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Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level

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Abstract
Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level
This report details a methodology for performing a cost-benefit analysis (CBA) identifying the most resource and cost-efficient solutions to meet heating and cooling demands for a given country or region in accordance with Article 14(3) and taking in account Part 1 of Annex IX of the of the Energy Efficiency Directive (EED) (EC, 2012). The methodology includes guidelines how to: (1) collect data about energy consumption and supply points needed to construct heat maps, (2) how to identify system boundaries, (3) assess the technical potential that can be satisfied by efficient technical solutions, including high efficiency cogeneration, micro-cogeneration and efficient district-heating and cooling. (4) define baseline and alternative scenarios, including quantifying the cost and benefits of both scenarios. This comprises for example the economic value of other effects is estimated, mainly, the changes in socio-economic and environmental factors.
Cost-Benefit Analyses integrate all costs and benefits over a long period are integrated in a unique estimate, the Net Present Value, which provides information about the net change of welfare derived from the implementation of the different heating and cooling scenarios. In the end, the cost-benefit analyses shall provide information about which are the most cost-efficient solutions to meet the heating and cooling needs of a country or a region.

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Executive Summary

This report details a methodology for performing a cost-benefit analysis (CBA) identifying the most resource and cost-efficient solutions to meet heating and cooling demands for a given country or region in accordance with Article 14(3) and taking in account Part 1 of Annex IX of the of the Energy Efficiency Directive (EED) [1].

General guidance to Member States (MS) regarding the Comprehensive Assessment (CA) is presented in EED Annex VIII. Further guidance is presented in the Commission Staff Working Document (CSWD) [2], particularly Point 18. Note that the guidance provided in the CSWD is not legally binding, but is meant to help MSs to interpret the EED Art 14.

This report has been prepared to provide step by step guidance for completing a national-level CBA relevant to energy efficient heating and cooling. This report does not aim to replace any national or European level appraisal guidance. It aims to provide supplementary context for supporting purposes.

The proposed methodology sets out an example approach of how to implement the requirements of the EED. However, since the EED only specifies what the requirements are, and not how they should be met, Member States have a degree of flexibility in implementing the requirements. Depending on the availability of modelling tools and information available in each MS, other advanced approaches could be implemented in order to take into account more complex relations and dynamic aspects, e.g., the impact of different diffusion rates on technology cost.

It is not possible within this report to cover every single option open to Member States. Instead the report, drawing upon a review of the literature and the expertise of the authors, describes an approach of what might be considered good practice, using either detailed data and advanced energy system models or more simple data and energy system models.

As a first step of the CA, the heating and cooling demand of the country should be established with a sufficient level of detail. The heating and cooling demand should be subdivided into the main sectors of activity: industrial, agricultural, residential and service, and then further disaggregated into relevant sub-sectors and different end uses. Once the current demand has been identified, forecasts about its most foreseeable evolution have to be done.

A key feature of the methodology is the collection and processing of relevant data that will result in a heat map showing the location of heating and cooling demand as well as the location of potential supply points and district heating and cooling (DHC) infrastructure. Based on a sectorial and spatial description of demand and supply, the areas with sufficient heating/cooling demand for DHC deployment and potential supply sources, e.g. industrial waste heat, can be identified. These areas

will constitute the system boundaries. The system boundaries identified are the unit of analysis so they should be consistent for all aspects and following steps of the analysis.

Once the system boundaries have been identified, the next step consists of assessing the technical potential that implies identifying those elements of the heat demand that technically could be satisfied by efficient technical solutions, including high efficiency cogeneration, micro-cogeneration and efficient district-heating and cooling. The technical potential is assessed as the theoretical maximum amount of energy that could be produced with efficient heating and cooling solutions, disregarding all non-engineering constraints.

In order to conduct the cost-benefit analysis, different heating and cooling scenarios have to be defined. The analysis should consider at least two different scenarios:

• A baseline scenario, which includes a description of the current supply and its likely evolution over time to cover the forecasted demand assessed before. This would include information on how the demand is met at present and assumptions about how it will be met in the future based on current knowledge, technological development and policy measures. This scenario will be considered as a reference to estimate changes in relevant economic effects derived from other scenarios.

• Alternative scenarios, which are based on the technical potential identified before. It is proposed to construct alternative scenarios to cover as much demand as is technically possible by each of the efficient heating and cooling solutions identified during the technical potential identification. So, each scenario will be built to evaluate the effects of expanding each technical solution to their maximum extent, i.e. taking into account its technical potential.

Once the baseline and the alternative scenarios for each system boundary are defined, the relevant effects need to be quantified and monetised, in terms of costs and benefits, for each scenario. Quantifying the cost and benefits in both scenarios is required to assess the changes in cost and benefits between baseline and an alternative scenario. There are different categories of costs and benefits: on the side of the costs, for example capital and operating costs of equipment, as well as fuel costs have to be accounted for. Additionally, the economic value of other effects have to be estimated, mainly, the changes in socio-economic and environmental factors. All costs and benefits over a long period will be integrated in a unique estimate, the Net Present Value, which provides information about the net change of welfare derived from the implementation of the different heating and cooling scenarios. Once the effects have been quantified and valued in economic terms, those parts of the technical potential that provide positive NPV, when compared to the baseline scenario, indicate that they are cost-effective and so constitute the economic potential of those technical solutions identified. Once the economic potentials have been estimated, the cost-benefit

analysis is further used in order to identify the combination of solutions that provides the most cost-efficient way of supplying heating and cooling needs. Additionally, a sensitivity analysis will be performed to assess the how particular parameters influence the results.

In the end, the cost-benefit analyses shall provide information about which are the most cost-efficient solutions to meet the heating and cooling needs.

A generalized scheme of the proposed methodology for preparing the CA is presented in Figure 1.
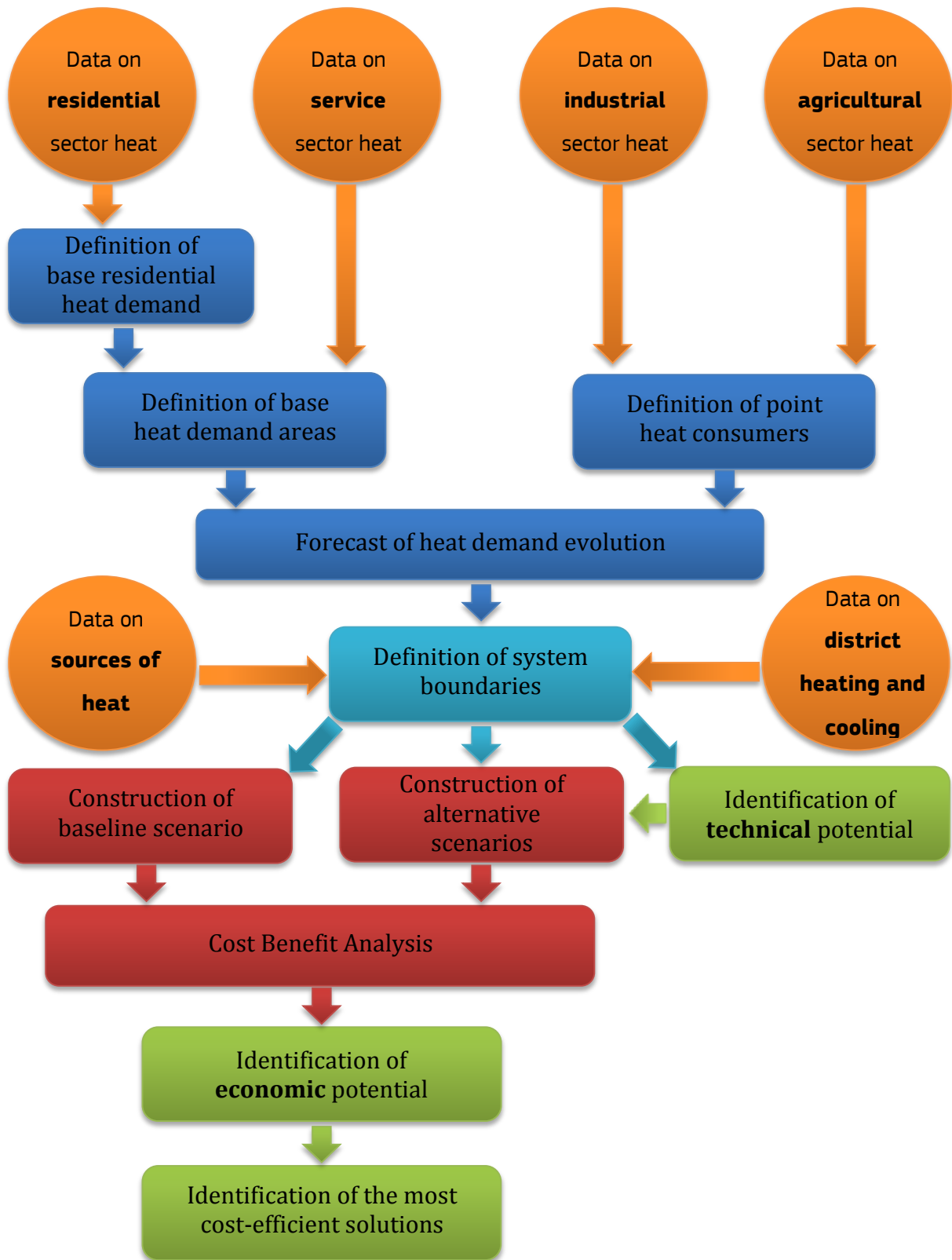
Figure 1. Generalized scheme of proposed methodology for preparation of CA.

List of abbreviations

BAU	Business As Usual
CA	Comprehensive assessment of national heating and cooling potentials
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CDD	Cooling Degree Days
CHP	Combined heat and power
COP	Coefficient of Performance
CPI	Current Policy Initiatives
CSWD	Commission Staff Working Document
DHC	District Heating and Cooling
EED	Energy Efficiency Directive
EU-ETS	European Union Energy Trading Scheme
GDP	Gross Domestic Product
GHG	Green House Gases
HDD	Heating Degree Days
LAU	Local Administrative Units
MS	Member states
NPV	Net Present Value
O&M	Operation and Maintenance
NUTS	Nomenclature of Units for Territorial Statistics
SHW	Sanitary Hot Water

List of definitions

Baseline scenario

Assumed evolution of heating and cooling system taking into consideration existing technical or policy measures and their most likely developments without the intervention of new policies

Alternative scenario

Possible evolution of heating and cooling system to be compared to the baseline scenario, where selected technologies are implemented

Base heat demand area

Smallest division of country territory for which a bottom-up assessment of the heat demand can be made (e.g. based on demographic data, energy data ...), e.g. a neighbourhood or postal code.

System boundary

Part of country territory, encompassing one or more base heat demand areas and heat source(s), used as an object for the Cost-Benefit Analysis

Heat linking

Operation of matching available heat supply with existing heating/cooling demand based on defined set of technical criteria, e.g. threshold distances, capacities, etc.

Technical potential

The amount of demand (measured in terms of useful energy, MWh/a) that could be covered by the technology solution or energy resource being evaluated, considering its maximum achievable penetration within the considered timeframe, considering technical or practical limitations, including topographic limitations, environmental, and land-use constraints, without taking into consideration economic criteria.. It can also be expressed in terms of the corresponding installed capacity of the technology (MW).

Economic potential

Economic potential is the subset of technical potential that is economically cost-effective as compared to conventional supply-side energy resources. The economic potential can be expressed in both (MWh/a) and (MW).

Cost-efficient potential

The cost-efficient potential is the contribution of a technical solution to the combination of solutions that provides the most cost-efficient way of supplying heating and cooling needs with efficient solutions. The economic potential can be expressed in both (MWh/a) and (MW).

Energy demand

Amount of useful energy required to satisfy end-users needs (e.g. heating/cooling needs) (MWh)

Energy consumption

Amount of energy effectively used to satisfy the demand, including,

	where appropriate, transformation, transport and distribution losses (MWh).
Primary energy	Energy in the form as it is found in the nature i.e. before transformation, transport or distribution (MWh). When calculating primary energy consumption, conventional rules are used for the non-fossil energy sources (e.g. renewables).
Final (or secondary) energy	Energy supplied to the end-user's door (MWh), including energy from renewable energy sources produced and consumed locally by the end-user.
Useful energy	Energy available to the end-users (e.g. heating, cooling) after the last conversion made in the end-user energy conversion equipment, hence final energy consumption minus conversion losses (MWh).
Peak load	The highest power/heat capacity required (MW)
Average load	Typical power/heat capacity required (MW)
Plot ratio	Ratio of useful floor area of buildings to the size of piece of land upon which they are built (including the empty space between and around those buildings e.g. gardens, roads, parking …)
Local Administrative Units (LAU)	Set up by Eurostat in order to provide statistical information on local level. LAU system comprises two levels, of which LAU-2 represents smallest territorial units. LAU-2 is usually the size of a municipality.
Nomenclature of Territorial Units for Statistics (NUTS)	A hierarchical system of subdivision of EU countries for different purposes, such as economic or statistical analysis of the regions. Currently there are 3 levels of NUTS regions, of which NUTS-3 represent smallest regions. This standard of area division is regulated by Eurostat and detailed information on it can be found on Eurostat web page
Specific heat consumption	Heat consumption per year and square meter (kWh/m²·a)
Heating Degree Days (HDD)	The number of degrees that a day's average temperature is below the temperature at which buildings need to be heated (e.g. below 18˚C).
Cooling Degree Days (CDD)	The number of degrees that a day's average temperature is above the temperature at which buildings need to be cooled (e.g. above 22˚C).
Efficiency	Useful energy generated per primary energy input, e.g. by a boiler (%)
Thermal efficiency	Heat generated (not for electricity) per primary energy input from

(for CHP)	Cogeneration plant (%)
Electrical efficiency (for CHP)	Electricity generated per primary energy input for Cogeneration plant (%)
Power to heat ratio	Ratio of power produced to heat for cogeneration plant
Coefficient Of Performance (COP)	Measure of efficiency of heat pumps. Ratio between heat/cold produced to electricity consumed
Technical lifetime	Period of time during which component or system can technically function before it must be replaced [hours or years]

1. Determining current and future heating and cooling demand, as well as the production and energy infrastructure

This chapter presents how the current and future heating and cooling demand for the purpose of the CA can be established. It covers the data collection and processing. It also covers energy generation and its possible future developments.

The accuracy and relevance of the CA results will depend on the quality of the data and models that are used to represent the heating cooling demand. Therefore, this chapter is of particular importance.

1.1 Description of the heating and cooling demand

The CSWD (18) states that: "The description of the heat demand should relate to real, i.e. measured and verified, consumption information as provided in national and European energy statistics and national energy balances. It should be provided in a detailed sectoral and geographical break down, and in any case not less detailed than in relevant European energy statistics. It should provide information about the consumption of the industrial, services, agricultural and household sectors. The description of heat demand should be based on the latest available data."

The CSWD (33) further states that "… a key to a successful cost-benefit analysis, is to describe the heat and cooling demand within the geographical boundary as precisely as possible. The collection of accurate, reliable and comprehensive heat and cooling data may be a challenge but is necessary if a Member State is to ensure high quality cost-benefit analyses and a sound decision base for the comprehensive assessment. "

The CSWD (18) points out a key element of the description of the heat demand:

- The geographical break down refers to being able to locate the main components of the heating/cooling demand. The need for geographical segmentation stems from the fact that one of the main objectives of the CA/CBA is to identify existing or future sources of waste heat that could potentially satisfy current or future heat demand, and in which areas DHC networks could be developed. This requires knowledge of the location of the main heating/cooling users and potential suppliers. Also, the geographical break down is useful when the various sectors and sub-sectors face different realities geographically, e.g. different climatic zones within a country. This will be also addressed in Chapter 3 (geographical and system boundaries).
- Sectoral break down refers to breaking down the heat demand into relevant sub-elements. For the industry it could be different industrial sub-sectors, for the residential sector it could relate to different types of buildings that are representative of the building stock in the country, etc.

- Energy use break-down refers to the need to collect data about energy use to cover heating, cooling and hot water preparation needs.

A description of the heating and cooling demand with a sufficient level of detail is essential for a proper execution of the CBA. Let us use as an example the assessment of cogeneration implementation in a residential area. Simply knowing energy consumption and the number of inhabitants concerned would not provide accurate results. It would be necessary to have a picture of the building stock too. For instance knowing the number of individual houses and their typical energy demand would allow determining the number and size of the required micro-cogeneration units, while knowing the number of larger apartment buildings would allow determining the number and size of the needed larger cogeneration units. From there other data useful for the CBA can be derived, e.g. cost of the equipment.

- There is no unique way to perform the break-down. The definition/choice of the sub-sectors depends on:
  - The realities of the sectors in the considered country or region;
  - The availability and reliability of data.

A proper break-down of the demand entails significant data requirements. It will often require the combination of different data sets, a mix of top-down and bottom-up approaches, and the use of a certain number of hypotheses. It is not necessary to possess individual data for every building or every small industrial plant. The purpose is to create a model, or a representation of the demand that is sufficiently close to the reality. Such models may have different degrees of complexity (from rather simple to rather elaborated) and different levels of accuracy (very accurate, based on extensive data, or less accurate where existing data is supplemented by means of several hypothesis). Typically such a model could entail the following steps:

1. Determine what are the relevant sub-sectors into which the demand shall be split, e.g. the country's main industrial activities, or representative categories of buildings;
2. Determine their characteristics, e.g. typical heat demand;
3. Establishing the geographical break down: how many units of each category there are, and where they are located;
4. Make sure that the total heat/cooling demand is properly split between the sub-sectors and the geographical locations.

When available data allows an intimate knowledge of the considered sector, a refined break-down can be achieved, making the CBA more relevant and accurate. When such data is not available, supplementary data can be collected or a suitable hypothesis would have to be established, based on the best knowledge available.

The following sub-sections illustrate how the required data can be collected.

1.2 Overview of the steps required for data collection

Before starting the execution of the CA, it should be determined at which level of detail that heat and cooling supply and demand data can be collected. MS have different systems for gathering statistical data on energy consumption with various levels of detail. This in turn will influence the range of possible methods that can be applied during the preparation of the CA. This chapter provides an overview of the kind of data that needs to be collected. Greater details are provided in the chapters that follow.

The CA will include different types of energy consumers with different properties. They can be divided into two major groups:

- Dispersed consumers consist of a large number of small consumers for which it is neither practical nor necessary to collect and use the individual data, for example in the case of small residential and service buildings. These consumers will be treated as dispersed energy consumers because their energy demand is primarily for space heating/cooling, which is mainly characterised by their heated/cooled building area. The collected data on consumption will be aggregated into demand areas and used in the CBA based on their collective heating and cooling demand and other characteristics.

- Point consumers consist of large individual consumers, mainly industrial and agricultural energy consumers for which the individual data can be determined. Their energy consumption is mainly influenced by the needs of industrial processes. Their energy demand location can easily be pinpointed. Point consumers can be included into the CBA individually as heating/cooling demand points or be grouped with demand areas.

For the identified heating and cooling consumers, a number of data should be collected, e.g. annual heating/cooling demands, peak loads, typical loads, seasonal variations in heating/cooling demands.

If directly derived energy consumption data is unavailable, indirectly derived data will have to be used. These could be based on population number in a territorial unit, energy consumption per capita, heated area of buildings per capita and so on. This methodology presents how this can be done, see Section 1.3.

After gathering information on energy consumers, the next step consists of gathering data on all potential sources of energy supply, i.e. heating/cooling generation and distribution installations, renewable sources that are locally available, such as geothermal, or waste heat sources from industrial clusters and plants, primary energy supply sources. Data on related infrastructures should also be collected, such as district heating networks and gas grids.

