database using the ArcGIS software.
 - b. Plant coordinates: EPER/E-PRTR database
 - i. It can be accessed through the European Pollutant Release and Transfer Register website. Then following steps were undertaken “Search the register” > “Facility level” > “Country” > “EU27” > “Region” > “All regions” > “Year” > “2013” > “Industrial activity” > “Energy sectors” > “Thermal power stations and other combustion industries” > “No sub-activities”
 - c. City coordinates: Google Earth
 - i. No description needed
- (4) Calculation of maximum conversion of CHP by using total conventional thermal combustion capacity and CHP electrical capacity; heat to power ratio by using heat generation from CHP plants and electricity generation from CHP plants; and maximum annual additional heat output by using the maximum conversion of CHP calculated, the heat to power ratio, and supposing a load factor of 0.6.
- (5) Restrictions on the type of plant (only conventional thermal plants with a rated power of over 300 MW are to be considered), distance (thermal plants shall be located at a distance below to 75 km of urban centers), population of urban centers (higher to 100,000 inhabitants) and heat demand in Northern and Central Europe (2000 GWh/year) and heat and cooling demand in Southern Europe (respectively 750 and 400 GWh/year) are applied.

- (6) Calculation of DHNs feasible potential by using the maximum annual additional heat and the fact that, after the restrictions imposed in 5), about 50% of the installed capacity of all conventional thermal power plants comply with those restrictions; calculation of conversion and district heating costs by classifying countries into Regions (Northern and Central Europe and Southern Europe) and taking into account heating (and cooling) costs in those regions.
- (7) Once DHNs' feasible potential is achieved and yearly savings in fuel are known, the cost of natural gas for domestic consumption is determined, and the usual fuel consumption per unit of heat supplied for boilers and cogeneration plants (for both cases separately) are assumed. Through the cost difference between the two technologies, fuel savings are obtained.
- (8) Finally, the results from previous steps (1–7) are analysed, and an energy strategy for the generalisation of district heating networks and cogeneration is proposed, achieving, consequently, the objectives of the research.

2.3 Theoretical Background

To know the true potential of any technology, in this case, the joint use of cogeneration and district heating networks, it is necessary to perform an assessment of its economic feasibility. In the existing literature, it is possible to find a relatively high volume of gray literature and scientific publications that carry out feasibility studies relating to the implementation of district heating networks.

One of the first was conducted in 1979 by the Ministry of Energy of the United Kingdom [8], where it was indicated that the joint use of cogeneration and district heating networks was competitive already at that time from an economic perspective in comparison to the fuels used to satisfy the heating demand (the largest infrastructural costs were offset by lower operating costs). This study recommended the development of a program that would implement district heating networks associated with cogeneration plants. Although this publication saw the light more than three decades ago, the results remain equally valid because, firstly, the technical installation of the district heating networks have improved and the costs have decreased [9] and, secondly, comparatively fuel-related costs have increased more than the cost of the necessary infrastructure [10].

A computerised methodology to estimate the potential of the joint use of cogeneration and district heating for various discount rates was used [11]. As shown in Table 2.1, it is only in the UK with a peak demand of 60 GW [12] that there is a potential of 33 GW for this technology for a discount rate of 3.5%. Due to similar weather conditions, this study is representative for much of northern and central Europe. As is clear from Table 2.1 and Fig. 2.4, the choice of the discount rate is crucial to the feasibility of the project.

In [12, 13], the possibility of using cogeneration and district heating networks is studied again, reaching similar conclusions. As is clear from these publications, the

Table 2.1 Potential joint use of cogeneration and district heating networks in the UK for various discount rates [11]

CH/CHP potential	Units	Discount rate (%)		
		3.5	6	9
Total net CH/CHP potential for UK	MWe	33,125	21,517	75
Total electricity produced	–	6897	4204	46
Total heat sold	GWh	189,472	123,119	518
Primary energy saving	GWh	230,358	149,686	630