Gathered data on heating/cooling demand areas and points, heat and other energy distribution infrastructure as well as potential waste heat suppliers will have to be included into a heat map of the MS territory. The heat map is a visual representation of data related to energy generation, supply and consumption on geographical map of given territory. The heat map and the underlying data will be used to facilitate the construction of the baseline and alternative scenarios as well as determining which consumers could be served by district heating/cooling and available waste heat sources. For these reasons, locational information of consumers is also required. For further details on construction of heat maps, see the JRC report called 'Background report providing guidance on tools and methods for the preparation of public heat map'.

1.3   Data on energy consumption

This section presents different aspects of data collection on heating and cooling consumers. It is necessary to collect data for different heating/cooling consumer groups or sectors, including:

1.   Industry;
2.   Agriculture;
3.   Residential (households);
4.   Service.

In order to achieve higher accuracy, these four sectors would have to be broken down into sub-sectors. For instance, by separating apartment buildings and detached single family houses we may take into account the fact that in general flats in apartment building consume less heating than detached single family houses. Moreover, the technical feasibility and the economic viability of the technologies to be considered in the context of the CA/CBA may vary greatly for heat consumers of different sub-sectors. Therefore, the break-down of the heat demand will facilitate making viable estimates about the applicability and economic viability of those technologies. For some countries information on heat consumer sub-sectors might be readily available, but for some it might only be estimated based on different combinations of statistical data and necessary assumptions.

Data on energy production and consumption might be acquired from national statistical organizations such as Statistic Austria, Central Bureau voor de Statistiek (Netherlands), or Statistics Lithuania, etc. as well as energy, environmental, statistical, or economic ministries or agencies, or regulatory authorities for gas and electricity markets. Other options are the European Commission's Statistical Pocketbook 2014 [3][1] and databases of Eurostat.

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[1] http://ec.europa.eu/energy/publications/doc/2014_pocketbook.pdf

The Statistical Pocketbook [3] p. 80 includes data on the final energy consumption in different MSs and its evolution between 1995 and 2012. The data for 2012 can be found in the tables on p. 81 according to sectors and different fuels (electricity is also included).

The first step would be to describe the final energy consumption on country scale. The main sectors, namely industry, agriculture, households and services should be reflected here and their geographical location and topography identified. The transport sector should be omitted unless it is directly related with the subject matter of EED, e.g. space heating of buildings offering/managing transport services and if not included in other sectors like the service sector.

1.3.1 Industry and agriculture

As mentioned above, large heating and cooling consumers of industry and agriculture are treated as point energy consumers. The sources of information on industrial and agricultural heating and cooling consumers might include national registries or data sets acquired from current energy and fuel suppliers. If such information is not readily available, it can be considered to distribute inquiries to identified energy consumers, either individually or through corresponding associations. Only industrial points/zones with total annual heating and cooling consumption of more than 20 GWh/a should be included into the heat map, as specified in Annex VIII [1] (c)(i) of EED; however, for the purposes of the CBA it is recommended to gather data about industrial points/zones that have lower consumption too.

For industrial zones it is necessary to collect data on heating and cooling demand, which should include at least the following information:

1. Geographical location of industrial or agricultural zones. Large industrial zones might have a number of concentrated areas of energy consumption and energy generation plants inside of them, e.g. such as production lines, buildings etc., separated by significant distance or displaying different patterns of energy consumption. In such cases, a logical approach would be to identify such consumption points separately. If this should prove unreasonable or too complicated to do, due to unavailability of proper data or for other reasons, the industrial zone can be represented during CBA as a single entity.

2. Heating and cooling demand of an industrial zone as a unity, as well as its separate demand points, if that will be deemed necessary. Such data should include maximum and average load (in kW, MW or similar units) as well as energy consumption data (in MWh/a, GWh/a or similar units).

3. Requirement for the quality of heat (temperature, phase (water or steam), is it required for heating of buildings or for industrial process, etc.).

4. Sub-sector to which a particular industrial or agricultural installation belongs to. For instance, industrial plants might be divided according to the key industrial activities present in the country, e.g. cement industry, pulp and paper, metallurgy.

5. Further break-down is desirable by economic activity, e.g. food or glass manufacturing etc., by size and amount of energy consumption, in order to distinguish for example large industrial plants and small industrial plants, energy intensive and energy non-intensive industry, etc.

6. Description of how heating and cooling demand is satisfied currently. It should be identified what kind of heating/cooling source and fuel is used, e.g. CHP unit, natural gas individual boiler, renewables.

Data on heating and cooling demand of agricultural complexes should include similar level of detail as in the case of industrial consumers. Only agricultural complexes with significant energy consumption, such as greenhouse clusters need to be considered.

The collected data can be organised as presented in Table 1.

Table 1. Example of possible data table for industrial and agricultural consumers.

N o.	Geographic location	Heating load (maximum/ average), MW	Cooling load (maximum/ average), MW	Annual demand of heat, GWh/a	Annual demand of cooling, GWh/a	Quality of heat required	Sub-sector to which consumer might be attributed	Current source of heating
1								
2								
3								

Improving level of detail of CA: organizers of CA can collect data about the patterns in heating and cooling use and availability such as daily or seasonal variations for more precise matching with possible sources of waste heat as described in other chapters of this methodology. If possible, it is advised to collect data on average monthly, or even more detailed, distribution of energy demand and supply, because it will contribute to better matching of energy generation and consumption points in later stages of CA. For instance, it would make a CHP plant much more efficient if is located near a residential district, which normally demands more energy in the cold season, while there would also be an industrial plant with higher energy demand during the warm season, thus levelling average demand during the whole year.

Heating and cooling demand (separated) patterns can be expressed in different ways depending on the chosen level of detail. A simplified approach could be attribution of given heating or cooling consumer or supplier to one of the following categories, identifying if their supply or demand pattern is:

1. Roughly constant throughout the year;
2. Predominant during cold season;
3. Predominant during warm season;
4. Variable (there is no systematic pattern);
5. Pattern unknown.

If a nearby consumer would be of (ii) category and a supplier of (i) or (ii) category, they could be investigated for potential of heat linking. If, in contrast, supplier would be of other categories, the potential for heat linking might be limited, but for the last two categories more data would be required to make a definitive conclusion.

Similar approach could be applied for description of consumption/supply patterns during the day, if such level of detail is deemed necessary.

1.3.2 Residential consumers

Residential consumers or households are treated as distributed energy consumers and are included into the CA as parts of particular heat demand areas and not as individual points. An important parameter for heat demand areas is the plot ratio. The plot ratio, employed in Annex IX of EED, is a factor often used to identify the feasibility of installing district heating systems or efficiency of their layout. It is defined as the ratio of useful (heated) floor area of buildings to the land area where the buildings are situated:

$$Plot\ ratio = \frac{Useful\ floor\ area\ of\ buildings, m^2}{Land\ area\ of\ territory\ where\ buildings\ are\ situated, m^2} \qquad (1)$$

The denominator of this equation includes not only land area beneath the buildings but also the area of empty land between buildings.

Improving level of detail of CA: although Annex VIII of EED refers to the plot ratio, there are other parameters fulfilling the same purpose, some of them are briefly described in Footnote 24 on p.8 of CSWD. For instance, commercial viability of district heating networks might be expressed in terms of heat density of an area (in kWh/m²/a or similar units). The heat density is an indicator

that complements the plot ratio indicator and it is desirable to use the two indicators in combination because they provide somewhat different information thus allowing making better decisions on feasibility of district heating and cooling implementation (see Section 2.2 for more information).

The plot ratio and heat density will be used in further stages of the CA to determine whether a particular demand area can be incorporated in a DHC network.

An essential step during the definition of residential heat demand areas to be used as objects of the CBA is to divide the MS territory into properly sized pieces, which will be further referred to as *base residential heat demand areas*. This allows making a correct calculation of plot ratios and is the basis for establishing heat densities. As a general rule, a base residential heat demand area should be the smallest territorial unit of a country for which reliable energy estimates can be elaborated, for example based on population data or other relevant data sources.

In order to make a reasonably correct calculation of plot ratios of demand areas, the size of territorial units used should not exceed 1.0 km². Generally, the smaller the size of territorial division, the less adjustments and assumptions will be needed.

A logical approach for a division of a country's territory could be to use a well-established system of territorial division of the country, for instance, Local Administrative Units (LAU). The most detailed of them is LAU-2[2] level, which in most countries corresponds to municipality level, although the definition and size of these territorial units may vary greatly on country by country basis.

Although LAU-2 regions are of much smaller size than NUTS-3[3] regions, in many cases they might still be too large to make a proper assessment of the heating and cooling demand based on the plot ratio threshold. In some countries LAU-2 regions can comprise large areas, consisting of a number of settlements, have very different area composition and also include agricultural or recreational land.

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[2] System of Local Administrative Units has been set up by Eurostat in order to provide statistical information on local level. LAU system comprises two levels, of which LAU-2 represents smallest territorial units. More information on these systems of MS subdivision can be found on the Eurostat web page.LAU-2 is usually the size of a municipality. LAU-2 was previously referred to as NUTS 5 level.

[3] The Nomenclature of Territorial Units for Statistics is a hierarchical system of subdivision of EU countries for different purposes, such as economic or statistical analysis of the regions. Currently there are 3 levels of NUTS regions, of which NUTS-3 represent smallest regions. This standard of area division is regulated by Eurostat and detailed information on it can be found on Eurostat web page http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

Therefore the need for further subdivision of LAU-2 regions might be necessary. MS often have various systems of finer territorial division, such as postcode districts or neighbourhoods.

After deciding which territorial division of a country that is to be used as a base residential heat demand area, it is necessary to gather data about population count, land area and other parameters of each such heat demand area.

Statistical data for different territorial units is available from many sources, for instance the Eurostat data bases[4] or data bases of national statistical organizations. Usually the information available, among others, comprises population number and land area of a particular territorial unit. Usually national databases contain detailed data, down to LAU-2 regions and in most cases detailed data can be found for separate settlements. Countries with an established system of fine territorial division, such as neighbourhoods or postcode districts, usually have statistical data available for them as well.

If available, data collected should preferably contain information about total annual energy consumption, total heated/cooled area of buildings, total number of buildings, etc. per each base heat demand area. Such information would make the estimation of plot ratio and energy density more accurate. If such information would be unavailable, then the average heated floor area of buildings per capita will be needed to finalize the estimation of plot ratio of base residential heat demand areas. It is usually collected by national statistical organizations and is presented in their web sites. Other sources of information might be dedicated projects, reports and articles, for instance ENTRANZE project web site[5]. Here information related with their country on average floor area per capita can be found. It comprises not only residential buildings, but also service sector buildings.

An example of neighbourhood system used in the Netherlands is presented in Example 2.

EXAMPLE 2 Case of Netherlands
In Netherlands LAU-2 territorial units are called gemeenten (municipalities). They are further subdivided into wijken (districts) and wijken into so-called buurten, which can be translated as neighbourhoods. Highly detailed statistical information about LAU-2 units is published every two years by national statistical organization of Netherlands Centraal Bureau voor de Statistiek (CBS). The latest

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[4] http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/local_administrative_units

[5] http://www.entranze.enerdata.eu/average-floor-area-per-capita.html

available iteration was published in 2011[6]. As an example the Alkmaar municipality [4] is discussed here. A map of this municipality with division into neighbourhoods is presented in Figure 2.
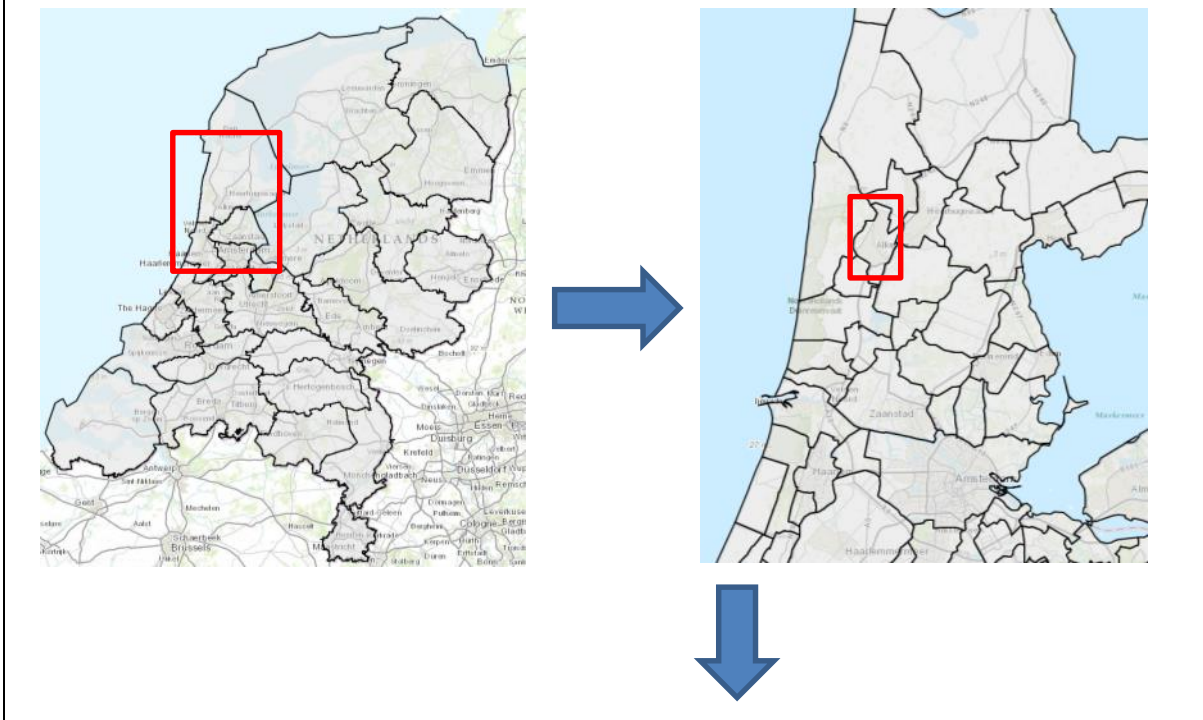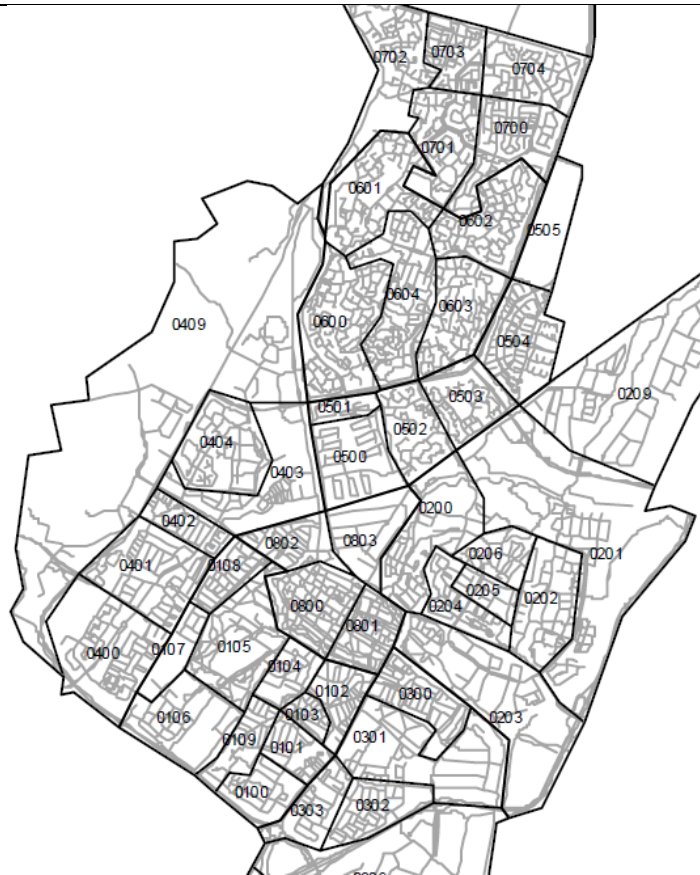
Figure 2. Map of Alkmaar municipality in Netherlands divided into neighbourhoods (source ETRI ArcGIS maps and [4]).

Data in the [4] report shows, that for instance, neighbourhood 0402 has a population of 1410 and its land area is 19 ha (190 000 m²). Information, presented in ENTRANZE project website suggests that combined average floor area of residential and service buildings in Netherlands is 56 m²/capita. Then the total floor area of buildings in this neighbourhood can be estimated as 1410 x 56 = 78960 m². Further, the plot ratio can be calculated as follows: 78960/190 000 = 0.416. The resulting plot ratio is higher than the threshold of 0.3 and thus this neighbourhood has to be considered for district heating and cooling.

Out of 51 neighbourhoods, presented in Figure 2, 32 have plot ratios higher than the threshold of 0.3 and should be further analysed for district heating and cooling.

A map with such neighbourhoods is presented in Figure 3.

It is worth noting that if the whole territory of Alkmaar municipality would be used as one entity for the calculation of plot ratio, the resulting plot ratio would be 0.18, which is below the threshold of 0.3.

28
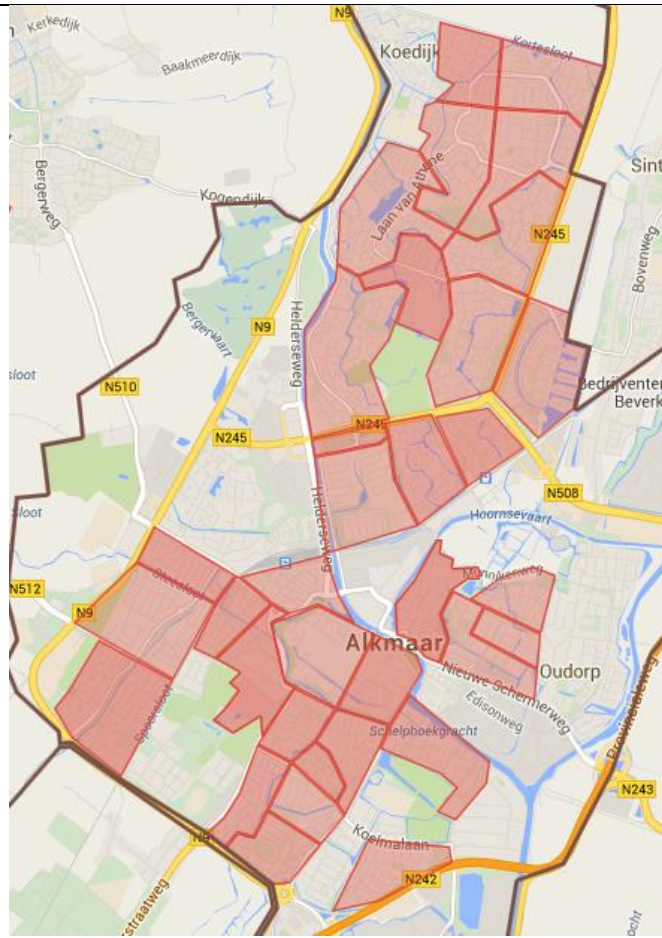
Figure 3. Areas of Alkmaar municipality with plot ratio exceeding 0.3 (Source of background map is Google Maps).

The next step is to establish the sub-sectors of residential buildings in each base heat demand area. The reasonable number of categories might be different from country to country due to regional particularities and building traditions. In general, the number of categories should reflect the number of building types with significantly different energy consumption characteristics or different applicability of heating technologies. For instance, residential sector might be subdivided into detached single-family houses, terraced houses and multi-family apartment buildings.

These building types are characterized by different specific annual demand of heat (kWh/m²·a). Such data might be available in data bases of national statistical organizations or in other relevant sources. For instance, energy performance of different age buildings can be obtained from TABULA WebTool[7]. Here data on energy demand for heating of typical buildings based on year of their

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[7] http://webtool.building-typology.eu/webtool/tabula.html

construction, type and climatic region and possible energy savings after renovation can be found. Currently data from 13 MS is published there. To use of neighbouring countries' data can be considered if a MS is not included in this web tool.

Another parameter needed would be the average heated area of buildings, belonging to different sub-sectors.

Heat demand of buildings belonging to a particular sub-sector located in given base heat demand area might be calculated by multiplying the number of buildings of a sub-sector by their average heated area and by their specific energy demand. Then the total heat demand of residential buildings can be established by adding the heat demand of all sub-sectors.

In case detailed energy performance of different sub-sectors of buildings would not be available, heating and cooling demand can be established using alternative methods, as described below. Establishing the consumption of thermal energy for space heating and domestic hot water preparation as well as electricity consumption in cooling equipment might be established based on population count of each base heat demand area. The data on electricity consumption would be used to estimate current demand of cooling in terms of corresponding thermal energy. Relevant data may be found in databases of national statistical organizations or other authorities (national/regional energy agencies). Here energy consumption according to the energy vector and according to end use can be found (space heating, cooking, lighting, etc.), e.g. national or regional energy balances.

Improving level of detail: an additional important source of information might be the energy distributors or retail energy sales companies as mentioned in Article 7(8) of the EED. According to that article extensive information on final customers' consumption can be requested from obliged parties. Enforcing the use of this article might be beyond the competence of the organizers of the CA, but this possibility can be discussed with national authorities.

Sometimes finding proper data for small base heat demand areas, such as neighbourhoods, might prove very difficult. In such a case data might be gathered for higher level territorial units such as NUTS-3 or LAU-2 regions and then divided among neighbourhoods located in such regions based on their population number.

EXAMPLE 3 Estimating distribution of energy consumption in households
Let's assume that during the collection of data it was established that final energy consumption in households of LAU-2(1) region in 2012 was 15.4 ktoe/a. Further data collection revealed that in 2009 the consumption of energy in all households of NUTS-3(1) region, to which region LAU-2(1) belongs, could be broken down as follows: 1. Space heating: 70.7 %; 2. Preparation of domestic hot water: 10.4 %; 3. Cooking: 7.2 %; 4. Lighting and electrical appliances: 11.7 %. Data for subsequent years is unavailable but no changes in policy or energy supply, which would alter distribution pattern significantly, have been observed. Also, there is no statistical information available about distribution of consumption in the LAU-2(1) region under consideration. Due to those reasons it might be necessary to assume that the pattern of heat consumption remained the same as in 2012 and that the pattern of energy consumption distribution is the same in all the LAU-2 regions of NUTS-3(1) region. This might not always be the case, therefore some corrections can be made, for instance, if the region has milder climate and therefore households need less energy for space heating but possibly more energy for air cooling. Based on these assumptions we can calculate that the distribution of energy consumption in households of LAU-2(1) region is as follows: 1. Space heating: 10.9 ktoe/a (70.7 %); 2. Preparation of domestic hot water: 1.6 ktoe/a (10.4 %); 3. Cooking: 1.1 ktoe/a (7.2 %); 4. Lighting and electrical appliances: 1.8 ktoe/a (11.7 %). LAU-2(1) region consists of 3 neighbourhoods: 1101 (8500 residents), 1102 (6000 residents) and 1103 (5500 residents). By dividing heat consumption among these 3 neighbourhoods based on their population number, we can derive, that in neighbourhood 1101 energy consumption distribution is as follows: 1. Space heating: 4.6 ktoe/a; 2. Preparation of domestic hot water: 0.7 ktoe/a; 3. Cooking: 0.5 ktoe/a; 4. Lighting and electrical appliances: 0.8 ktoe/a. Total: 6.6 ktoe/a.

Be aware of the fact that the figures on energy consumption for space heating and preparation of domestic hot water, presented in statistical data bases, may contain not only heat but also a share

of electricity. When establishing space heat demand data, the technologies used to produce this heat in the particular geographical zones needs to be taken into account. A part of this electricity may be used for powering auxiliary equipment, such as pumps and another part might be used for space heating, either directly (in electrical heaters) or indirectly (for instance, in heat pumps). Statistical data, presented in p. 11 of Report on Odyssee Mure Project website [5][8] suggests that electricity consumption for space heating might be significantly higher in some countries, e.g. instance Nordic countries and France, than in the other. It should also be noted that this particular report deals with all building types, not just residential, but the trends in residential sector seem to be similar, see report entitled Energy Efficiency Trends for Households [6] on the same web site.

Energy used for cooking should be excluded from further analysis since it is beyond subject matter of EED. Space heating and preparation of domestic hot water are two components, which together contribute to the heat demand and as such will be used during the construction of the heat map, see accompanying EC report 'Background report providing guidance on tools and methods for the preparation of the heat maps'.

The fourth component from the example above, named "Lighting and electrical appliances" usually includes only electrical energy and consists of power used in lighting devices, household appliances and air cooling equipment, of which only the third component (electricity consumption for cooling equipment) is important to establish in the context of the CA. In case reliable statistical information about current power consumption in cooling devices would prove impossible to obtain, an approximation might be employed, see description below.

It might be assumed that currently cooling demand of buildings is covered by conventional electrical air conditioning units. Such an assumption is usually valid for residential buildings. Therefore, a part of the overall electrical energy consumption might be directly connected to the cooling demand. Residential buildings use air conditioning in noticeable quantities only in some EU states, mostly located in warmer climate zones. Information may be extracted from the Odyssee Mure Project web site, especially p.27 of the report on Energy Efficiency Trends for Households in the EU [6][9]. Referring to Example 3, if the LAU-2(1) region would be located, for instance, in Malta, then data on p. 27 of this report says that approx. 23.7 % of electricity, consumed by households, would be used for cooling.

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[8] http://www.odyssee-mure.eu/publications/efficiency-by-sector/buildings/

[9] http://www.odyssee-mure.eu/publications/efficiency-by-sector/household/household-eu.pdf

EXAMPLE 4 Calculation of specific energy demand

During the initial stages of data collection it was established that the consumption of final energy in households of region LAU-2(1) is equal to (see Example 3):

1. Space heating: 10.9 ktoe/a;

2. Preparation of domestic hot water: 1.6 ktoe/a;

3. Cooking: 1.1 ktoe/a;

4. Lighting and electrical appliances: 1.8 ktoe/a.

It was also mentioned that cooking is a special case of energy consumption which falls out of the scope of EED and is to be removed from further analysis in the CA.

It was also established that in this region heat pumps or other electrical heating devices are not widely used for space heating and therefore it may be assumed that the first two parts of the energy consumption are mainly made of final thermal energy and total consumption in households of region LAU-2(1) is equal to 10.9+1.6=12.5 ktoe/a (which equals to 145 GWh/a).

We also assume that efficiency of combustion devices is equal to 0.9. Thus total useful energy demand is equal to 145 GWh/a*0.9 = 130.5 GWh/a.

Since the population count in this region is 20 000 people, then the specific heat demand (benchmark) is 130.5 GWh/a / 20 000 people = 0.0065 GWh/person·a = 6.5 MWh/person·a.

The fourth share of consumption incorporates electricity used for cooling. In p.27 of report Energy Efficiency Trends for Households in the EU it can be found that in the country where this region is located 20 % of electricity in households is consumed for cooling purposes, thus giving us 1.8 ktoe/a x 0.2 = 0.36 ktoe/a (4.2 GWh/a). By assuming a coefficient of performance (COP) of air conditioning units of 2.6 one may obtain useful cooling demand in households of region NUTS-3(1): 4.2 x 2.6 = 10.9 GWh/a.*

Specific cooling demand can be calculated as follows: 12.6 GWh/a / 20 000 people = 0.63 MWh/person·a.

Electricity driven vapour compression cooling machines can displace more thermal energy than they consume electricity. This is expressed by the coefficient of performance (COP) of heat pump. Hence the need to calculate not only final electricity consumption for cooling but also useful cooling demand, i.e. the amount of thermal energy that is transferred during cooling process using this electricity amount.

Another way of establishing cooling demand might be to use representative surveys of the housing stock. Selected buildings, representing different sub-sectors, could be examined in detail by direct examination or distribution of questionnaires to residents. The results of such surveys could be used to estimate energy demand for cooling in different sub-sectors and in the whole residential sector.

In case such surveys would be difficult to perform, scientific literature and different project outcomes might be consulted for relevant information. For instance, the report [7][10] might be consulted for values on heating and cooling energy demand for different building types in selected European countries. That report contains information about energy demand for heating and cooling in single houses, apartment blocks, offices and schools of 10 cities, located in 8 EU countries representing different geographical regions. Other reports contain data on average space cooling consumption in different EU countries [8].

Important information, which will be needed for the CBA analyses of this methodology, is the way heating and cooling are generated for distributed energy consumers at present. Fuels and technologies used in a given territory can be represented in percentages. If such data would not be available, then at least the prevailing fuel used or equipment employed in particular area should be identified. The data for heating and cooling demand can be collected in data tables as presented in Table 2.

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[10]

http://www.entranze.eu/files/downloads/D2_3/Heating_and_cooling_energy_demand_and_loads_for_building_types_in_different_countries_of_the_EU.pdf

Table 2. Example of possible data table for residential consumers.

Sub-sector				Detached houses	Terraced houses	Apartment buildings
Region				NUTS-3(1) LAU-2(1-1)		
Base residential heat demand area				1101		
Basic data	No. of buildings			xxx	xxx	xxx
	No. of dwellings			xxx	xxx	xxx
Annual energy demand per dwelling, kWh/a	Heating			xxx	xxx	xxx
	SHW			xxx	xxx	xxx
	Cooling			xxx	xxx	xxx
Use of energy stream and technology, %	Heating	District heating		%	%	%
		Electricity	Resistance heaters	%	%	%
			Heat pumps	%	%	%
			...	%	%	%
		Natural gas	Boilers	%	%	%
			...	%	%	%
		Solar thermal	Solar panels	%	%	%
		...	...	%	%	%
	SHW	District heating		%	%	%
		Electricity	...	%	%	%
		...	...	%	%	%
	Cooling	District cooling		%	%	%
		Electricity	...	%	%	%
		...	...	%	%	%
Total energy demand, GWh/a	Heating			xxx	xxx	xxx
	SHW[1]			xxx	xxx	xxx
	Cooling			xxx	xxx	xxx

[1] SHW – sanitary hot water

EXAMPLE 5 Heating and cooling data of the residential sector within a base heat demand area

This example shows a possible way how to collect information of the residential sector, considering a specific base heat demand area. The hypothetical demand area chosen is named Demand Area 1101. The first task of the analytical process is to collect information about those variables that will allow the analyst to assess the heating and cooling consumption of the area. Some of these variables could be:

- Specific consumption per square meter of heated floor area (MWh/m^2), by end use category (considering three end uses: heating; cooling and hot water);
- Percentage of heated floor area with cooling (%);
- Fuel shares (%), by end use;
- Hours of energy consumption per year (h), by end use category.
- Conversion efficiencies of different technologies (%).
- Correction factors to convert average demand into maximum demand[11].

It is convenient to collect this information per type of building, especially for those variables that are more dependent of the type of buildings (as, i.e., Specific consumption per m^2 of floor area). Other variables will remain constant between type of buildings (as, i.e., efficiencies or corrector factors). An example of the data gathering can be found in the Table 3.

Table 3. Data gathering of variables affecting residential consumption.

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[11]This correction factor for heating demand is calculated as: $\theta_{heating} = \frac{\theta_C - \theta_{min}}{\theta_C - \theta_{avg}}$, where θ_C, is the base temperature (indoor temperature of the buildings, usually assumed to be 18 °C), °C; θ_{avg}, is the average outside air temperature throughout heating season, °C; and θ_{min}, is the average minimum temperature in given region or a country, °C. The correction factor for cooling demand is calculated as: $\theta_{cooling} = \frac{\theta_{max} - \theta_C}{\theta_C - \theta_{avg}}$

			Multistore building	Terraced	Single
Average floor are per household (m2)			80	90	100
Specific consumption per m2 of heated floor area, by end use category (MWh/m^2)	Heating		0.08	0.07	0.12
	Cooling		0.05	0.04	0.05
	Hot water		0.02	0.02	0.03
% heated floor area with cooling			65%	70%	85%
Fuel shares, by end use (%)	Heating	Gas	80%	70%	72%
		Electricity	20%	30%	28%
	Cooling	Electricity	100%	100%	100%
	Hot water	Gas	100%	100%	100%
Hours of energy consumption per year, by end use category (h)	Heating		1177	1205	1201
	Cooling		638	653	650
	Hot water		2100	2100	2100
Conversion efficiency of technologies (%)	Heating	Gas boiler	89%	89%	89%
		Heat pumps	300%	300%	300%
	Cooling	Heat pumps	300%	300%	300%
	Hot water	Gas boiler	89%	89%	89%
Correction factors to convert average demand into maximum	Heating		1.6	1.6	1.6
	Cooling		1.1	1.1	1.1

Once the analyst has collected the information regarding these parameters, the next step consists of gathering information on the inventory of buildings, mainly:

- Number of buildings.
- Heated floor area (m^2).

Based on this inventory and using the variables mentioned before, the analyst can assess the total energy demand in each demand area (MWh) and the installed capacity of different heating and cooling solutions (MW). The results of the Example 5 can be found in the following Table 4.

Table 4. Inventory data and consumption of residential sector at Demand Area 1101.			AREA 1101		
			Households		
			Multistore	Terraced	Single
Inventory data		No. buildings	279	7541	6363
		No. dwellings	1114	7541	6363
		Heated floor area (m^2)	89153	678682	636297
Installed capacity by end use category and technology (MW)	**Heating**	Gas boiler	8.4	49.3	80.1
		Heat pump	0.6	6.3	9.2
	Cooling	Heat pumps	1.5	10.2	16.1
	Hot water	Gas boiler	1.0	7.2	11.3
Annual energy consumption, by end use category (MWh)		Heating	6864	47229	74295
		Cooling	2631	18104	28480
		Hot water	1945	13382	21050

If a particular MS does not have an established system of a fine territorial division (such as neighbourhoods) it might have to use larger territorial units as base residential demand areas. In such a case the accuracy of the CA might be improved by application of different correction factors. For instance, large areas of undeveloped land, such as parks, forests, fields, etc. should be excluded from the total land area of a given base residential demand area, because its inclusion would underestimate the plot ratio and thereby distort the calculation results.

The area of undeveloped land and green spaces could be subtracted from the total area of analysed territory more easily by acquisition of maps with information on different land use (urban, undeveloped, etc.). This could be available either on national, regional or local level (for instance, GIS tools could be used to subtract green spaces on a map from the urban land map). An alternative solution would be to use statistical data on the share of green spaces in residential areas. Statistical data sources of the country, regional or municipality level or scientific literature on corresponding numbers can also be consulted. It should be noted that such generalized evaluation should be used with caution, because it would inevitably cause additional discrepancies due to that areas of green spaces being very different even between districts of the same city [9].

EXAMPLE 6 Refining results of plot ratio calculation – evaluation of green space area
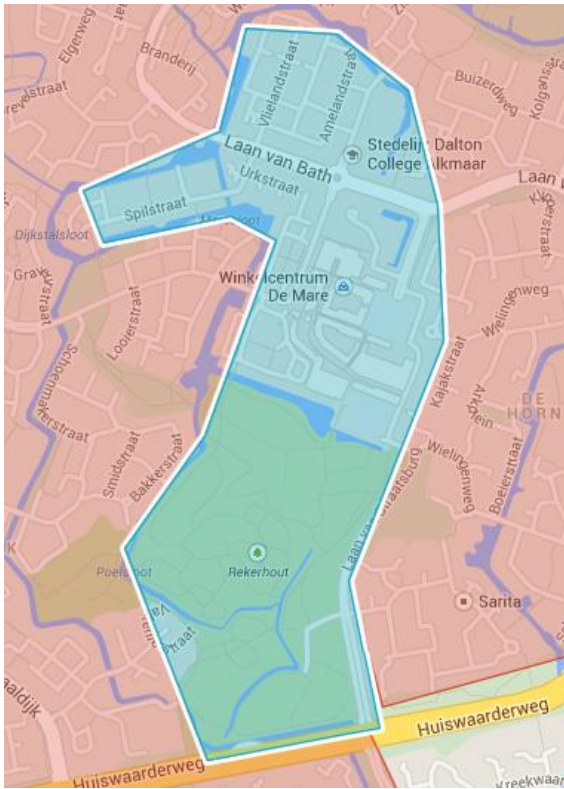
Figure 4. Map of neighbourhood with significant green space area (Source of background – Google Map Maker).

The population of the highlighted neighbourhood in Figure 4 is 2620, and the total land area is 0.55 km². Applying the method of calculation as described in Example 6 yields that the total floor area of residential and dispersed service buildings is 146 720 m² and the plot ratio is 0.267.

Analysis of this map shows that a very large part of it is taken by undeveloped land in the form of a park. The area of such land is 0.25 km² or 45.5 % of the total area of this neighbourhood.

After subtraction of this area from the total area of the analysed territory, the actual plot ratio of built up part is estimated to 0.489.

In order to calculate the plot ratio it might be necessary to evaluate zones with different types of buildings located in an analysed territory. For instance, inside of the same neighbourhood or other given territories there might be sub-clusters of buildings with very different characteristics. Part 1 of such a territory might be covered by multi-storeyed residential buildings, giving this sub-territory a high plot ratio. Part 2 might be covered by dispersed single family houses giving such sub-territory a low plot ratio. The situation might occur that when the average plot ratio is calculated for the whole territory it will be lower than the threshold and hence it would not have been identified for DHC. As was already stated, the outcome of the analysis is highly dependent on the granularity of the territorial division. If small enough territorial units would be chosen as basic units of analysis, the importance of these issues would be small as such additional calculation might not be necessary.

1.3.3 Service sector

Similar to the residential sector, the service sector has to be further subdivided into sub-sectors. Also, similar to households, heating and cooling consumers of the service sector can be treated as distributed energy consumers within a given geographical area, thus information about them would be used to supplement already established base residential heat demand areas, see Table 2.

Number of sub-sectors might be different in different countries, but the break-down should be sufficient to reflect the distribution of buildings with significantly different energy consumption characteristics. For instance, the service sector might be sub-divided into:

a. Government institutions/public buildings;

b. Education institutions (schools, nurseries, universities and so on.);

c. Hotels;

d. Hospitals;

e. Shopping malls;

f. Office buildings;

e. Other.

It may be useful to sub-divide further the demand into size of buildings, their energy efficiency level etc.

It might be possible to collect actual data on energy consumption of large and easily identifiable individual buildings, belonging to service sector, such as shopping malls, complexes of office buildings, schools, etc. This would require the collection of the following information:

6. Location of consumer.
7. Type of consumer (office building, educational institution, warehouse, shopping centre, etc.).
8. Heated floor area.
9. Demand of energy for space heating and sanitary hot water and for space cooling.
10. Description of how the heating and cooling demand is satisfied currently. This should include heating/cooling source and fuel used, e.g. CHP unit, individual gas boiler, individual biomass boiler, district heating, district cooling, etc.

Possible information sources could be similar to the ones described in the sections 1.2.1 and 1.2.2 about industrial consumers and households. An additional important source of information on large

service sector buildings might be the registers/databases of energy performance certificates, which have been created in a number of MSs[12].

The method that involves gathering of detailed data on individual consumers, as described above, can be employed for large service sector buildings or complexes. The time and effort required for collection of such precise data could be justified by the relatively large amounts of energy those buildings consume and by their significance to the CA.