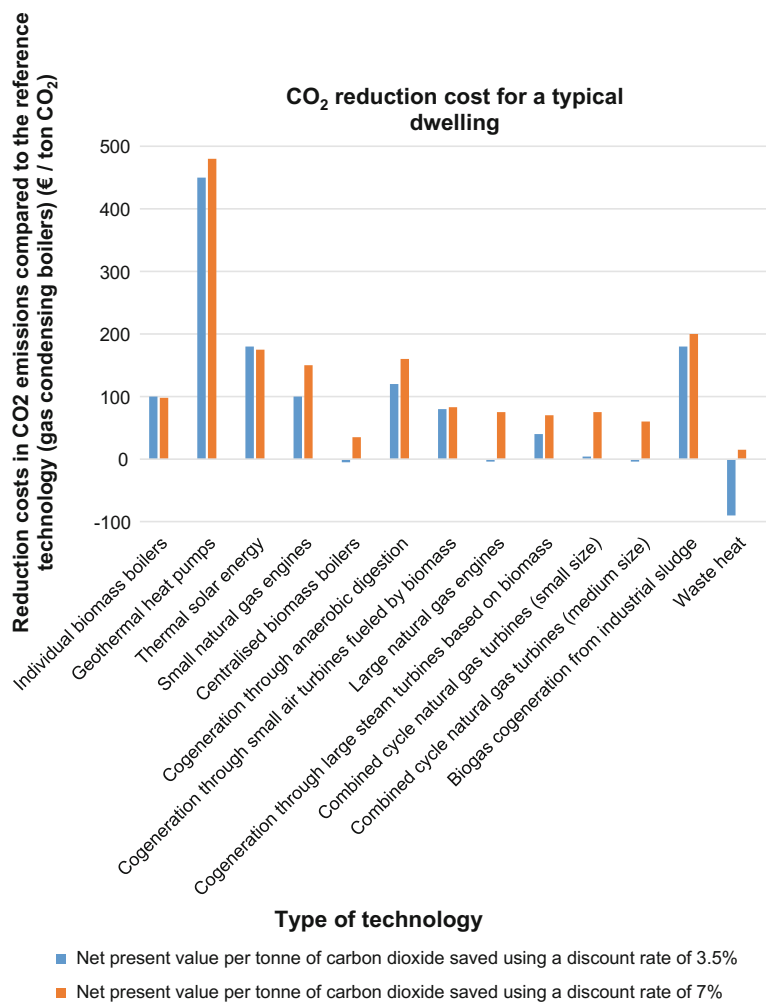


Fig. 2.4 The cost of CO₂ reduction for the typical UK dwelling [15]

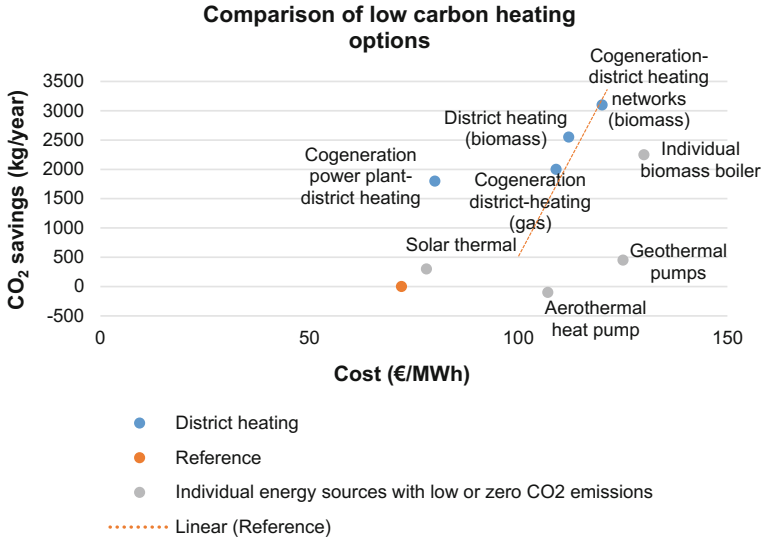


Fig. 2.5 Comparison of different energy solutions with low emissions of carbon dioxide [16]

joint use of these technologies provokes one of the greatest savings, in terms of CO₂ emissions, at one of the lowest costs per not emitted tonne [13, 14] (Figs. 2.4, 2.5).

At a European level, [15] confirms the possibility of stopping to emit 400 MtCO₂ per year, which would mean a reduction of 9% compared to current emissions, if the penetration of district heating and cooling were to be doubled.