However, there exist a large number of smaller service sector energy consumers, whose identification, description and individual inclusion into the CA might require excessive effort. An example of such consumers might be shops, offices or restaurants which very often occupy ground floors of residential buildings, especially in central parts of cities or near main streets, etc. Heating/cooling consumption of such distributed service sector energy consumers could be estimated similarly to residential sector energy consumers.

Therefore information about distributed service sector consumers would serve as a supplement to information on base residential heat demand areas, gathered as described in previous sections of this methodology. If possible, data about heated area and heating/cooling consumption of service buildings, located in each base residential heat demand area, could be gathered from energy market operators or other relevant sources.

If such information would be impossible to acquire, then it can be estimated based on statistical information about heated floor area of service sector buildings per capita and specific energy demand per floor area unit. Relevant statistical data can be found in databases of national statistical organizations and other relevant sources of information, such as reports, websites and so on. For instance the ENTRANZE project website[13] might be consulted for information on average floor area per capita of service sector buildings. Also, the different reports may contain valuable information, for instance in the report [10]. Statistical data on non-residential buildings floor area for selected countries of EU can be found on p. 26 of that report. The statistical review in [3] p.81 contains statistical information about the final energy consumption in the service sector of all MSs. Also reports, published in the Odyssee Mure Project website[14] provide information on the ratio of energy consumption in residential and service sector buildings.

Gathered or estimated data on heated area of service sector buildings as well as their heating and cooling demand should be added to previously gathered for residential heat consumers, as presented

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[12] http://www.iea.org/media/workshops/2011/buildingenvelope/19_Economidou.pdf

[13] http://www.entranze.enerdata.eu/average-floor-area-per-capita.html

[14] http://www.odyssee-mure.eu/publications/efficiency-by-sector/household/household-eu.pdf

in Table 2. This should be done for each base residential heat demand areas, thus resulting in *base heat demand areas*.

After establishing the base heat demand areas (based on distributed residential and service sector heat consumers) the next step would be the addition of large service sector buildings such as shopping malls, office building complexes, hospitals, etc to each such area. Their addition should be based on heated floor area, either actual or relative. Relative floor area is heated area of equivalent residential building, consuming the same amount of energy. It is usual that large service buildings, such as hospitals, require more heating per floor area unit than residential buildings. Thus the use of relative floor area would mean that residential buildings are summed with service buildings on equal terms. An example of such a calculation is presented in Example 7.

EXAMPLE 7 Adding service sector building to base heat demand area

The population in the green highlighted area in Figure 5 is 1575; total land area is 0.56 km². Total floor area of residential and dispersed service buildings is 88 200 m² and plot ratio is 0.16.

Figure 5. Map of analysed neighbourhood (Source of background – Google Map Maker).

However, a large public building complex (hospital) is located inside of this territory, highlighted in black. The total actual floor area of the hospital is 100 000 m². Annual heating demand is equal to 34.4 GWh/a. Heat density of this neighbourhood can be calculated by simply summing up heat

demands of residential consumers and the hospital.

The total plot ratio of this neighbourhood, however, should be calculated bearing in mind the fact that specific demand of energy in hospitals is higher than in average residential buildings. Let us assume that specific heat demand in residential buildings of analysed country on average is equal to 100 kWh·a/m². Then relative floor area of named hospital can be calculated as follows: 34.4 GWh/a / 100 kWh·a/m² = 344 000 m².

If the relative floor area of the hospital 344000 m² would be added to the 88200 m² already calculated, the resulting plot ratio of this area would be equal to 0.771 which is above designated threshold.

The result of this section of methodology might be a data table as presented in Tables 5.

Table 5. Example of possible combined data table for residential and service sector consumers.

Sector			Residential			Service		
Sub-sector			Detached houses	Terraced houses	Apartment buildings	Hotels	Offices	...
Region			NUTS-3(1) LAU-2(1-1)					
Base residential heat demand area			1101					
Basic data	No. of buildings		xxx	xxx	xxx	xxx	xxx	xxx
	No. of dwellings		xxx	xxx	xxx	xxx	xxx	xxx
Annual energy demand per dwelling, kWh/a	Heating		xxx	xxx	xxx	xxx	xxx	xxx
	SHW		xxx	xxx	xxx	xxx	xxx	xxx
	Cooling		xxx	xxx	xxx	xxx	xxx	xxx
Use of energy stream and technology, %	Heating	District heating	%	%	%	%	%	%
		Electricity	Resistance	%	%	%	%	%	%
			Heat pumps	%	%	%	%	%	%
			...	%	%	%	%	%	%
		Natural gas	Boilers	%	%	%	%	%	%
			...	%	%	%	%	%	%
		Solar thermal	Solar panels	%	%	%	%	%	%
		...	...	%	%	%	%	%	%
	SHW	District heating	%	%	%	%	%	%
		Electricity	...	%	%	%	%	%	%
		...	...	%	%	%	%	%	%
	Cooling	District cooling	%	%	%	%	%	%
		Electricity	...	%	%	%	%	%	%
		...	...	%	%	%	%	%	%
Total energy demand, GWh/a	Heating		xxx	xxx	xxx	xxx	xxx	xxx
	SHW		xxx	xxx	xxx	xxx	xxx	xxx
	Cooling		xxx	xxx	xxx	xxx	xxx	xxx

This example shows a possible way how to collect information about the service sector. As mentioned in Example 5, the first task of the analytical process is to collect information about those variables that will allow the analyst to assess the heating and cooling consumption of the service sector. Some of these parameters could be:

- Specific consumption per square meter of heated floor area (MWh/m^2), by end use category;
- Percentage of heated floor area with cooling (%);
- Fuel shares (%), by end use;
- Hours of energy consumption per year (h), by end use category.
- Conversion efficiencies (%) of different technologies.
- Correction factors to convert average demand into maximum demand

It is convenient to collect this information per sub-category of the service sector. An example of the data gathering can be found in the Table 6:

Table 6. Data gathering of variables affecting service sector consumption.

			Public buildings	Education	Hotels	Hospitals	Shopping malls	Offices buildings	Other
Average floor are per subsector building (m2)			313	2063	481	2407	1228	344	64
Specific consumption per m2 of heated floor area, by end use category (MWh/m2)	Heating		0.22	0.10	0.20	0.40	0.14	0.20	0.18
	Cooling		0.15	0.07	0.13	0.27	0.09	0.13	0.12
	Hot water		0.06	0.03	0.05	0.10	0.04	0.05	0.05
% heated floor area with cooling			88%	64%	96%	80%	72%	76%	80%
Fuel shares, by end use (%)	Heating	Gas	80%	82%	92%	83%	92%	96%	85%
		Electricity	20%	18%	8%	17%	8%	4%	15%
	Cooling	Electricity	100%	100%	100%	100%	100%	100%	100%
	Hot water	Gas	100%	100%	100%	100%	100%	100%	100%
Hours of energy consumption per year, by end use category (h)	Heating		991	721	1081	901	811	856	901
	Cooling		1097	798	1196	997	897	947	997
	Hot water		2310	1680	2520	2100	1890	1995	2100
Conversion efficiency of technologies (%)	Heating	Gas boiler	89%	89%	89%	89%	89%	89%	89%
		Heat pumps	300%	300%	300%	300%	300%	300%	300%
	Cooling	Heat pumps	300%	300%	300%	300%	300%	300%	300%
	Hot water	Gas boiler	89%	89%	89%	89%	89%	89%	89%
Correction factors to convert average into maximum demand	Heating		1.6	1.6	1.6	1.6	1.6	1.6	1.6
	Cooling		1.1	1.1	1.1	1.1	1.1	1.1	1.1

Once the analyst has collected the information regarding these variables, the next step consists of gathering information on the inventory of the service sector within each base heat demand areas, for example:

- Number of buildings.
- Total floor area per sub-category of the service sector (m^2).

Based on this inventory and using the variables mentioned before, the analyst can assess the total

energy demand in each demand area (MWh) and the installed capacity of different heating and cooling solutions (MW). The results of the Example 8 can be found in the Table 7.

Table 7. Inventory data and consumption of service sector at Demand Area 1101.

			Public buildings	Education	Hotels	Hospitals	Shopping malls	Offices buildings	Other
Inventory data	No. buildings		18	4	15	1	2	24	36
	Heated floor area (m^2)		5627	8253	7221	2407	2456	8253	2293
Installed capacity by end use category and technology (MW)	**Heating**	Gas boiler	1.80	1.69	2.21	1.59	0.70	3.33	0.70
		Electricity	0.13	0.12	0.05	0.11	0.05	0.03	0.10
	Cooling	Electricity	0.24	0.16	0.28	0.19	0.07	0.32	0.08
	Hot water	Gas boiler	0.15	0.14	0.16	0.13	0.05	0.23	0.06
Annual energy consumption, by end use category (MWh)	Heating		1238	825	1444	963	344	1651	413
	Cooling		726	352	924	513	165	836	220
	Hot water		309	206	361	241	86	413	103

1.4 Data on energy supply

The purpose of this step is to collect data on potential sources of energy, which could supply heating and/or cooling to previously identified heat demand areas and points.

The EED Annex VIII specifies that the CA should include identification of potential heating and cooling supply points, including:

- Electricity generation installations with total annual production of electricity exceeding 20 GWh;
- Waste incineration plants;
- Existing and planned cogeneration installations based on technologies listed in Part II of Annex I of EED;
- District heating installations, meaning producers of thermal energy supplying district heating networks;
- Industrial installations.

This list is not exhaustive and represents the minimum of what should be included. Additional energy sources should be added, if they are necessary for completeness and accuracy of the analysis.

In addition, available renewable sources (geothermal, solar, etc.), waste heat sources and other energy supply sources, such as the availability of piped natural gas or other gases (alternative fuels) should be identified, if relevant.

1.4.1 Already utilised heat sources

Information on available heat sources should include at least the following information:

1. Name and location of the plant. Information on location might include coordinates and/or address. Geographical information about location of the plant should also be acquired for later processing with Geographical Information Systems (GIS) tools and easier inclusion into heat map.

2. Type of energy generation installation. Information gathered should allow attribution of installation to one of the categories (and their sub-categories) of potential heating and cooling supply points listed above.

Improving level of detail of CA: individual installations would preferably be assigned to subcategories. Number and details of subcategories might be settled by organizers of the CA based on the situation in each particular MS. For instance, electricity generation installations might be subdivided into categories based on their size or employed technologies (steam turbine, combined cycle, etc.), cogeneration installations might be subdivided based on technologies used by them, referring to the list presented in Part II of Annex I of EED and so on.

3. Fuel used. In case of dual or more fuel the percentages of different types of fuel consumed should be presented.

4. Quantity (in GWh/a or similar units) and quality of waste heat available. It should be indicated what is the temperature of available waste heat.

5. Availability of waste heat in hours per year.

6. Year of beginning of operation (either actual or planned).

It might be difficult to acquire all the necessary information for all the categories of potential waste heat sources, especially about the availability of the waste heat. Due to that the following sub-sections are intended to provide guidance on the estimation of waste heat availability from power generation and industrial installations.

1.4.2 Waste heat from power generation installations

Waste heat from electricity generation installations can be recuperated using different methods and technologies. The selection of method will influence the amount of waste heat available. The available methods may include:

a) Upgrade of electricity only installation into CHP plant at the expense of the lowered electricity production but maintaining the same primary energy input;

b) Upgrade of electricity only installation into CHP plant with the same electricity production but increasing primary energy consumption.

The first step in both cases would be to identify the location of each installation and its primary fuel consumption. Usually data about power plants and all electricity generation installations are available

either in private datasets such as Platts World Electric Power Plants Database[15] or in national registries. The following information is considered to be known in any case:

- Electrical capacity (MW$_e$)

- Thermal capacity (MW$_{th}$) or reference nominal efficiency

- Location

The difference between the thermal and electrical capacity is the heat dissipated to the environment as a result of the thermodynamic cycle. This heat is close to ambient temperature so it is not directly usable for district heating or any other application. However, this potential can be harnessed by upgrading the heat to a usable quality. This can be done by converting the power plant to cogeneration. In steam turbine based plants, steam can be extracted from an extraction/condensing turbine to the required pressure/saturation temperature. The trade-off is that electricity production is reduced, or equivalently more primary energy will be needed in order to maintain the same electricity production.

The power loss ratio can be used as a metric to identify the energy penalty. It corresponds to the electric efficiency that the extracted heat would have if it was 'converted to electricity', e.g. a power loss ratio of 10 % implies that for each 100 MW$_{th}$ extracted the net nominal power output is decreased by 10 MW$_e$. In other words is the electricity generation potential of the portion of heat that was not extracted. For low extraction temperatures (~100 °C) this ratio is very close to the Carnot efficiency between the extraction and the ambient temperature. Simple thermodynamic cycle calculations for a typical steam turbine plant lead to the figures of Table 8.

Gas turbine plants have no power loss penalty since the hot air at the exhaust of the gas turbine can be directly recovered with a heat recovery steam generator.

Table 8. Approximate power loss based on required heat quality for steam turbine based plants.[16]

Use of heat	Saturation Temperature (°C)	Power lost (% of heat extracted)
District heating 4th generation	80 °C	10%
District heating 3rd generation	120 °C	17%
Process heat - Medium pressure	220 °C	30%
EXAMPLE 9: Estimation of heat generation potential from electricity generation installations		
An installation has 100 MW$_{th}$ thermal capacity and 38 MW$_e$ net electric capacity which corresponds to an efficiency of 38 %. The internal losses for auxiliary loads are limited to 4 %		

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[15] http://www.platts.com/products/world-electric-power-plants-database

[16]Source: Own calculations

The heat is dissipated to the environment is 100 – 38 = 62 MW_{th} of low quality heat. 96 % of this heat = ~60 MW_{th} are dissipated in the condenser.

If the entire heat was not expanded till ambient temperature but till the point where the saturation pressure corresponds to a temperature of 120°C (via a backpressure turbine) then according to Table 8 there would be 17 % * 60 = 10 MW_e lost.

Thus, the converted cogeneration plant would have an output of :

28 MW_e of electric energy and 70MW_{th} of useful heat.

Information about cogeneration technologies and costs are presented in Annex A of this methodology.

1.4.3 Waste heat from industrial installations

A difficulty when estimating industrial waste heat sources is that waste or surplus heat data from industrial installations is not systematically recorded in international and national energy statistics. Furthermore, waste heat recovery potential is sector-specific and even for a same product depends on site-specific process routes. Sector and site specific information might be gathered from relevant publications and by contacting site managers. In this case, a standard questionnaire in the form of tables or lists which would facilitate data gathering could be prepared as it would later contribute to easier and more systematic processing of large amounts of the data.

If gathering of data from individual industrial installations would not be possible, then the method of waste heat quantity estimation, presented in this sub-section of methodology, could be employed. The proposed method is based on the procedure presented by McKenna et al. (2009). This procedure is based on the fact that the majority of industrial heat demand is accounted for by a small number of sectors and usually correspond to be the most energy-intensive ones. McKenna et al. estimated the technical potential for heat recovery in industry throughout the UK based on site-specific data contained in the EU ETS. Heat users are categorised into broad temperature bands; heat usage and waste at different temperatures are quantified; and lastly the technical potential for heat recovery based on current technologies is estimated.

Information and assumptions about individual subsectors allowed parameters such as the fuel split, load factor, and combustion efficiencies to be estimated, which were then used as key input parameters in determining site-level heat loads. The stepwise procedure is presented schematically in Figure 6.
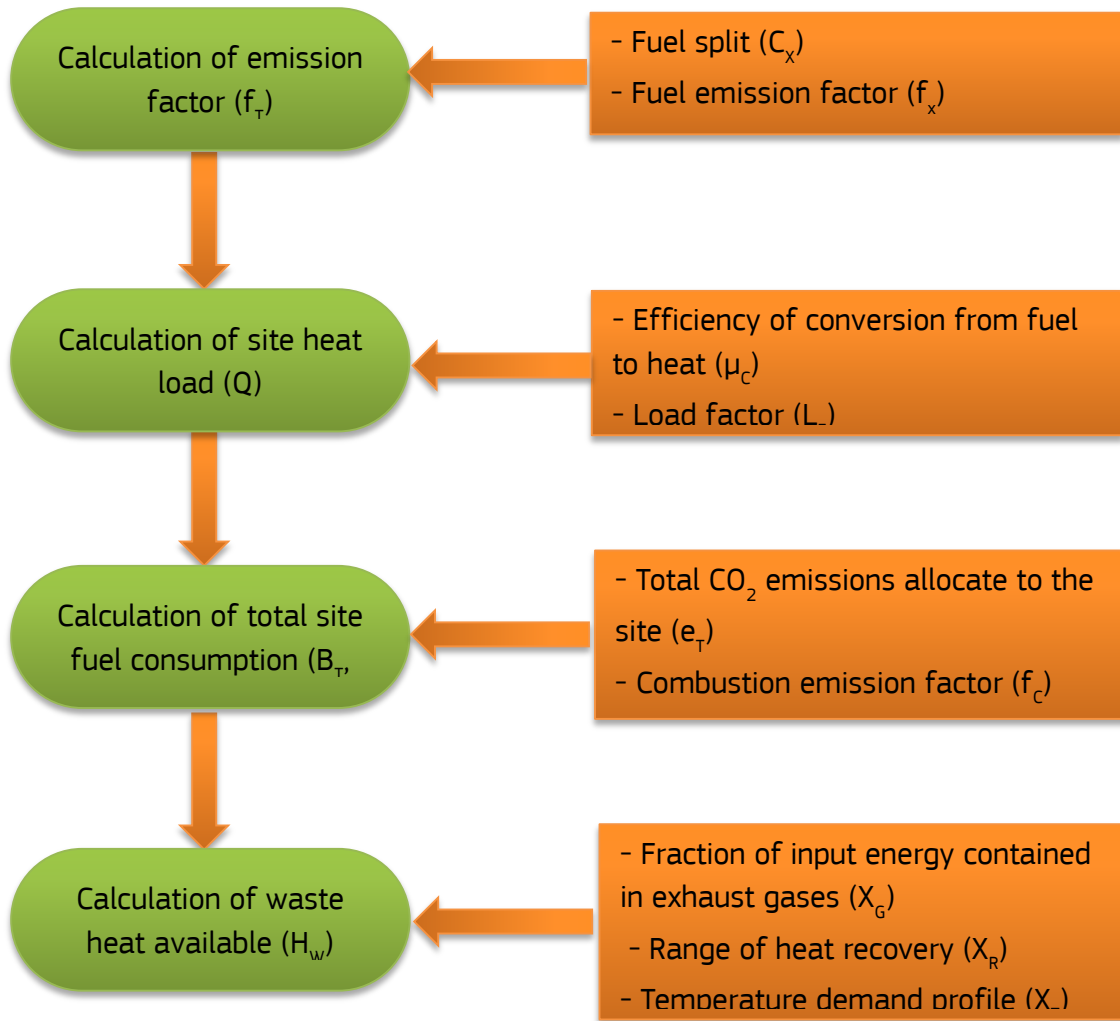
Figure 6. Scheme of the proposed method to estimate the technical potential for waste heat recovery.