2.4 Results

Given its economic and environmental benefits, the joint use of cogeneration and district heating networks should experience significant growth in coming years (Fig. 2.6) [16]. For district heating networks to achieve a penetration of over 90% in a big city, several decades may elapse, in the case of Copenhagen, it took more than 40 years [17], depending largely on the commitment of the authorities [18]. Appendix H includes additional information concerning the case of Copenhagen. Note that the actions to take for the widespread introduction of district heating networks from the market entry stage (going through the market penetration phase) to the stage of market maturity will depend, in any case, on the casuistry of each location; therefore, an adaptation of the measures to be taken depending on specific circumstances will be necessary.

To know the potential costs and energy savings, it has been supposed as a target that 50% of all domestic and commercial heating loads from the EU-28 can be satisfied from waste heat from conventional power stations and district heating

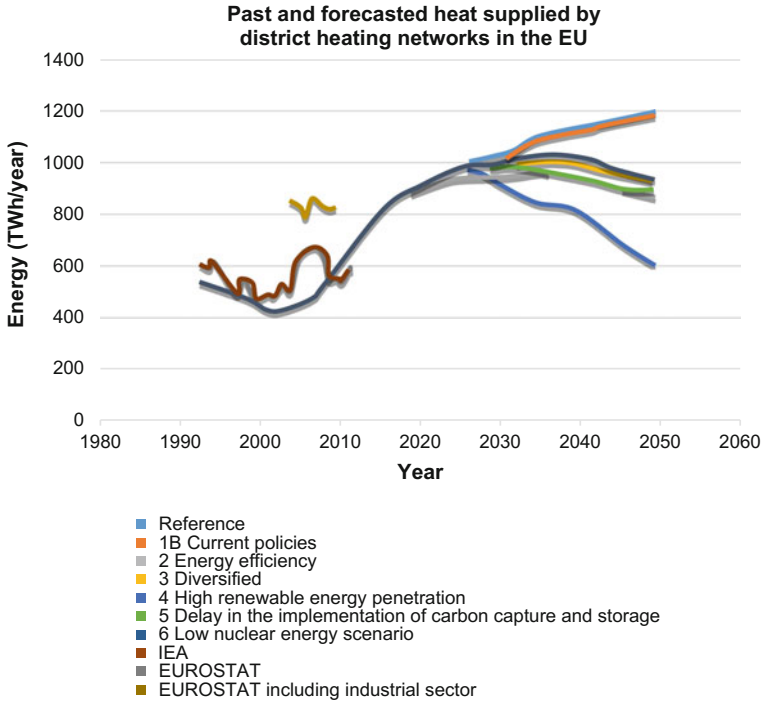


Fig. 2.6 Different scenarios for the heat supplied by district heating networks and cogeneration plants located in the EU until 2050 [16]

networks. These results are compared country by country assuming power plants are converted into cogeneration plants.

The estimate has been made as follows:

1. Table 2.2 gives the total installed capacity of thermal power plants using fossil fuels by member state in column A.
2. Column B shows the total installed capacity of cogeneration per member state (Table 2.2).
3. Column C presents the combined heat and power (electrical) generation percentage from each member state (Table 2.2).
4. Column D (Table 2.2) shows the installable capacity in the EU-28, assuming that 100% of conventional thermal power plants that use fossil fuels are converted into cogeneration plants (although not all the heat is used because the heat generated is higher than the actual demand).

Column E (Table 2.3) represents the additional energy obtained from converting all conventional power plants placed in the EU-28 into cogeneration plants, as shown in column D (Table 2.2). It is supposed that once the conventional thermal power plant has been converted, LF is 0.6. HPR calculations were carried out, taking into account columns A and B (Table 2.3), which correspond to the statistics

Table 2.2 Installed capacity per member state to achieve full conversion of conventional thermal power plants in cogeneration plants