The flowchart (left column, green boxes, top to bottom):
- Calculation of emission factor (f_T)
- Calculation of site heat load (Q)
- Calculation of total site fuel consumption (B_T,
- Calculation of waste heat available (H_W)

Corresponding inputs (right column, orange boxes):
- Fuel split (C_x)
- Fuel emission factor (f_x)

- Efficiency of conversion from fuel to heat (μ_C)
- Load factor (L)

- Total CO_2 emissions allocate to the site (e_T)
- Combustion emission factor (f_C)

- Fraction of input energy contained in exhaust gases (X_G)
- Range of heat recovery (X_R)
- Temperature demand profile (X)

Process of waste heat identification in industrial installations consists of the following steps:

1. Collection of data on CO_2 emissions per individual industrial installations. Information about greenhouse emissions of each electricity generation installation could be obtained from national registries. In case national registries would not be available or would be incomplete, European data bases, such as EU Emissions Trading Scheme (EU-ETS)[17] could be used. Another source of information on electricity generation installations is the E-PRTR (European Pollutant Release and Transfer Register)[18] which is a European register of environmental data for industrial facilities. It should be noted that the EU-ETS and E-PRTR databases include only large installations based on the thresholds of installation's capacity or its annual greenhouse

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[17] http://ec.europa.eu/clima/policies/ets/registry/documentation_en.htm

[18] http://prtr.ec.europa.eu/pgDownloadDataSet.aspx

emissions. In any relevant case, the split between process emissions and combustion emissions for the sector is then estimated in order to determine the purely combustion-related emissions.

2. The second step is to determine an overall emission factor, f_T (tC/TJ), for the subsector according to

$$f_T = \frac{\sum_{x=1}^{N} C_x f_x}{\sum_{x=1}^{N} C_x} \qquad (2)$$

here C_x – fraction of the fuel x used in the sector, f_x (tC/TJ) – emission factor of the fuel x; N – the number of different fuels excluding electricity.

Greenhouse emission factors can be found in different reports and scientific literature, for instance in the Annex 3.3.3 of UK Greenhouse Gas Inventory 1990 to 2010 [11][19]. Fuel splits might be obtained from trade associations, international and national energy statistics, European Commission Best Available Techniques (BREFs) documents and literature.

3. Once the overall emission factor for each subsector is estimated, the total site primary energy input B_{TF} (TJ) can be calculated as follows:

$$B_{TF} = \frac{e_T f_c}{f_T} \qquad (3)$$

where e_T – the total emissions allocated to the site; f_c – the combustion emission fraction.

4. Further, the fraction of electricity use X_{el} within the sector has to be taken into account in order to estimate the total site energy use B_T (TJ) according to:

$$B_T = \frac{B_{TF}}{1 - X_{el}} \qquad (4)$$

The total site energy use can then be multiplied by the respective fuel split factors for the subsector in order to yield approximate fuel uses for the site.

5. Once the total energy consumption is estimated, the site heat load (TJ/a) can then be determined according to

$$Q = \frac{B_{TF} \mu_C}{t \, L_F} \qquad (5)$$

where μ_c is the combustion efficiency and reflects that not all of the primary fuel use is converted to heat, L_F is the load factor and t represents time scale. Special attention should be

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paid to those industrial subsectors, such as aluminium and iron and steel production through Electric Arc Furnaces, in which site electricity highly contributes to the heat load.

In order to estimate the amount of waste heat for each site, and therefore an indication of potential for heat recovery, estimates published in energy statistics and literature for the fraction of the total input energy that is contained in the exhaust gases x_G might be used. Furthermore, the impossibility of recovering all the waste heat should also be taken into account and introduced in the analysis as a range of heat recovery fraction x_R for each subsector.

$$H_W = Q x_G x_R \qquad\qquad (6)$$

Additionally, the temperature demand profile x_T for each subsector can also be introduced in the analysis by estimating the fraction of the heat used within the temperature bands. Temperature profiles for industry can be found in the BREFs documents and were also estimated in the ECOHEATCOOL project [12].

Yet, in highly heterogeneous industrial subsectors[20] with either very diverse processing paths or significant lack of data, a capacity-based approach might be the only option to estimate waste heat potentials. This method involves using data relating to production capacities for individual sites and products, in conjunction with the specific energy consumptions (SECs) for these processes that can be obtained from the relevant sector BREFs. By employing appropriate load factors the energy and heat load for each site could then be estimated.

Table 9. Summary of estimates of potential for waste heat recovery in industry (% of energy use).

	UK (McKenna et al.)	Sweden (Fjärrvärme AB)	STRATEGO (2015)
Chemicals	7	24	25
Aluminium	20	n.a.	50
Cement	25	n.a.	25
Ceramics	20	n.a.	25
Food and drink	7	9	25
Glass	20	n.a.	10
Iron and steel	15	20	25
Basic metals	n.a.	11	25
Pulp and paper	7	6	n.a.
Wood production	n.a.	18	25

Additional information and discussion of plausible techniques to estimate the potential for waste heat in industry can also be found in similar studies carried out in Sweden [13] and Norway (Enova, 2009) and STRATEGO project (2015), results are included in Table 9. It should be noted that for

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[20] Examples of heterogeneous subsectors are the chemical, petrochemical and food industry.

heterogeneous sectors, such as chemical, petrochemical, food and beverage, in which the use of very diverse technology and production processes is involved, the estimation of waste heat can result in considerable different figures depending on the MS.

More information about waste recovery from industry is presented in Annex D of this methodology

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EXAMPLE 10 Heating & cooling data of the industrial sector within a heat demand area

As was done in the Example 5 and Example 8, this example shows a possible way how to collect information about the industrial sector. As mentioned before, the first task of the analytical process is to collect information about those variables that will allow the analyst to assess the heating and cooling consumption of the industrial sector. Some of these parameters could be, for example:

- Specific consumption per unit of economic output, by end use category (MWh/MEUR);
- Fuel shares (%), by end use;
- Hours of energy consumption per year (h), by end use category;
- Conversion efficiencies (%) of different technologies.

It is convenient to collect this information per sub-category of the industrial sector. An example of the data gathering can be found in the Table 10:

Table 10. Data gathering of variables affecting industrial sector consumption.

			Cement	Paper	Alumi-nium	...	Other
Specific consumption per unit of output, by end use category (MWh/MEUR)		High temperature heat	0.42	0.21	0.47	...	0.28
		Medium temperature heat	0.08	0.04	0.09	...	0.05
		Low temperature heat	0.06	0.03	0.08	...	0.04
Fuel shares, by end use (%)	**Heating**	Gas	92%	85%	82%	...	80%
		Oil	8%	15%	18%	...	20%
	Cooling	Electricity	100%	100%	100%	...	100%
	Hot water	Gas	92%	85%	82%	...	80%
		Oil	8%	15%	18%	...	20%
Hours of energy consumption per year, by end use category (h)		Heating	6100	5256	7008	...	4818
		Cooling	1097	798	1196	...	997
		Hot water	2310	1680	2520	...	2100
Conversion efficiency (%)	**Heating**	Gas boiler	89%	89%	89%	...	89%
		Oil boiler	32%	32%	32%	...	32%
	Cooling	Heat pumps	300%	300%	300%	...	300%
	Hot water	Gas boiler	89%	89%	89%	...	89%
		Oil boiler	32%	32%	32%	...	32%

Once the analyst has collected the information regarding these variables, the next step consists

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of gathering information on the inventory of the industrial sector within each base heat demand area, for example:

- Number of industrial plants;
- Total economic output per sub-category (MEUR).

Based on this inventory and using the variables mentioned before, the analyst can assess the total energy demand in each demand area by the industrial sector (MWh) and the installed capacity of different heating and cooling solutions (MW). The results of the Example 10 can be found in the Table 11. As can be seen, it has been supposed that this demand area has no industrial activity.

Table 11. Inventory data and consumption of industrial sector at Demand Area 1101

			Cement	Paper	Alumi-nium	…	Other
Inventory data	No. plants		0	0	0	…	0
	Total output (MEUR)		0	0	0	…	0
Installed capacity by end use category and technology (MW)	**Heating**	Gas boiler	0	0	0	…	0
		Electricity	0	0	0	…	0
	Cooling	Electricity	0	0	0	…	0
	Hot water	Gas boiler	0	0	0	…	0
Annual energy consumption, by end use category (MWh)	Heating		0	0	0		0
	Cooling		0	0	0	…	0
	Hot water		0	0	0		0

1.5 Data on district heating and cooling infrastructure

The purpose of this step of the methodology is to collect data on existing or planned district heating and cooling (DHC) infrastructure. This data allows determining the most attractive opportunities for heat linking as well as a better estimate of the costs for transporting heat. Additionally, this information will enable identifying energy efficiency potentials of energy distribution infrastructure.

Data on DHC infrastructure will in most cases likely be owned by operators/owners of DHC companies and it might not be publically available. Ownership of DHC networks might have different forms of private or public/state ownership. Thus, in order to collect such information national DHC organization can be contacted for a complete list of DHC providers and to contact them either individually or through representatives of the national organization. It is advisable to prepare a standard questionnaire and distribute it among potential providers of relevant information.

Another potential source of information on general issues surrounding DHC such as statistics, developments, policies, etc., might be reliable studies and reports, for instance District Heating and

Cooling Country by Country Surveys published by Euroheat&Power every two years that is available to purchase at their web site[21].

Information which is required for the CA about DHC infrastructure might be subject to confidentiality issues. Information to be collected about DHC infrastructure should include the following:

1. Location of the network and other related equipment. In order to avoid confusion, it does not have to include data on energy production installations since they should be covered in the energy production part, discussed in previous sub-section. It is advisable to collect information about networks in form of a shape file[22] to facilitate their later inclusion into a heat map of the country. In case visual representation of a pipeline configuration in the heat map would be restricted due to confidentiality or other issues, at least the boundary of territory served by DHC network should be identified.

2. Status of DHC network: operational or planned. Also the year of beginning of operation, either actual or planned should also be stated.

3. Peak/average load in MW or equivalent units over some period, for instance 3 years. These numbers should be available for all distinctive modes of operation, for instance winter and summer seasons.

4. Annual heating and cooling demand of consumers as well as heat losses in the network, in GWh/a or equivalent units. Data for a certain period (at least 3 years, preferably more) should be obtained. It is advisable to collect data on monthly energy consumption (GWh/month) since it would make the evaluation of heat linking possibilities much more accurate.

5. Average annual heat losses of the network, GWh/a. This information will be needed to identify energy efficiency potentials of district heating and cooling infrastructure.

The result of this section of methodology might be a data table as presented in Table 12.

Table 12. Example of possible data table for district heating and cooling infrastructure.Table 12. Example of possible data table for district heating and cooling infrastructure

No.	Geographic location of the network	Status of the network, operating/planned	Peak load of heating (winter/summer season), MW	Peak load of cooling, MW	Annual demand of energy in the network (heating/cooling), GWh/a	Annual heat losses of the network, GWh/a
1						
2						
3						

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[21] http://www.euroheat.org/Publications-8.aspx

[22] The shape file is a standard way to store geospatial vector data used in geographical information system (GIS) software.

1.6 Data on climatic conditions of territory

Be aware that energy consumption data needs to be corrected to average (normal) climatic conditions. Because climate variations from year to year are natural, it is common to use average temperatures over a period of 20 to 30 years for calculating temperature corrected energy consumption data.

Statistical databases and reports may already contain adjusted data, i.e. data on energy consumption of a particular year, converted into consumption of average (normal) year. In other cases this data may be presented in "raw" form as it was registered in a particular year. Using such untreated data may lead to significant discrepancies in the final results of the CA and an under- or overestimation of the heating and cooling demand. Only energy consumption for space heating and cooling should be adjusted to average climatic conditions. Other energy needs, such as domestic hot water preparation, are mostly independent of climatic conditions. Energy consumption in industry may also be somewhat dependent on climatic conditions, but it may also be governed by other factors, such as peculiarities of industrial process.

It is recommended, that in general climatic conditions should be collected for no larger territorial units than NUTS-2 or NUTS-3 regions, represented by a particular city or a meteorological station. The most important indicators of climatic conditions are heating degree days (HDD) and cooling degree days (CDD). These can be used to estimate the energy demand for space heating and cooling of a particular building or group of buildings in regard to climatic conditions. This is since the heating and cooling demand of a particular building is directly proportional to the number of HDD or CDD.

These indicators are usually calculated by national meteorological organizations. If they are not readily available, then they can be calculated. The HDD and CDD are defined in relation to the base temperature. For the HDD calculation the base temperature is usually an indoor temperature of 17, 18 or 19°C. Such a temperature corresponds to human comfort limit, since internal heat releases from equipment and people raise this temperature by about 2 °C. For CDD calculations the base temperature is usually higher, some scientific literature sources [14] recommend using 22 °C. It should be noted that the HDD and CDD calculations can involve additional parameters, but the simplest sequence would be as follows:

1. Gather average daily outdoor temperatures for every day of the year.
2. Calculate HDD using this formula

$$HDD = \sum_{O=1}^{n}(\theta_C - \theta_o) \tag{7}$$

where *n* is a number of cold days (when average daily outdoor temperature is below base temperature); θ_C – base temperature for HDD, °C. This temperature should be clearly identified; θ_o – an average outdoor temperature of particular day, °C.

3. *CDD* can similarly be calculated as follows

$$CDD = \sum_{O=1}^{n}(\theta_0 - \theta_H) \tag{8}$$

where *n* is a number of hot season days when the outdoor temperature is above base temperature; θ_H – base temperature for CDD, °C; θ_o –an average outdoor temperature of particular day, °C.

In case of DHC networks with known start and end of the official heating season, those data can be incorporated into the HDD calculation sequence in order to arrive at more accurate estimates.

EXAMPLE 11 Adjustment of energy consumption data to average climatic conditions

Let's assume that the consumption of thermal energy for space heating and actual climatic data of a particular year and climatic data of an average year are distributed during heating season as presented in Table 13. In this example the actual heating season ends on 23rd April (including) and starts on the 13th October (including). The period between these dates corresponds to the cold (heating) season, when the average daily outside air temperature was below the base temperature.

Table 13. Actual thermal energy consumption for space heating and climatic data.

	Heating days		Monthly outdoor temperature, °C		Heating degree days	
	Actual	Average	Actual	Average	Actual	Average
January	31	31	0.5	-6.0	543	744
February	28	28	-9.0	-5.2	756	650
March	31	31	4.8	-1.2	409	595
April	23	30	6.0	5.5	276	375
...						
October	19	31	7.4	6.6	201	353
November	30	30	0.5	1.4	525	498
December	31	31	0.4	-3.2	546	657
Total	193	212	-	-	3256	3872

Comparison of data in Table 13 shows that actual year was significantly milder than the average year would be, thus adjustment of actual thermal energy consumption is required. It can be performed by calculating adjustment coefficients through division of average and actual heating degree days:

$$\text{Adjustment coefficient (January)} = 744 / 543 = 1.37$$

Multiplication of actual heat demand by such coefficient would yield heat demand during an

average year as presented in Table 14.

Table 14. Thermal energy demand for space heating during average (normal) year.

	Actual demand of heat, MWh	Correction coefficients	Adjusted demand of heat, MWh
January	14.4	1.37	19.7
February	21.2	0.86	18.2
March	10.9	1.45	15.8
April	7.8	1.36	10.6
…			
October	4.3	1.75	7.5
November	13.4	0.95	12.7
December	15.2	1.20	18.2
Total	87.2		102.7

Climatic data might be acquired from national meteorological organizations. Some of these publish extensive climatological data on their web sites (for instance Royal Meteorological Institute of Netherlands[23]) while others will have to be contacted in order to obtain relevant data.

1.7 Forecast of heating and cooling demand evolution

EED Annex VIII Point 1(b) states that the comprehensive assessment of national heating and cooling potentials should include a forecast of how heating and cooling demand *'will change in the next 10 years, taking into account in particular the evolution of demand in buildings and the different sectors of industry'*.

More details are provided in the CSWD Point 18, where it is stated that forecast is a second step of CA and that *'this forecast should take into account the trends in the major sectors of the economy. It should analyse the likely evolution of heat demand in industrial sectors, taking into account longer*

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[23] http://www.klimaatatlas.nl/klimaatatlas.php?wel=temperatuur

term structural trends (such as de-industrialisation or re-industrialisation or efficiency improvements and the impact of new production technologies) as well as shorter term cyclical changes'. Further on, CSWD provides recommendations for energy consumption forecast in residential buildings and states that *'the evolution of heat demand in buildings should be given specific consideration, including an analysis of the impact of energy efficiency improvements in buildings, such as those required under the Energy Performance of Buildings Directive (2010/31/EU)[23] and the EED'*.

Although the requirement according to EED is to make a forecast for the next 10 years, it is advised to consider making a forecast for a longer timeframe, coinciding with the chosen time horizon of CBA. As is mentioned in Annex IX (e)(iii) of EED, the time horizon might be tied to technical lifetimes of energy installations, for instance 30 years in the case of DHC networks, so the forecasts of heating and cooling demand could be prepared for the same duration.

When preparing forecasts of possible future developments, the segmentation already established to determine the current demand should be used (Residential, services etc. and their sub-segments);

The recommended starting point in preparing forecasts could be the EC report on EU energy, transport and GHG emissions, published in 2014 [15] which is based on the statistical year of 2010. Since this report has been prepared in 2013, it incorporates the implications of current crisis on different sectors of the economy. It projects energy, transport and greenhouse gas (GHG) emission trends up to 2050. Reference scenarios are available in Appendix 2 for the EU as a whole and for each of its 28 MSs. Scenarios take into account developments in EU energy system under current trends and policies. The current trends on population and economic development were evaluated as well as changes influenced by national and EU policies and measures adopted till the spring of 2012. Scenarios in this report include all targets set in the EU legislation regarding development of renewable energies, reduction of GHG emissions and latest legislation intended to promote energy efficiency. However, policy measures or other tendencies that were adopted after the spring of 2012 or are foreseen in the future could be included into the forecast of energy efficiency improvements.

Projections in the above mentioned report are presented from 2010 (2010 is represented by actual data) in 5 year steps till 2050. Projections on energy consumption in different sectors of a country's economy are presented in Appendix 2 of this report. These could be used to make detailed projections for a country and its different regions.

It should be noted that the report [15] contains data on the so-called reference scenario which can be considered to be a projection and not a forecast of developments in energy demand on the basis of current policies. In order to make a forecast of energy demand, it is necessary to supplement information taken from the report [15] with information taken from other relevant data sources thus taking into account recent developments and latest policies on energy efficiency, energy taxation and

infrastructure as well as other related issues. The Energy Roadmap 2050 report [16] can be consulted for further information on construction of so-called Current Policy Initiatives (CPI) scenario, which would take into account all above mentioned issues. For instance, p.121 of the same report [16] contains a comparison of final energy demand in different scenarios, including Reference and CPI scenarios although the numbers presented there are generalized for the whole Europe.

Improving level of detail of CA: data in Appendix 2 of report [15] does not distinguish between energy consumption in households for space heating and domestic hot water production. Separate forecasts for those two energy flows are recommended, because large changes in heat consumption occurs in space heating, while changes in domestic hot water consumption would involve changes in consumer behaviour that takes more time.

Prevailing age of the buildings in a given territorial unit might also be taken into account. In the case that newly built houses prevail in some area, it is likely that their energy efficiency improvement potential is much lower than in case of old buildings and vice versa.

It should also be noted that report [15] and other similar documents usually deal with forecasts on country scale and high quality forecasts for regional or even municipal scale are generally lacking.

Improving level of detail of CA: in separate regions of the country, the rate of changes might be very different, for instance some regions might experience acute population demise while others might retain stable population count or might be even growing. It is advised to look at forecasts or population change at regional or municipal scale in order to determine expected changes in population and resulting heating and cooling demands. This might not be so important for existing housing since buildings will need heating or cooling, but it might influence the construction rate of new buildings and associated energy demand.