	A	B	C	D
	Total conventional thermal combustion capacity [41] (GW)	CHP electrical capacity [42] (GW)	Share of CHP in electricity production [42]	Maximum conversion of CHP (GW)
	2013	2013	2013	Vision
AT—Austria	6.3	4.4	14.4%	1.9
BE—Belgium	7.6	2.3	15.2%	5.3
BG—Bulgaria	4.6	1.2	8.5%	3.4
CY—Cyprus	1.6	0.0	1.4%	1.6
CZ—Czech Republic	10.5	4.6	13.7%	5.9
DE—Germany	82.0	27.0	12.4%	55.0
DK—Denmark	7.6	5.7	50.6%	1.9
EE—Estonia	2.6	0.5	9.3%	2.1
ES—Spain	49.8	4.0	8.5%	45.8
FI—Finland	8.4	6.3	34.5%	2.1
FR—France	23.0	5.5	2.4%	17.5
GR—Greece	10.7	0.6	3.4%	10.1
HU—Hungary	5.8	1.6	13.4%	4.2
HR—Croatia	1.7	0.7	12.6%	1.0
IE—Ireland	6.0	0.3	7.8%	5.7
IT—Italy	70.6	7.6	12.7%	63.0
LT—Lithuania	2.8	1.2	35.0%	1.6
LU—Luxembourg	0.5	0.5	14.7%	0.0
LV—Latvia	1.2	1.0	38.3%	0.2
MT—Malta	0.6	0.0	0.0%	0.6
NL—Netherlands	21.4	9.2	34.5%	12.2
PL—Poland	28.2	8.3	15.9%	19.9
PT—Portugal	6.4	1.4	13.8%	5.0
RO—Romania	9.0	2.2	11.2%	6.8
SE—Sweden	6.6	4.5	10.2%	2.1
SI—Slovenia	1.2	0.3	7.1%	0.9
SK—Slovakia	2.8	4.4	77.0%	0.0
UK—United Kingdom	59.0	6.2	5.5%	52.8
EU-28	438.5	111.5		328.6

Source Adapted from [41, 42]

Table 2.3 Calculation of the annual heat obtained from the conversion of conventional thermal power plants located in the EU-28

	A	B	C	D	E
	Electricity generation from CHP plants [43] (TWh)	Heat generation from CHP plants [43] (TWh)	Heat to power ratio	Maximum conversion of CHP (GW)	Maximum annual additional heat output (TWh)
	2013	2013	2013	Vision	Vision
AT—Austria	9.9	30.8	3.1	1.9	31.0
BE—Belgium	12.7	7.6	0.6	5.3	16.7
BG—Bulgaria	3.7	11.2	3.0	3.4	53.6
CY—Cyprus	0.1	0.0	/	1.6	8.4
CZ—Czech Republic	12.0	33.6	2.8	5.9	86.8
DE—Germany	78.7	181.7	2.3	55.0	664.9
DK—Denmark	17.6	28.7	1.6	1.9	16.0
EE—Estonia	1.2	3.5	2.9	2.1	32.0
ES—Spain	24.1	48.6	2.0	45.8	481.4
FI—Finland	24.3	69.8	2.9	2.1	32.0
FR—France	14.0	41.8	3.0	17.5	275.9
GR—Greece	2.0	2.9	1.5	10.1	79.6
HU—Hungary	3.9	7.5	1.9	4.2	41.9
HR—Croatia	1.7	3.7	2.2	1.0	11.6
IE—Ireland	2.0	3.4	1.7	5.7	51.0
IT—Italy	36.7	59.1	1.6	63.0	529.8
LT—Lithuania	1.7	4.3	2.5	1.6	21.0
LU—Luxembourg	0.4	0.9	2.3	0.0	0.0
LV—Latvia	2.4	3.1	1.3	0.2	1.4
MT—Malta	0.0	0.0	/	0.6	3.2
NL—Netherlands	34.8	60.5	1.4	12.2	89.8
PL—Poland	26.1	71.5	2.7	19.9	282.4
PT—Portugal	7.2	19.0	2.6	5.0	68.3
RO—Romania	6.6	16.1	2.4	6.8	85.8
SE—Sweden	15.6	45.9	2.9	2.1	32.0
SI—Slovenia	1.2	3.0	2.5	0.9	11.8
SK—Slovakia	22.2	7.7	0.3	0.0	0.0
UK—United Kingdom	19.7	39.6	2.0	52.8	555.0
EU-28	390.1	789.4	/	328.6	3563.3

Source Adapted from [42]

available from EUROSTAT for the main power producers and not for the one of the auto-producers, and assuming that the heat of a CHP plant will feed district heating networks.

We have proceeded in this way due to the fact that:

1. the vast majority of non-cogeneration thermal power plants belong to large power producers and not to auto-producers
2. and that the uncertainty of connecting the waste heat from a power plant to a district heating network is much lower than the one that would be obtained if industrial waste heat were to be used, where other factors, such as the possibility that a given industry remains at least 60 years working in a given location, should be evaluated.

Because district heating networks always will have availability restrictions, this book has centered on HHW requirements for tertiary and residential sectors. An analysis of the technical potential of the district heating networks is shown in Table 2.4. As indicated earlier in this section, it has been assumed that district heating networks can supply roughly 50% of all heating requirements, domestic and commercial ones. In Table 2.4, it is possible to see that it has been supposed that the potential feasible for district heating networks (column E) is 50% of the maximum theoretical heat, a scenario in which all domestic and commercial loads have access and are satisfied through district heating networks (column C).

Finally, the costs related to the conversion of conventional thermal power plants into cogeneration plants and the investment required for the expansion of the district heating networks are estimated in column G (Table 2.4). Expansion costs include costs relating to both heat transport as those incurred in the district heating network itself. It should be noted that the cost of network expansion will vary depending on the region under analysis. Locations where AHDD is high incur smaller expenses (for district heating) than those for regions with a low heat demand, where a lower number of buildings will need to be connected to the district heating network. For those projects located in northern and central Europe, denoted respectively under the “N-C” acronym (see column F of Table 2.4), it has been assumed that they incur an annual heat demand cost of 45 €/GJ [19]. The costs of providing heat and cold jointly to those projects located in southern European countries, denoted by the acronym “S” (column F of Table 2.4), were assumed to be 60 €/GJ [6]. Note, however, that carrying out an appropriate assessment of the factual potentiality of associating current thermal generating plants to DHNs (district heating networks) requires a detailed analysis of each particular case, in which various techno-economic parameters are taken into account—see [6]. That is an extra feature to this book, as this analysis is beyond the scope of this book.

As can be seen in column C (Table 2.4), about 12% of the citizens of the EU-28 have access to district heating networks, with significant differences between countries. It is possible to find cases where the contribution of district heating networks to heat demand is virtually zero, as in the case of Spain, and others where the weight of district heating networks is high (nearly 2 out of 3 Danish have access

Table 2.4 Analysis of the technical potential of district heating networks

	A	B	C	D	E	F	G
	Final total energy consumption [3] (PJ)	Total district heating networks sales [44] (PJ)	Percentage of citizens served by district heating [44, 45]	Maximum annual additional heat (PJ)	DHNs feasible potential (PJ)	Region	Conversion cost + DHNs cost [6] (annual cost of investment in milliards of €)
	2013	2013	2013	Vision	Vision		Vision
AT—Austria	1170.2	80.7	24%	111.6	55.8	N-C	2.4
BE—Belgium	1457.1	21.0	3%	60.1	30.1	N-C	1.4
BG—Bulgaria	367.2	18.0	18%	193.0	96.5	N-C	4.2
CY—Cyprus	67.6	0.0	0%	30.2	15.1	S	1.0
CZ—Czech Republic	1000.0	89.4	38%	312.5	156.3	N-C	6.8
DE—Germany	9096.0	254.8	12%	2393.6	1196.8	N-C	52.6
DK—Denmark	594.3	105.5	63%	57.6	28.8	N-C	1.4
EE—Estonia	120.2	23.0	62%	115.2	57.6	N-C	2.6
ES—Spain	3397.0	0.0	0%	1733.0	866.5	S	52
FI—Finland	1030.6	114.2	50%	115.2	57.6	N-C	2.6
FR—France	6366.3	96.1	7%	993.2	496.6	N-C	20.2
GR—Greece	642.2	1.0	0%	286.6	143.3	S	8.6
HU—Hungary	628.8	31.0	15%	150.8	75.4	N-C	3.4
HR—Croatia	243.4	9.7	10%	41.8	20.9	N-C	1.0
IE—Ireland	449.6	0.1	0%	183.6	91.8	N-C	4.0
IT—Italy	4969.6	33.1	6%	1907.3	953.7	S	57.2
LT—Lithuania	198.3	27.1	57%	75.6	37.8	N-C	1.6
LU—Luxembourg	172.9	2.0	6%	0.0	0.0	N-C	0.0

(continued)

Table 2.4 (continued)