EXAMPLE 12 Forecast of energy demand

Let us assume that the consumption of final energy in households of region NUTS-3(1) is equal to:

 1. Heat

   a. Space heating: 109.3 ktoe/a;

   b. Preparation of domestic hot water: 16.1 ktoe/a;

 2. Cooling (air conditioning): 3.62 ktoe/a.

Let's assume that tendencies of the reference scenario in energy consumption in this region will follow the general tendencies for Belgium as presented in p.92 of [15] and CPI scenario relationship to Reference scenario would follow tendencies presented in p.121 of [16]. The graph of final annual energy consumption change in households forecasted (CPI scenario) for this region is presented in Figure 7.
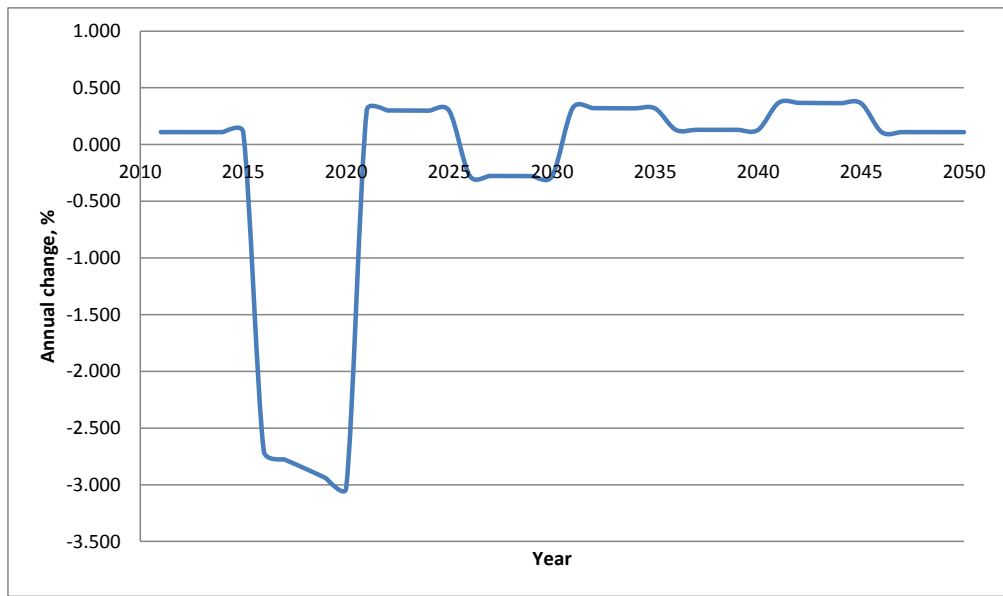
Figure 7.Forecasted rate of annual final energy demand change in households of analysed region.

Based on this information we can calculate the forecasted changes in heat consumption of households in a NUTS-3(1) region. The final energy consumption is presented in Figure 8.
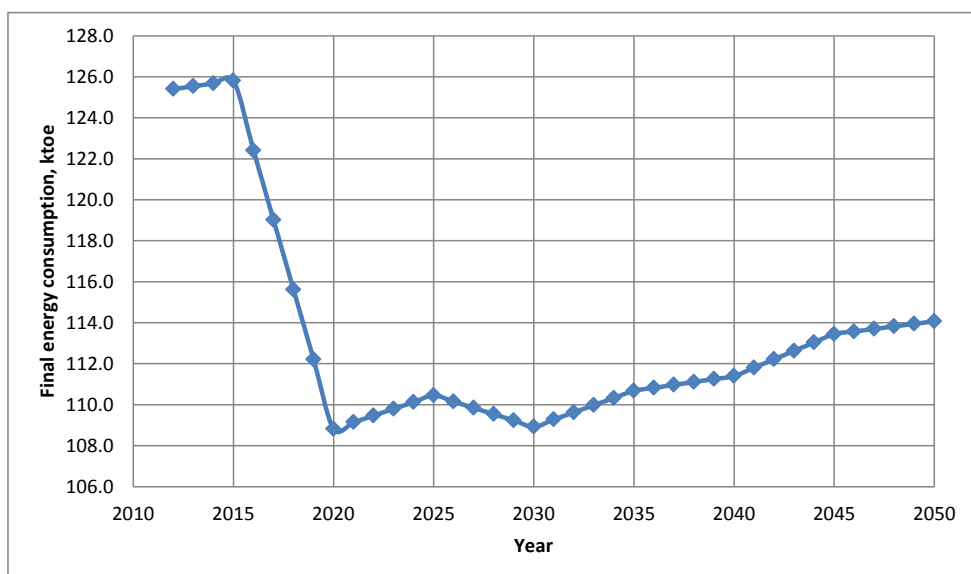
A similar approach might be used when forecasting changes in heat consumption in service sector buildings.

Heat consumption changes in the industrial sector should be forecasted separately following general tendencies of final energy consumption changes as presented in Appendix 2 of report [15].

Improving level of detail of CA: because the industrial sector consists of different sub-sectors with their own specific tendencies, hence it is advisable to evaluate their likely projections of energy demand rather than applying average coefficients. In pp. 15 and 16 of report [15] there are assumptions for different sectors of industry and Table 4 on p. 36 gives an insight on average annual changes of energy consumption in sub-sectors of the industry sector at EU level, although industries in different countries might display different tendencies, at least in the short term.

The report on EU industrial structure [17] or Short-Term Industrial Outlook series[24] can be consulted for some tendencies on industry development. Also a report on Energy Efficiency Trends in Industry in the EU published in 2012 on Odyssee-Mure Project website [25] may be consulted for trends in development of industry sectors from 1990 till 2010. Although this report will not provide a forecast, it contains some ideas for forecasting future development trends in different sectors of their country's industry.

Most documents deal only with future heating and electricity demand trends. Forecasting cooling demand development is a more challenging task due to the general lack of information on this subject. Table 5 of Appendix 1 in report The European Cold Market published by Euroheat & Power [12] and more recent study [18][26] may be consulted. Here, data on calculated specific cooling demand in residential and service sector buildings in kWh/m^2 for all EU MS can be found. By multiplying specific cooling demand with floor area of buildings in a given territory, it is possible to calculate the maximum possible cooling demand. Then, it is necessary to make predictions about future

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[24] http://ec.europa.eu/enterprise/policies/industrial-competitiveness/competitiveness-analysis/index_en.htm

[25] http://www.odyssee-mure.eu/publications/br/energy-efficiency-trends-industry.html

[26] https://ec.europa.eu/energy/sites/ener/files/documents/2014_final_report_eu_building_heat_demand.pdf

penetration of cooling in buildings of the analysed territory. A number of factors are here in play. One factor is the current state of cooling use. If cooling is already near saturation in some sectors, then further significant increase in cooling demand may be unlikely. This might especially be true in service sector buildings. Another factor is a future development of building stock in light of recent EU directives, such as EED and Energy Performance of Buildings Directive [19] and others as well as national legislation documents concerned with energy efficiency improvement. More efficient, better insulated and managed buildings have not only lesser heating demand, but cooling demand as well. Hence, an increase in cooling demand due to higher technology penetration might be balanced by decrease in specific cooling demand, due to better building efficiencies.

It is likely that most of the large service sector buildings have already cooling equipment installed. Predictions should be made, probably after discussion with representatives of the service sector, on likely development of cooling demand in such buildings taking into account likely implementation of energy efficiency improvement measures in the future.

Similar observations are valid for cooling demand in industry, and predictions here could be based on likely development of a particular branch of industry which is current consumer or will be likely consumer of cooling in the future.

EXAMPLE 13 Demand forecast
This Example shows a possible way how to collect information about the heating and cooling demand and its forecast. The Example shows figures for the Base Heat Demand Area 1101 (presented previously in Examples 5, 8 and 10). The first step of this task consists of assessing the evolution during the time frame of the assessment of those variables that allow the analyst to estimate the heating and cooling consumption of different areas. Some of these parameters could be: ▪ Specific consumption per square meter of heated floor area (MWh/m^2), by end use category;   ▪ Percentage of heated floor area with cooling (%);   As explained in previous sections, it is important to collect this information per type of building and sub-category, in the case of the service sector and the industry. An example of the data gathering for the demand area 1101 can be find on the following Table:

				2015	...	2030	...	2050
Households	**Multistore**	**Inventory data**	% heated floor area with cooling	0.65	...	0.71	...	0.78
		Specific consumption per m2 of heated floor area, by end use category (MWh/m2)	Heating	0.08	...	0.07	...	0.06
			Cooling	0.05	...	0.05	...	0.05
			Hot water	0.02	...	0.02	...	0.02
	Terraced	**Inventory data**	% heated floor area with cooling	0.70	...	0.75	...	0.81
		Specific consumption per m2 of heated floor area, by end use category (MWh/m2)	Heating	0.07	...	0.06	...	0.06
			Cooling	0.04	...	0.04	...	0.05
			Hot water	0.02	...	0.02	...	0.02
	Single	**Inventory data**	% heated floor area with cooling	0.85	...	0.90	...	0.98
		Specific consumption per m2 of heated floor area, by end use category (MWh/m2)	Heating	0.12	...	0.11	...	0.09
			Cooling	0.05	...	0.06	...	0.06
			Hot water	0.03	...	0.03	...	0.03
Service	**Public buildings**	**Inventory data**	% heated floor area with cooling	0.88	...	0.94	...	1.01
		Specific consumption per m2 of heated floor area, by end use category (MWh/m2)	Heating	0.22	...	0.20	...	0.18
			Cooling	0.15	...	0.16	...	0.18
			Hot water	0.06	...	0.06	...	0.06
	Education	**Inventory data**	% heated floor area with cooling	0.64	...	0.69	...	0.74
		Specific consumption per m2 of heated area, by end use category (MWh/a)	Heating	0.10	...	0.09	...	0.08
			Cooling	0.07	...	0.07	...	0.08
			Hot water	0.03	...	0.03	...	0.03
	...	**...**	...	...	...	...	...	...
	Other	**Inventory data**	% heated floor area with cooling	0.80	...	0.86	...	0.92
		Specific consumption per m2 of heated area, by end use category (MWh/a)	Heating	0.18	...	0.16	...	0.14
			Cooling	0.12	...	0.13	...	0.14
			Hot water	0.05	...	0.05	...	0.05

Once the analyst has collected the information regarding the forecast of these variables, the next step consists of gathering information on the possible evolution of inventory of buildings, as for example:

- Number of buildings,
- Total heated floor area (m^2).

Based on the forecast of the inventory data and using the forecasted variables mentioned before, the analyst can assess the total energy demand in each demand area (MWh). The results of the Example 13 can be found in the following Table.

					2015	...	2030	...	2050
System boundary 1	Households	Multistore	Inventory data	No. buildings	279	...	291	...	306
				Heated floor area (m^2)	89,153	...	93,610	...	98,068
			Total energy consumption by end use, GWh/a	Heating	6,864	...	6,486	...	6,040
				Cooling	2,631	...	3,300	...	4,168
				Hot water	1,945	...	2,042	...	2,139
		Terraced	Inventory data	No. buildings	7,541	...	7,874	...	8,295
				Heated floor area (m^2)	678,682	...	712,616	...	746,550
			Total energy consumption by end use, GWh/a	Heating	47,229	...	44,631	...	41,562
				Cooling	18,104	...	22,255	...	31,728
				Hot water	13,382	...	14,051	...	14,720
		Single	Inventory data	No. buildings	6,363	...	6,924	...	7,636
				Heated floor area (m^2)	636,297		668,112		699,927
			Total energy consumption for heating & cooling by source, GWh/a	Heating	74,295	...	70,209	...	65,380
				Cooling	28,480	...	35,009	...	43,232
				Hot water	21,050	...	22,103	...	23,155
	Service	Public buildings	Inventory data	No. buildings	18	...	19	...	21
				Heated floor area (m^2)	5,627	...	5,740	...	5,796
			Total energy consumption by end use, GWh/a	Heating	1,238	...	818	...	1,020
				Cooling	726	...	867	...	1,032
				Hot water	309	...	316	...	319
		...	...	...	...	...	...	...	...
		Other	Inventory data	No. buildings	81	...	89	...	96
				Heated floor area (m^2)	2,293	...	2,522	...	2,706
			Total energy consumption by end use, GWh/a	Heating	413	...	409	...	390
				Cooling	220	...	312	...	394
				Hot water	103	...	114	...	122

2 Definition of geographical and system boundaries

At this step of the methodology the geographical and the system boundaries are defined. This is needed to define meaningful entities for which the analysis can be performed.

The EED Annex IX notes that the geographical boundary *shall cover a suitable well-defined geographical area, e.g. a given region or metropolitan area, in order to avoid selecting sub-optimized solutions on a project by project basis.*

The geographical boundary should enclose a territory which the CA evaluates. The overall geographical boundary of the CA will in most cases coincide with the administrative boundary of a given MS, i.e. the whole country. However, in the case of larger MS it might be practical to divide their territory into regions in order to make energy mapping and planning exercise more manageable. Then geographical boundaries could coincide with an administrative boundary of a large region of the MS (such as NUTS-1 regions). Within the geographical boundary opportunities to link heating and cooling demand areas/points with sources of waste heat and local renewable sources should be identified. A too small geographical boundary might limit the possibilities of heat linking and thus it should be chosen with careful consideration.

Within the geographical boundary there will typically be a number of systems boundaries each containing identified heat demand areas/points, possibly linked with particular waste heat and/or renewable energy source(s). A number of local systems of "heat demand area(s)/point(s)-supply pipeline(s)-waste heat and renewable energy supply point(s)" will be used as objects in the CBA. The system boundaries will be identified through a relation of previously identified heating/cooling demand areas and points with identified potential sources of waste heat and renewable energy through a procedure called heat linking. This implies that the analysis needs to be at a level of spatial resolution that captures all relevant supply and demand sources.

2.1 Conversion of heat demand into heat load

The purpose of this section is to give general guidance on how to estimate the capacity of heating/cooling generation installations necessary to cover the demand identified as described in Chapter 1. This is needed if data does not contain information about heat loads (in MW or similar) but instead contains information about heating demand (in MWh/a, GWh/a or similar).

Calculating average and peak load of heat consumers

Average heat load of a building or group of buildings for heating can be calculated according to the formula:

$$Q_{AVG}^h = \frac{Q_{annual} \cdot \beta}{24 \cdot n_h} \tag{9}$$

here Q_{AVG}^h – average heat load of buildings for heating, MW; Q_{annual} – annual demand of heat, MWh/a; n_h - average duration of heating season in climatic or geographical region or country, days; β – share of annual heat demand for heating in total heat demand. National statistics could provide data of this heat demand component. For instance, if it would be defined that 90 % of heat consumed annually is used for heating purposes and 10 % is used for sanitary hot water, then the coefficient would be 0.9.

Average heat load of a building or group of buildings for preparation of domestic hot water can be calculated according to the formula:

$$Q_{AVG}^{h/w} = \frac{Q_{annual} \cdot (1-\beta)}{24 \cdot 365} \tag{10}$$

here $Q_{AVG}^{h/w}$ – average heat load of buildings for preparation of domestic hot water, MW; Q_{annual} – annual demand of heat, MWh/a.

Thus total average heat load of heat consumers can be calculated according to the formula:

$$Q_{AVG} = Q_{AVG}^h + Q_{AVG}^{h/w} \tag{11}$$

Maximum heat load of a building or group of buildings for heating can be calculated according to the formula:

$$Q_{MAX}^h = Q_{AVG}^h \cdot \frac{\theta_C - \theta_{min}}{\theta_C - \theta_{avg}} \tag{12}$$

here Q_{MAX} – maximum heat load of the building or building group, MW; θ_C – base temperature (indoor temperature of the buildings, usually assumed to be 18 °C), °C; θ_{avg} – average outside air temperature throughout heating season (during n_h days), °C; θ_{min} – average minimum temperature in given region or a country, °C.

Maximum heat load of a building or group of buildings for preparation of domestic hot water can be calculated according to the formula:

$$Q_{MAX}^{h/w} = k_w \cdot Q_{AVG}^{h/w} \tag{13}$$

here k_w – coefficient, which expresses unevenness in hot water consumption. Depending of the type of hot water consumers and other factors, usually its value varies from 1 to 2.

Thus total peak heat load of heat consumers can be calculated according to the formula:

$$Q_{MAX} = Q_{MAX}^h + Q_{MAX}^{h/w} \tag{14}$$

Calculating peak load of district heating network

In order to know the average load of a district heating network, its heat losses should be added. Heat load to cover heat losses Q_{LOSS} in the network depends on many factors, such as the quality of pipes insulation, configuration of the network, mode of network operation control and so on. Since most of DHC networks are ground-buried, these losses are also influenced by the ground temperature. For well-designed and maintained DHC networks average yearly losses do not exceed 10 % of heat supplied into the network, for old and neglected networks they may reach 20 % or more [20]. Thus heat losses might be calculated according to the formula:

$$Q_{LOSS} = \frac{Q_{annual} \cdot \gamma}{24 \cdot 365} \tag{15}$$

here Q_{LOSS} –capacity of heat losses in the district heating network, MW; γ – share of average yearly heat losses of the total heat amount supplied into the network ($0.1 \div 0.2$).

Maximum heat load of a district heating network can be calculated according to the formula:

$$Q_{MAX}^{DH} = Q_{MAX} + Q_{LOSS} \tag{16}$$

Calculating capacity of equipment to cover calculated load

The equipment can be sized based on the load characteristics. Firstly, one needs to determine whether the equipment is going to cover the base, intermediate, peak or the entire load.

An indicator that is used in this context is the capacity factor. The capacity factor is defined as the ratio of the energy produced to the energy that could be produced if the unit was operating at nominal capacity all over the year:

$$CF = \frac{Q_{prod}}{P_{MAX} \cdot 24 \cdot 365} = \frac{\overline{Q_{prod}}}{P_{MAX}} \tag{17}$$

here P_{MAX} is the nominal capacity of the unit (MW), Q_{prod} the annual production of energy (MWh) and $\overline{Q_{prod}}$ the average hourly production of energy (MW)

Baseload plants have a capacity factor close to 100 %, intermediate load plants between 40 % – 70 % and peak load plants between 5 %–10 %. Usually technologies that are selected for peak load have low specific capital costs and high operating costs. Technologies selected for base load have high specific capital costs and low operating costs. Technologies selected for intermediate loads will have to be flexible enough to allow load following operation.

In many cases, e.g. residential boilers, the energy load will have to be fully covered by the installation. In this case:

$$P_{MAX} = Q_{MAX} \tag{18}$$

Non-dispatchable technologies that are using resources with variable production, e.g. solar thermal, are highly affected by the seasonality effect. It is common to size such plants on technical/land use restrictions and cover the rest of the load with other dispatchable sources. In this case for a given size, the energy produced can be estimated by means of Eq. (13). Capacity factors of such units depend on exogenous parameters e.g. latitude, solar radiation, and the location.

For heat linking pipelines, the link size depends mainly on the operational patterns of the supplier and the load curve of the demand. If the heat source is a centralized cogeneration power plant, its operation will depend on the electricity production demand. As a result, heat coming from such plant is considered to be non-dispatchable, as it will be available when the power plant needs to produce electricity. For a baseload electricity plant this will not be an issue, since its operational patterns are predictable. Such plants can cover the base heat load or part of it depending on their size. Similarly, if the source is industrial waste heat, depending on the industry type (batch or continuous operation), it can cover part of the base load or a part of the intermediate load that remains constant for the specified daily time interval. For both cases it is possible to cover a bigger part of the fluctuating heat loads, if heat storage is introduced and properly designed.

For other cases, it can be assumed that the capacity of the main energy generation installations or sources, such as CHP plants with a technology that is able to operate in load following mode would be equal to $P_{MAX} = Q_{AVG}^{DH}$ (in case of district heating network) or $P_{MAX} = Q_{AVG}$ (in case of point consumers). The rest of the heat load – the difference between maximum and average heat loads – would be covered by supplementary heat generators, for instance conventional gas boilers, and heat storage systems. In any case, the total capacity of selected energy generation equipment must be able to cover all the peak demand of energy consumers.