	A	B	C	D	E	F	G
	Final total energy consumption [3] (PJ)	Total district heating networks sales [44] (PJ)	Percentage of citizens served by district heating [44, 45]	Maximum annual additional heat (PJ)	DHNs feasible potential (PJ)	Region	Conversion cost + DHNs cost [6] (annual cost of investment in milliards of €)
	2013	2013	2013	Vision	Vision		Vision
LV—Latvia	161.4	21.5	65%	5.0	2.5	N-C	0.2
MT—Malta	21.0	0.0	0%	11.5	5.8	S	0.4
NL—Netherlands	2141.8	26.1	4%	323.3	161.7	N-C	7.2
PL—Poland	2655.0	248.7	53%	1016.7	508.4	N-C	22.4
PT—Portugal	663.5	9.0	2%	245.9	123.0	S	7.4
RO—Romania	911.0	54.0	23%	308.9	155.0	N-C	6.8
SE—Sweden	1322.8	176.0	52%	115.2	57.6	N-C	2.6
SI—Slovenia	200.9	7.7	15%	42.5	21.3	N-C	1.0
SK—Slovakia	454.9	82.7	35%	0.0	0.0	N-C	0.0
UK—United Kingdom	5712.2	41.5	2%	1998.0	999.0	N-C	44.0
EU-28	46 214.5	1573.9	11.8%	12,827.9	6414.9		315.0

Source Adapted from [3, 6, 44, 45]

to this technology). A historical of the heat price provided by the district heating networks, the contribution of cogeneration to produce electricity, and the percentage of citizens who have access to district heating networks is presented in Figs. B-1, B-2, and B-3 in Appendix B section.

It is possible to see that the length of the pipes for transporting heat from the thermal power station located at Wilhelmshaven (757 MW) to the city of Oldenbourg is of more than 60 km and that this conversion would be feasible from an economic point of view. So it can be assumed conservatively that about 50% of all the electric power allocable to conventional thermal power plants is located within a reasonable distance to convert these plants in cogeneration plants [6]. This percentage has been obtained—from the database (E-PTR) [20]—after imposing as constraints that only will be valid for conversion to cogeneration plants those conventional thermal power plants with a rated output of over 300 MW placed at a distance of less than 75 km from towns of more than 100,000 inhabitants, which results in about 23% (this represents a 56% of the installed capacity of this technology) of all conventional thermal power plants not yet converted to cogeneration plants placed in the EU-28 (in 2013) to comply with these restrictions (see Table 2.5).

According to Table 2.4, if all potentially convertible thermal power plants, those with a rated power of over 300 MW located within 75 km of urban centers of more than 100,000 inhabitants, were converted into cogeneration plants and they would have access to district heating networks, about 6400 PJ of heat could be used, with a low carbon footprint, if an investment of some 315 billion euros will be made. After having consulted the database [20], it was found that in most countries, the limiting factor is, rather than lack of heat loads, the availability of thermal plants. However, in some locations, it was possible to observe the opposite, as groups of thermal power plants located relatively remote or at uneconomical distances to transport heat happened.

To get a clearer idea of the economic benefits of investing in district heating networks, let us assume that fuel consumption per unit of heat supplied is 1.1 in the case of boilers [21], being meanwhile 0.125 in the case of cogeneration plants [21]. Assuming that the cost of natural gas for domestic consumers was about 15 €/GJ for the second half of 2014 [22], yearly savings of 93.6 billion euros would be achieved only in fuel for an annual investment 315 billion euros.

Table 2.5 Conventional thermal power plants (not converted to cogeneration power plants) with a rated output of over 300 MW placed at a distance of less than 75 km from towns of more than 100,000 inhabitants

Number of conventional thermal plants (unconverted) near urban centers (distance <75 km and P > 300 MW)	Total conventional thermal power plants (unconverted) near urban centers (GWe)	Total number of conventional thermal power plants
393	246.5	1690

Source Database of E-PTR [20]

This estimate is only intended to give context about the treated magnitudes; in any case, it needs further evaluation case by case to debug this rough approximation; see [6]. It should be noted that, obviously, this amount is in itself an upper limit, which is subject to considerable uncertainty and that some of the conventional thermal plants that here have been supposed to be convertible eventually will not. However, if a greater commitment at the European level in promoting the joint use of district heating networks and cogeneration would be obtained, in the long term, it would be possible to approach the upper limit as new cogeneration power plants were built close to the thermal loads. Certainly, the barriers that the joint use of cogeneration and district heating faces are not technological but institutional and financial; see [23] to know these barriers in detail.

2.5 Discussion

As in most of the district heating networks of the member countries of the European Union that belonged to the former USSR and in the early stages as compared to the rest of the EU, it was common practice to use auxiliary boilers that only generated heat without there being at first a willingness to convert them into cogeneration plants [24–27]. Commonly, they used cheap or subsidised hydrocarbons [28] that had difficulties in burning [29]. With the passage of time, a number of auxiliary boilers from some cities were connected to other thermal generating plants that could use their reject heat. In Prague, what really triggered the connection of the Poříčí II power plant with the associated desulfurised emissions to the existing district heating network, even taking into account that the pipes carrying steam and hot water should have a length of about 40 km each one, was the realisation of the fact that there was a need to desulfurise emissions from plants that burned dirty fuels [30].

It might be thought that the joint use of cogeneration and district heating networks would only be profitable in the Northern European states due to their cooler climate and greater thermal requirements, rather than be consequently applicable to the rest of the EU-28. However, the fact that homes in these countries have better insulation has as a consequence that the specific thermal demands are lower (Fig. 2.7). Moreover, it is unlikely that the thermal loads in buildings will decrease so that the joint use of cogeneration and district heating networks becomes non-viable [31].

On the other hand, usual reductions of heat losses in buildings are not as high as expected in the first instance (the users to see an improvement in the efficiency of an energy service that leads to a reduction of the actual cost of the service tend to consume more, causing the known *rebound effect*) [32]. This effect, although difficult to quantify (but real), might result in a decrease in thermal load reductions of between 10 and 30% [32]. The vision of the not or, at least, modest changes in heat demand is based on forecasts conducted by each of the member states. As an example, it is presented the case of Ireland (Table 2.6), where it is possible to see

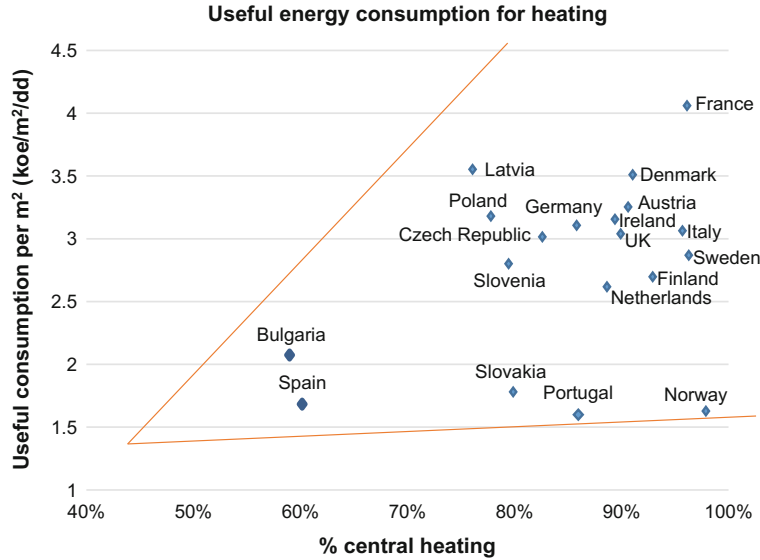


Fig. 2.7 Useful energy consumption for heating in equivalent kilograms of oil per m² and heating days with respect to the percentage of centralised heating for some EU member states [40]

Table 2.6 Thermal energy consumption by sector for Ireland (2008–2020) [33]

	Total final demand (ktoe)			Growth (%)	Average annual growth (%)			Sectoral shares (%)		
	2008	2012	2020	2008–2020	2008–2020	2008–2012	2012–2020	2008	2010	2020
End-use										
Industrial	139	148	150		0.6	1.5	0.2	2.5	2.8	2.6
Residential	44	43	41		−0.5	−0.5	−0.5	0.8	0.8	0.7
Services	15	14	14		−0.5	−1.0	−0.02	0.3	0.3	0.2
Total renewable energies	198	205	205	3.7	0.3	0.9	0.0			
Total consumption	5502	5209	5718	4.0	0.3	−1.3	1.2			
Heating from renewable energies								3.6	3.9	3.6

that for the period 2008–2020, it is expected to increase the thermal energy consumption by only a 0.3% [33], very much in line with other countries EU-28.