Similar equations can be used to estimate the capacity of cooling generation installations necessary to cover the demand identified as described in previous chapters of this methodology.

Improving level of detail of CA: Energy demand is highly variable, with important implications for the design of plants and their incorporation into the electrical/heat generation system. If detailed data can be obtained, then a more accurate way to size heat generation installations would be to construct detailed yearly or hourly heat load graphs/curves. The load duration curve is a nice tool that provides the time period during which the load is greater than a specific value (cumulative distribution of load on an annual basis), see Figure 9. The selection of necessary capacities of heat generation equipment and heat linking pipelines can be based on characteristic curves.

Figure 9. Example of theoretical load duration curve.
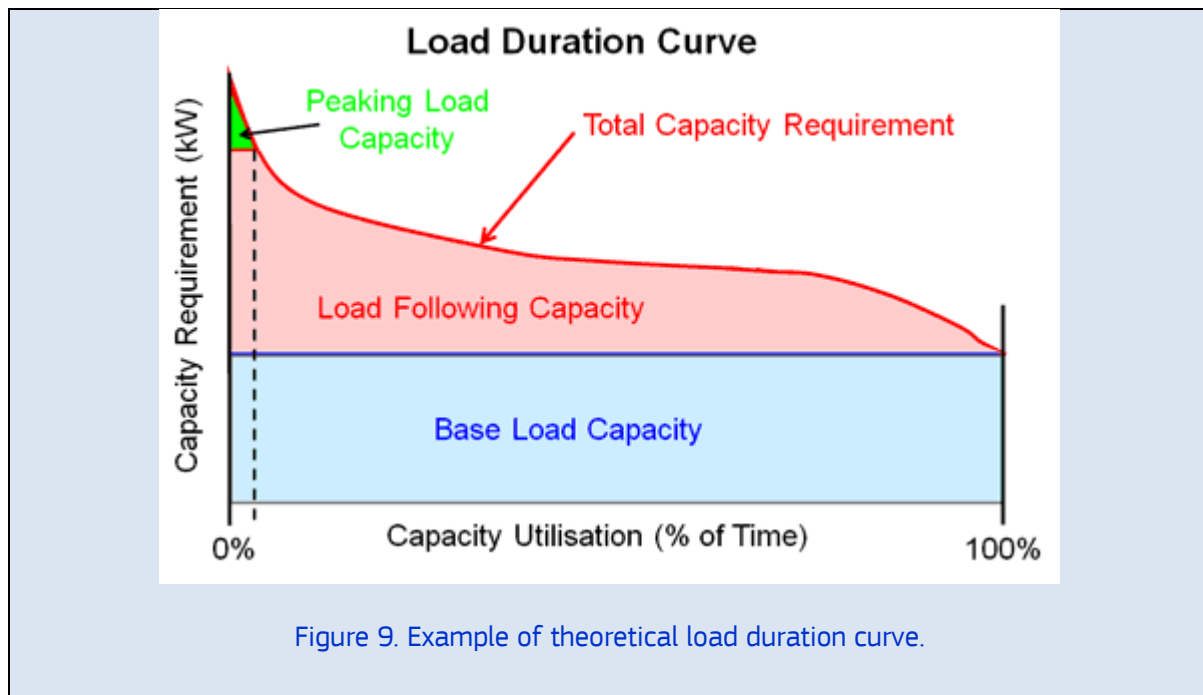
2.2 Definition of system boundaries

The method described in his section allows identifying suitable areas of the national territory in which the deployment of DHC should be considered in the context of the CBA. Those areas that are identified as potentially belonging to a common DHC network are grouped within the same system boundary. In the context of the CA, the system boundary will constitute the smallest units of CBA analyses.

The method is based on a systematic analysis of the territory that allows identifying system boundaries with sufficient heat/cold demand to cover the costs associated with DHC deployment and exploitation. The resulting systems with their boundaries will be analysed in the CBA in order to determine whether it is worthwhile economically to pursue the implementation of identified heat links. Such systems are referred to as *high demand density systems* later in the text.

If a heat link from a heat demand area/point to a waste heat and renewable energy source is absent, then the system boundary will coincide with the boundary of the heat demand area/point.

Setting of system boundaries and grouping of heat consumers by using proper parameters are very important steps in analysing the feasibility of DHC networks because of the collective nature of such form of heat supply. Other identified heat consumers, for whom only individual heat supply solutions will be analysed, should also be grouped into systems on the regional, municipal or other basis into what later in the text is referred as *low demand density systems*.

These concepts are graphically presented in Figure 10.
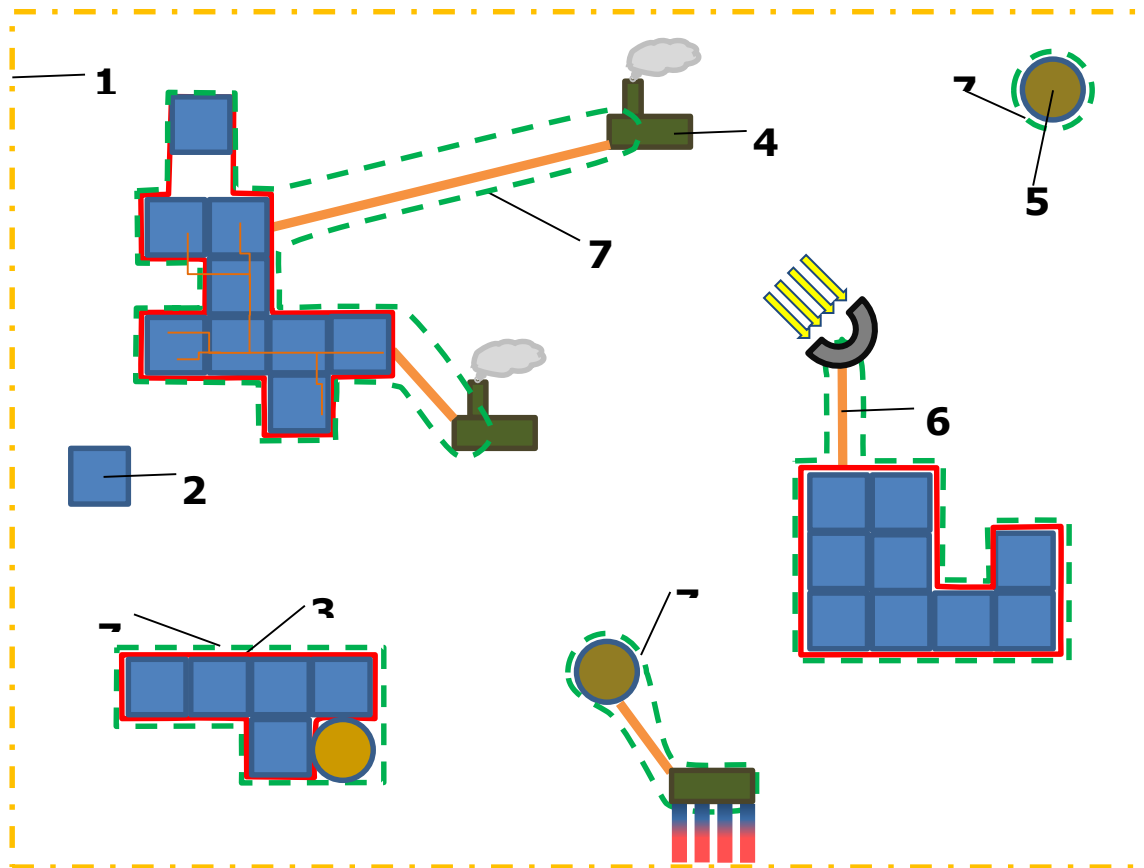
Figure 10. Definition of system boundaries. 1 – geographical boundary; 2 – base heat demand area; 3 – greater heat demand area; 4 – source of waste heat or renewable energy; 5 – heat demand point; 6 – heat linking pipeline; 7 – system boundary.

In order to set the system boundaries in a systematic manner appropriate selection criteria are needed. Such criteria must be based on parameters that are representative of the economics of DHC at the local level. Further in this chapter, the plot ratio is used for illustrative purposes, but as explained below other potentially more suitable parameters do exist. A well-thought selection of the criteria is important because it will affect the reliability of the results.

2.2.1   Selection of an appropriate parameter

Several parameters can be considered:

- Plot ratio: ratio of the building floor area to the land area;
- Heat density: amount of useful heat/cold demand per unit of land area and per year;
- Linear Heat Density: amount of useful heat/cold demand per unit of trench length;
- Supplementary parameter: Total heat/cold demand within the system boundaries.

The plot ratio is the parameter mentioned in the EED annex VIII for the establishment of the heat map, but this does not mean that only this particular parameter has to be used to assess DHC

solutions in the context of the CBA. The plot ratio provides an insight on the habitat density in a given area. This is not an optimal factor to determine feasibility of DHC because the plot ratio is only an indirect measure of the energy demand in the concerned area. The latter will be also determined by the specific heat demand of the concerned buildings (useful heat demand per unit of floor area), which vary depending on the buildings fabrics (level of thermal insulation), climatic conditions, usage, etc.

Heat density is a better parameter than plot ratio, because it provides a direct measure of the amount of the heat/cold that could be sold within a given area. However both parameters fail to account for the spatial distribution of the habitat within the considered area, which affects the length of pipes and hence the installation costs.

Linear Heat Density provides therefore a better insight on economic feasibility of DHC. It requires an estimate of the length of trench required to install DHC in the considered area, which could be a complex exercise in the context of the CBA. However when performing the economic valuation of scenarios involving DHC, such an estimate will have to be made anyway, in order to evaluate the capital costs of the considered DHC network. This means that in principle an estimate of the linear heat density could be available, see Annex B for more information.

The total heat/cold demand within the system boundaries can be used as an additional parameter, in order to make sure that there is a sufficient total demand within the system boundaries to justify the capital expenses associated with DHC. For example this would allow ruling out densely built neighbourhoods of very small size.

2.2.2   Determination and optimisation of parameter threshold

Once the parameter have been selected, appropriate threshold values have to be established. The knowledge of such threshold simplifies greatly the CBA by concentrating the DHC analysis in those areas where DHC is likely to make sense. In the areas below this threshold only individual heating/cooling would be considered.

Proper selection of the threshold is important because if the threshold is set too high, the analysis could miss areas where DHC could still make sense from an economic perspective.

The threshold can be uniform for the whole national territory or could be differentiated according to regional or even local circumstances e.g. climatic zone etc. The selection of this threshold can be based on:

- Practical experience within the country (or countries with similar conditions) and/or;
- Performing the CBA for a limited number of representative areas and typical DHC solutions. For instance if it can be seen that below a certain value of the threshold the economic NVP is

systematically negative, it is not useful to consider those areas for which the threshold is below that value, and/or;

- Performing the whole CBA for the whole territory (or large regions) with different values of the threshold in order to determine the threshold which delivers the highest NPV (large-scale optimisation).

EXAMPLE 14 Optimisation of parameter threshold

Performing the CBA using a pre-set threshold in all analysed cases could sometimes diminish potential of DHC implementation. One possible situation is the following: consider a system boundary (e.g. a city) comprising areas with plot ratio values (or heat densities) that differ significantly, e.g. some of them being only slightly above while others being significantly above threshold, see Figure 11.
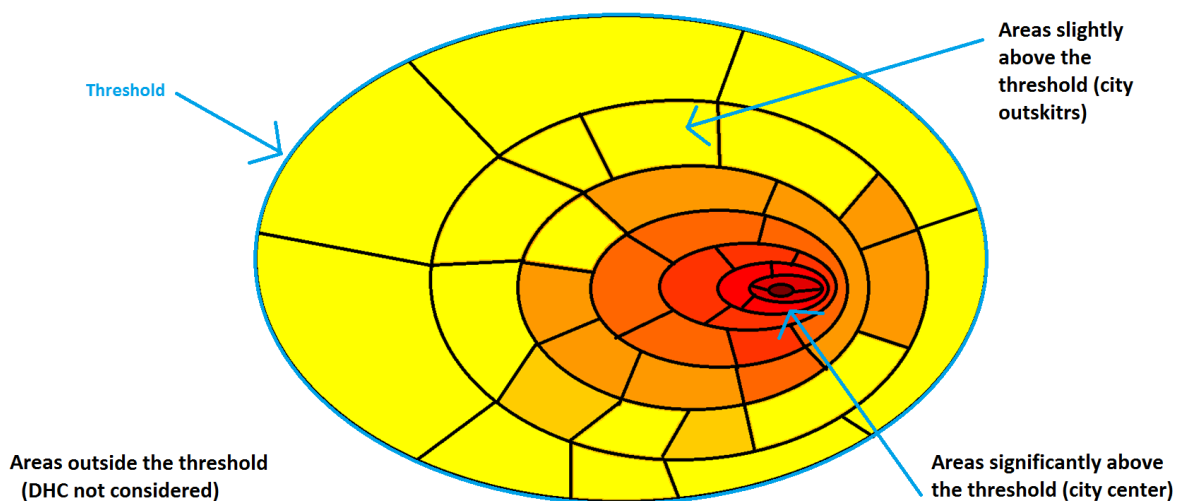
Figure 11. Example of heat map of a city.

Let's assume that the resulting NVP for the whole system boundary is negative (e.g. because the areas of relatively lower plot ratio values all result in a negative economic NPV because of higher DHC costs due to local circumstances). If the analysis would stop here, the resulting solution (i.e. individual H&C solutions within the entire system boundary) might be sub-optimal because individual solutions would be also applied to the core of the city with high plot ratio where DHC might be economical.

In this case the threshold for the concerned areas might be increased, the system boundaries redefined and then the CBA performed again. If NVP is still negative, the procedure can be reiterated with a higher threshold until a positive NPV is reached. These iterations can be performed manually if the number of concerned systems is low, but if needed they can be automated. It is even possible to consider an automated optimisation procedure as explained in the next section.

The example above illustrated a situation where the utilisation of the threshold results locally in a sub-optimal solution. There are other possible situations that can lead to such sub-optimal situations. Such situation is likely to occur when:

- There are uncertainties on the value of the threshold;
- The cost estimates of DHC deployment can vary regionally/locally (e.g. due to differences in resource cost / availability, local configuration etc.);
- If plot ratio is used: regional/local variations in building fabrics, in climatic conditions, in occupation/usage (e.g. seasonal occupation in tourist resort areas);
- Etc.

In those situations, the likeliness of sub-optimal situations is high. Therefore it may be useful to consider a (systematic) iterative optimisation of the threshold. The feasibility of this iterative process depends on the software used to exploit the data, the complexity and amount of data, and the computation power of the hardware.

2.2.3 Setting the system boundaries

Here plot ratio threshold of 0.3 has been selected for illustration purposes; however, as it was discussed, other parameters and threshold values can be used for such an exercise as well. Setting the system boundary within the geographical boundary can be accomplished following these steps:

1. Combine previously identified base heat demand areas with plot ratio higher than 0.3, into larger units, further referred to as *System boundaries*. A system boundary consists of one or more base heat demand areas that are potentially suitable for the implementation of a common district heating/cooling system, see Figure 10. System boundaries would generally not expand beyond the administrative boundaries of a city or other settlement. System boundaries covering very large cities can be divided into smaller parts. All previously identified base heat demand areas (such as neighbourhoods or similar territorial sub-units) inside system boundary limits would be treated as a part of a single energy demand area. The result of this step would be a larger geographical area with known boundaries, whose heating and cooling demand as well as heating and cooling demand would be the sum of demands of its smaller components. Example 15 illustrates this concept.

2. When determining heat demand areas to be considered for DHC implementation another important factor to take into account is the total annual energy consumption of a particular heat demand area. It might be reasonable to assume that only significantly large heat demand areas are viable places for DHC investment. As was mentioned previously, EED proposes to use 20 GWh/a threshold for industrial zones. Heat demand thresholds, based on annual heating and/or cooling consumption, can be also applied for screening of greater heat

demand areas. Such thresholds could be based, for instance, on the experience of existing networks.

3. Adjoining demand areas (for instance suburbs) can be added to this territory if they are too small to be evaluated as separate heat demand areas and if they are within a defined threshold distance (threshold distance in this case should not be very large, for instance 2 or 3 km). Such a limiting distance should be introduced in order to avoid that the amount of heat needed by such additional consumers would be larger or comparable to the heat losses incurred by connecting heat supply pipelines.

4. Industrial zones (point consumers) can be treated following the same logic. If they are located inside of a heat demand area, then their heating/cooling load and heating/cooling demand can be added to the load and demand of this area on the condition that they require similar heat temperatures as residential consumers. If they are outside of heat demand area, then they can be added given that the distance is short. Otherwise they would be treated as separate entities.

5. Link demand areas/points with potential sources of waste heat and renewable energy, thus setting system boundaries. Linking of heat consumers and suppliers can be accomplished applying the approach described below including the following equation:

$$k = P_D / \left(L \cdot \sqrt{P_D / P_S} \right) \qquad (19)$$

here P_S – heat load, which can be supplied by a particular supplier, MW; P_D – heat load of a particular demand area/point, MW; L – distance from demand area/point to a particular heat supplier, m.

This empirical equation was derived with the intention to minimize the number of heat links and to minimize their length. It should be applied following these steps:

1. Within the threshold distance[27] coefficient k should be calculated for all the possible heat links to heat consumers for each heat supply point;

2. Starting from the heat link which has the highest value of coefficient k, all heat links will be ranked, see Table 15;

3. Links are considered one by one, starting with the link displaying the highest value for k. After identification of a particular heat link, heat demand and supply used by that heat link should be removed from further linking process. After linking of this particular heat source with heat demand area/point that heat source might still have available waste heat and thus it can form a part of another heat link. In the essence this means that the same source can supply

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[27] Threshold distances can be based on notifications produced by each MS under Article 14.6 of EED.

a number of consumers and vice versa, i.e. large consumers can be supplied by a number of heat sources;

4. Coefficient *k* should be recalculated for remaining heat links, the next largest value determined, and then this process is repeated until either there is no heat supply that can be used or heat demand that can be covered.

In order to speed up linking process these steps can be automated.

Improving level of detail of CA: when identifying the distance between heat sources and demands the simplest way would be to measure using a straight line connection, but such a method might be inaccurate. Bearing in mind that identifying the precise trajectory of a heat linking pipeline is very demanding task, one can consider adding a percentage over the straight line distance. At the very least, the trajectory of the identified heat link should not cross over other identified heat consumption areas or insurmountable territories such as large bodies of water (lakes, sea inlets, etc.). Using GIS tools may facilitate this exercise.

When linking a supply point to a demand area, the heat linking pipeline should proceed till the boundary of heat demand area. From that point it will be distributed to consumers using a DHC network. If the heat demand area has multiple heat suppliers with different heat linking pipelines, each pipeline should connect to the nearest point of the boundary of the heat demand area. In such a case, the DHC network would have a number of heat distribution hubs.

EXAMPLE 15 Setting of system boundaries

This example follows the steps for setting of system boundaries, described in the text above.