Furthermore, there are several reasons why it is easier to increase generation from renewable sources (particularly wind) than from cogeneration. In the EU-28, wind energy (along with hydroelectric power) is the dominant energy source from renewable origins [34, 35], being necessary in this case only that the promoter

locates a location and would obtain the various needed permits. Because there are usually many locations where to deploy a project, there are high chances that the same is carried out. By contrast, cogeneration is undoubtedly much more restricted because it inevitably has to be used in cities and industries—obviously, the difficulties associated with implementing a district heating network to an entire city are of a different order than those found in obtaining permission for implementing a wind farm.

The cogeneration plants are also subject to more restrictions than those plants that produce heat and electricity separately. This is because although the electricity is cheap and easy to transport over long distances (in Appendix C section it is possible to find additional information concerning large-scale heat transportation), heat needs to be generated locally and can only be transported to much shorter distances. Consequently, a heat-generating unit will always be connected to the end user; meanwhile, electricity will feed to the electric grid in general. In other words, the cogeneration plant will have to compete in the heat market with, for example, heat boilers or heat pumps, and in the electricity market with more flexible power plants [36].

Despite these restrictions, it is to be emphasised that a higher CHP and DHNs generalisation (and their associated thermal storage; see Appendix E section) is of vital importance in reducing overall energy consumption in the EU-28, which obviously will impact CO₂ emissions. This view has been the one that has enabled Denmark, along with increased energy requirements of buildings, to prevent an increase in its energy consumption over the last 30 years despite having experienced an increase of 70% of GDP during this period [37].

Literature findings are certainly inconclusive in what district heating networks and cogeneration potential are respected at a pan-European level. In fact, even though some studies have been undertaken for specific countries or regions, scientific literature has not given the same attention to the potential and the economic and environmental benefits resulting from the implementation of an energy strategy based on a massive increase of the joint use of district heating networks and cogeneration in the EU-28. As a result, and due to the aforementioned lack of attention, a comparison between this book and other scientific publications is, at least, problematic (in particular, and for Southern Europe countries, attention given has been virtually zero). However, it is possible to indicate that one of the main strengths of this book is that, by using a simple methodology, its approach and perspective provide both novel results for the scientific literature and new insights to the European Union as a whole about the true potential of this underexploited technology. Paradoxically, this strength of the simple methodology is at the same time a shortcoming due to inaccuracies in the district heating and cogeneration potential assessment, and further research on this issue would be interesting for refinement purposes. Finally, and as another research extension, it would be interesting to evaluate the applicability of other reject heat from other types of thermal power plants such as biomass and nuclear ones for district heating purposes.

2.6 Conclusions

About half of the installed electric capacity in the EU-28, from conventional thermal power plants, is located at an appropriate distance to be able to convert these plants into cogeneration plants and to use their wasted heat in district heating networks. Taking into account the maximum penetration that is economically feasible, from an annualised investment in infrastructures of 315 billion euros, the costs, assignable to fuel, would be reduced by 95 billion euros per year and would save about 6400 PJ of primary energy. This represents about 15% of the total final energy consumption in the EU-28 in 2013 (46 214.5 PJ). All these savings are achieved from a by-product, such as the waste heat from conventional power plants, currently not utilised in order to meet any thermal load due to their low temperature (about 30 °C). If the energy vision, proposed in this book, were implemented, it would quadruple (from 12 to 50%) the access of the citizens of the EU-28 to the technology of district heating networks.

This estimate has important political implications as a generalisation of the joint use of cogeneration plants to raise the aforementioned temperature, and district heating networks would entail some economic, environmental, and energy security benefits that are necessary for the fulfillment of the legal basis of the H2020 Societal Challenges “Secure, Clean, and Efficient Energy” in a sustainable way. It has been consequently justified that, definitely, the barriers that the proposed new vision face are not of a technological nor of an economic nature but are institutional and financial.

It is worth to remark the forecast that, if a policy, committed to the development of district heating networks and cogeneration, is obtained, it would imply that over the next decades more and more power plants will be built in proximity to thermal loads and decommission those located remotely. Finally, and as a possible research extension, it would be interesting to consider reject heat from other thermal power plants, such as biomass and nuclear ones. Even though the latter ones should be considered cautiously due to their typical locations (normally far from heat loads), rejected heat from nuclear power plants might represent a significant increase in the joint use of CHP and DHNs, as currently they represent about 30% of the electricity provided in the EU-28.

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Colmenar-Santos, A.; Borge Diez, D.; Rosales Asensio, E.

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