1. Let us assume that inside the administrative boundaries of a city 6 base heat demand areas with plot ratio exceeding 0.3 and with different heat demand have been identified. They are combined into a single heat demand territory with total heat load of 14 MW.
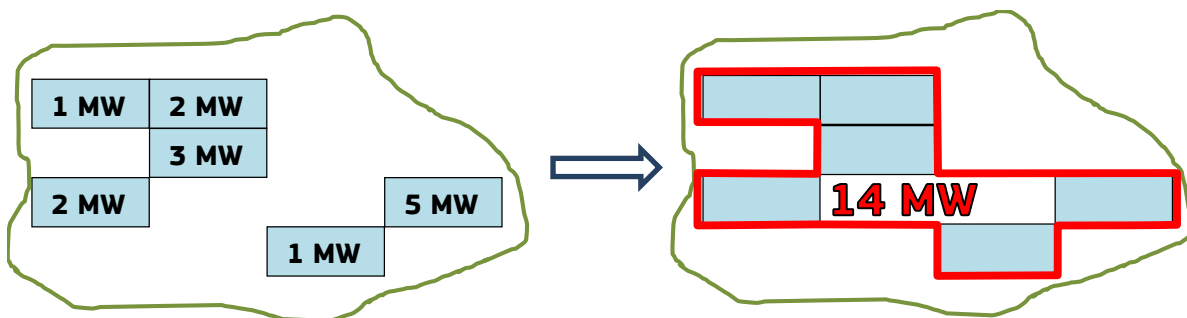
Figure 12. Combination of base heat demand areas within administrative boundary of a city into one heat demand area.

The end result in Figure 12 is heat demand area whose heat demand consists only of demands of six identified base heat demand areas (each of them having plot ratio higher than 0.3). All other territories are used only for connection of those six base heat demand territories into one entity. Their heat demand is not accounted for further here due to the fact that their plot ratios previously were identified to be below 0.3.

2. Around this heat demand area there are 3 additional heat demand territories with different demands and within different distances between each other, see Figure 13. Let us assume that two thresholds are set: a) the load threshold to make a decision about the size of demand area is set to 3 MW; b) distance threshold for joining of territories is set to 2 km.

14 MW demand territory is above the size threshold and is treated as a separate heat demand area.

The 1 MW demand territory is too small to be a separate demand area. It is also within the distance threshold. It is joined to the previously identified 14 MW area, thus making a part of joint 15 MW area.

2 MW demand territory is too small to be a separate demand area but the distance exceeds the distance threshold of 2 km. Thus this area would not be joined with other areas and is removed from further analysis of joining demand areas.
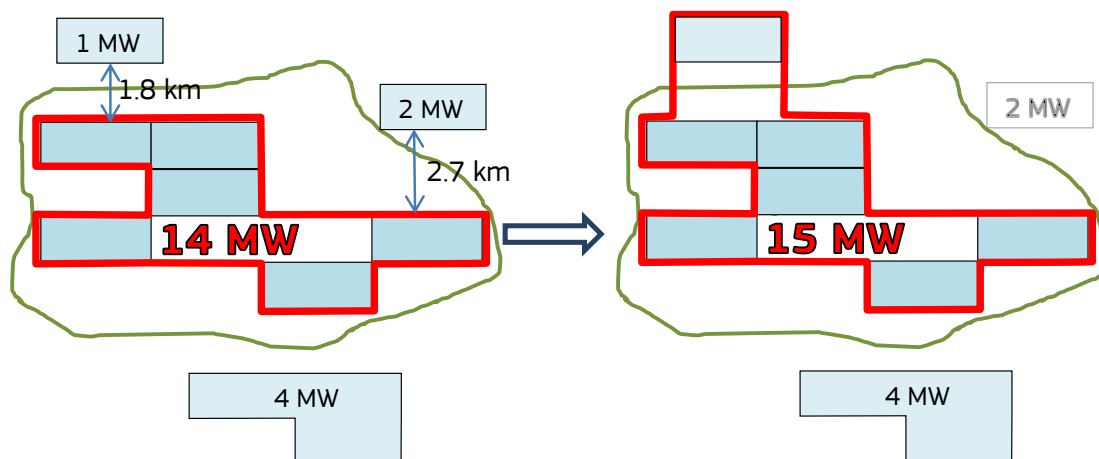
Figure 13. Joining of adjacent demand areas.

3. Nearby there are three industrial heat demand installations with different capacities and characteristics and within different distances to the identified demand areas, see Figure 14. Let us assume that the distance threshold is the same as above – 2 km.

A 4 MW industrial installation is outside the threshold of 2 km and is treated as a separate entity.

A 3 MW installation is inside of the distance threshold, but due to the high temperature heat of 150

°C is incompatible with residential district heating, it is also treated as a separate entity.

A 2 MW installation is inside of the 4 MW demand area, it requires 100 °C heat, which is compatible with residential district heating and is joined to this area thus forming a part of joint 6 MW demand territory.

At the end of this step we have 4 heat demand areas and points.
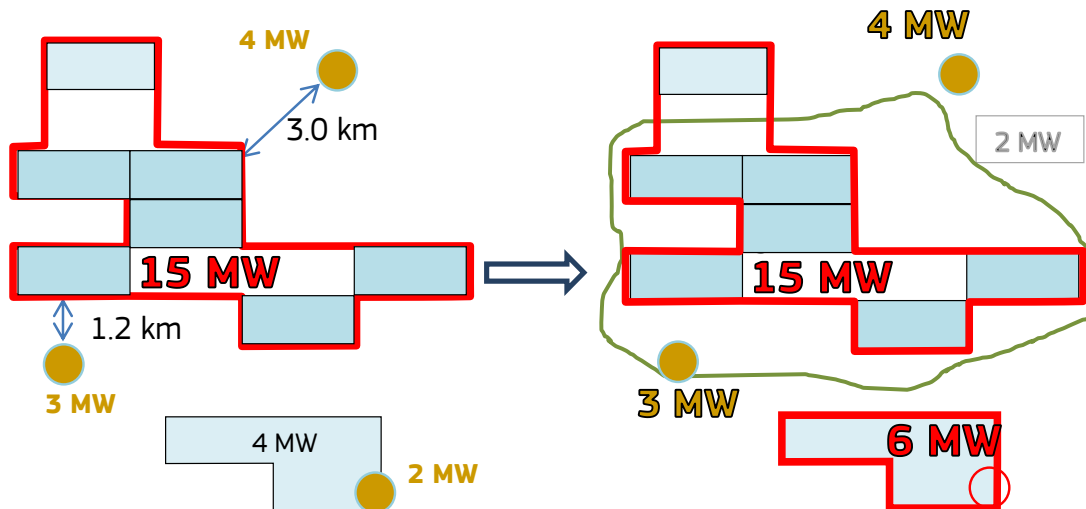
Figure 14. Joining of industrial installations.

4. In the vicinity of identified heat demand areas and points there are three sources of waste heat. Total available waste heat in this area is 24 MW and total demand 28 MW.

Let us assume that the technical distance threshold is set to 15 km. The largest waste heat source is 12 MW. Table 15 contains information about all possible heat links as well as calculated k values.

Table 15. Possible heat links within geographical boundary.

Heat supplier	Possible heat consumer	Distance, km	Coefficient k
12 MW	15 MW	8.0	1.677
	4 MW	14.5	0.478
8 MW	15 MW	12.5	0.876
	6 MW	7.0	0.990
	3 MW	8.5	0.576
4 MW	15 MW	2.0	3.873

	6 MW	7.5	0.653	

As can be seen from Table 15, the highest value of *k* coefficient identifies linking the 4 MW supply with a 15 MW demand area. After removal of the heat associated with this link from the analysis, the next largest k value is for heat link 12 MW supplier – 11 MW demand area (11 MW is left uncovered of 15 MW demand area after attributing 4 MW supplier to it in previous step) and so on. The outcome of this step is 4 systems with their boundaries as presented in Figure 15 (industrial consumer of 4 MW is the fourth system, although currently no waste heat source is available for it).
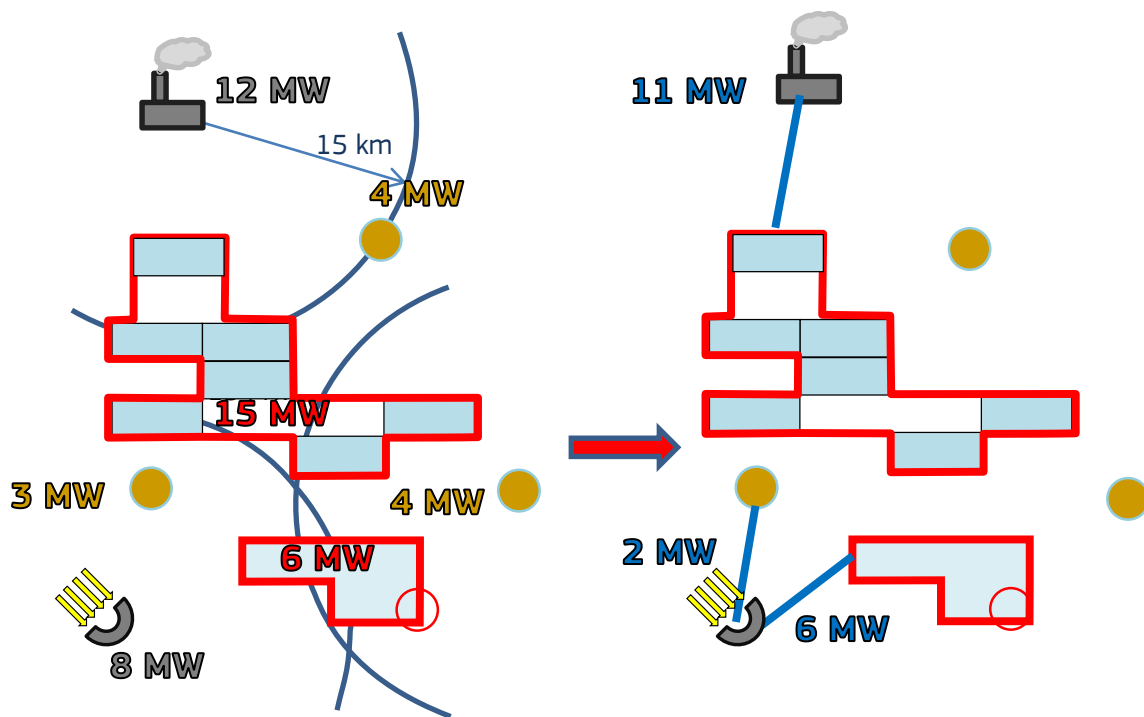
Figure 15. Linking of demand areas/point with waste heat sources.

Improving level of detail of CA: it should be noted that Example 15 presents a simplified way of performing a heat linking. In order to improve accuracy additional factors, such as patterns of waste heat availability of a particular heat source and heat demand patterns of a particular consumer can be taken into account also.

The outcome of this Section of the methodology can be a data table relating one or more base heat demand points/areas to a common heat system, possibly supplied with one or more waste heat or renewable energy sources, as presented in Table 16.

The approach above can be repeated with different plot ratios, and/or with different distance thresholds for the heat linking. Each repetition will result in a different definition of system boundaries, showing different possible extensions of DHC and different options for using waste heat. All these alternatives can be included in specific scenarios and evaluated separately with the CBA. In these scenarios, hypotheses will have to be made about which technologies are to be used for the demand areas/points that are not (in full or in part) covered by waste heat sources and/or DHC, see Chapter 5.

Table 16. Example of possible data table for heat demand systems.

Heat demand system	Made of base heat demand areas and point heat consumers	Annual demand of heating, GWh/a	Annual demand of cooling, GWh/a	Heating load, MW, max./average	Cooling load, MW, max./average	Identified potential sources of waste heat and renewable energy	Heat load of system that can be covered by identified waste heat sources, MW	Existing/planned DHC networks
1	Area 1101					Power plant 1 Solar thermal installation 1		
	Area 1102							
	Industrial plant 1							
2	Area 1103					Power plant 2, Waste incineration plant 1		
	Area 1202							
	Area 1203							
3	Area 2101					none		
	Area 2102							
4	Industrial plant 2					Industrial plant 3		
...	...					...		

Table 17. Combination of data on base heat demand areas into one system.

EXAMPLE 16 Heating and cooling data of a system boundary

Following the Examples 5, 8 and 10, this example collects information about the hypothetical System boundary 1 integrated two base heat demand areas: demand area 1101 (the one showed in the previous examples) and demand area 1102. In this example, it is considered that there is no industrial demand within this system boundary. Besides, the service sector data is not showed in its totality to simplify the data presentation but it is important to mention that the different sub-categories of the service sector have to be analysed separately to implement the whole analysis properly.

			AREA 1101						AREA 1102						System boundary 1 (AREA 1101 + 1102)					
			Households					Service	Households					Service	Households					Service
			Multistore	Terraced	Single	Public buildings	...	Other	Multistore	Terraced	Single	Public buildings	...	Other	Multistore	Terraced	Single	Public buildings	...	Other
Inventory data		No. buildings	279	7541	6363	18	...	81	125	3393	2863	8	...	36	404	10,934	9,226	26	...	117
		Heated floor area (m²)	89153	678682	636297	5627	...	2293	40119	305407	286334	2532	...	1032	129271	984089	922631	8159	...	3325
Installed capacity by end use category and technology (MW)	Heating techn.	Gas boiler	8.4	49.3	80.1	1.8	...	0.4	3.8	22.2	36.0	0.8	...	0.2	12.2	71.5	116.1	2.6	...	0.6
		Heat pump	0.6	6.3	9.2	0.1	...	0.1	0.3	2.8	4.2	0.1	...	0.0	0.9	9.1	13.4	0.2	...	0.1
	Cooling techn.	Heat pumps	1.5	10.2	16.1	0.2	...	0.2	0.7	4.6	7.2	0.1	...	0.1	2.2	14.7	23.3	0.4	...	0.3
	Hot water techn.	Gas boiler	1.0	7.2	11.3	0.2	...	0.2	0.5	3.2	5.1	0.1	...	0.1	1.5	10.4	16.3	0.2	...	0.2
Annual energy consumption, by end use category (MWh)		Heating	6864	47229	74295	1238	...	413	3089	21253	33433	557	...	186	9953	68482	107728	1795	...	598
		Cooling	2631	18104	28480	726	...	220	1184	8147	12816	327	...	99	3815	26251	41296	1053	...	319
		Hot water	1945	13382	21050	309	...	103	875	6022	9473	139	...	46	2820	19403	30523	449	...	150

3 Identification of technical potential of efficient heating and cooling solutions

As described by the CSWD (see point 18.4), ´based on the identified heat demand and heat demand forecast, the next step consists of identifying those elements of the heat demand that technically could be satisfied by the applicable efficient solutions, including high efficiency cogeneration, micro-cogeneration and efficient district-heating and cooling. This means establishing the maximum or technical potential´. The technical potential is assessed as the theoretical maximum amount of energy that could be produced with efficient heating and cooling solutions, disregarding all non-engineering constraints such as economic or market barriers [21]. So, the technical potential of a solution could be defined as: ''the amount of demand (measured in terms of useful energy, MWh/a) that could be covered by the technology or energy resource being evaluated, considering its maximum achievable penetration within the considered timeframe, considering technical or practical limitations, including topographic limitations, environmental, and land-use constraints, without taking into consideration economic criteria.'' It can also be expressed in terms of the corresponding installed capacity of the technology (MW).

Thus, the followings aspects have to be taken into account to determine the technical potential:

- The availability of resource. This factor will be a limiting factor for some efficient solutions but not for all. It will be a restricting element in the case of solutions based in renewable resources and in the case of recovered resources, e.g., waste heat from existing power plants or industry.
- The technical factors that intervene in the energy conversion and/or use processes (efficiencies, temperature ranges, etc.).
- The size of the demand. This parameter is taken into account in order to determine the maximum amount of useful energy that is required. In those cases where the technical availability of the resource is higher than the demand, the demand delimits the amount that will be evaluated or considered within the technical potential of a solution. Similarly, in those cases where there is no relevant restriction on the technical availability of the resource, e.g., air heat pumps or micro-cogeneration, the technical potential will be sized as a function of the demand.

So, the identification of technical potential has to be conducted at a system boundary level, considering the demand of the different segments of demand within it.

As mentioned before, the assessment of the technical potential is based on pure technical aspects. The aim of the assessment is to obtain the theoretical maximum amount of energy that could be

produced with efficient heating and cooling solutions. In the next step of the analysis (see section 7), the economic evaluation will be conducted in order to identify which part of that technical potential can economically be met by efficient heating and cooling solutions. The output of the cost-benefit analysis will allow determining the economic potential of efficient heating and cooling options.

This section provides firstly, an extensive identification of possible technical solutions that should be considered within the frame of Art.14 of the EED. The aim of this subsection is to provide a comprehensive inventory of solutions that should be considered by analysts. Any option that is technically viable and for which there are resources at MS level, should be considered within the Comprehensive Assessment and its technical potential should be assessed. The second part of the section provides some guidelines to assess the technical potential of those solutions.

3.1 Identification of technical solutions

A wide range of high efficiency heating and cooling solutions could satisfy the heating and cooling demand identified in the previous steps of methodology. A '**solution**' is a 'combination of three elements named:

- A resource that is used as a source of energy, e.g. waste heat, biomass or electricity:
- A technology that is used to convert the source of energy into a useful form of energy for consumers, e.g. Heat recovery, efficient boilers or heat pumps, and;
- A distribution system that allows providing the useful energy to consumers (centralized or decentralized).

This sub-section provides an extensive but non-exhaustive list of available solutions. Other solutions can be used as long as they fall into the category of efficient district heating and cooling or efficient individual heating and cooling[28]. These solutions have been described in greater detail in Annexes A-H. Table 18 summarizes the main technological solutions in the context of the CA to help in the identification process.

Regarding the type of resource, the technological solutions can be grouped in the following categories:

- **Solutions using recovered resources**, which encompass the use of waste heat from industry or power generation. These resources can be used for different uses: only heat; heat

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[28] See the descriptions provided in Article 2 (41), (42) and (43) of EED.

and power; cooling. Within this category, different technologies can be used, including: heat recovery; CHP-Organic Rankine Cycle, absorption chillers and heat pumps.

- **Solutions using renewables**, which mainly (but not only) encompasses geothermal, solar; biomass and waste to energy, for different uses (only heat; heat and power; cooling). Within this category, different technologies can be used, including: heat recovery; CHP-Organic Rankine Cycle, absorption chillers; heat pumps; efficient boilers; turbines, furnaces etc.

- **Solutions using conventional resources**, which encompass fossil fuels and electricity, similarly, for different uses (only heat; heat and power; cooling). Within this category, different technologies can be used, including: turbines, engines, Rankine cycle, boilers and heat pumps.

Table 18. Identification of technological solutions, as well as distribution systems, for improving efficiency on heating and cooling supply

Type	Resource	Use	Technology	Centralized (District networks or large scale consumers)	Decentralized (Small scale consumers)	Annex
Recovered resources	**Waste heat from industry or power generation**[1]	Direct use of heat	Heat recovery	√		D
		Upgrade heat*	Heat pump			D, E
		Heat and Power	CHP – Organic Rankine Cycle			D, A
		Cooling	Absorption chiller			D, C
Renewable resources	**Geothermal**[1]	Direct use of heat	Heat recovery	√		H, D
		Upgrade heat*	Heat pump			H, E
		Heat and Power	CHP – Organic Rankine Cycle			H, A
		Cooling*	Absorption chiller			H, C
	Solar thermal	Direct use	Heat recovery	√	√	G,D
		Heat and Power	CHP – Rankine Cycle			G,A
		Cooling*	Absorption chiller			G,C
	Biomass	Production of heat	Efficient Boilers	√	√	F
		Heat and Power	Turbines, engines, Rankine Cycle[2]			A
	Waste to energy (Municipal and industrial)	Production of heat	Furnaces, efficient boilers	√		D, F
		Heat and Power	CHP – Rankine Cycle			A
Conventional resources	**Fossil Fuel**	Heat and Power	Turbines, engines, Rankine Cycle[2]	√	√	A
		Production of heat	Efficient Boilers			F
	Electricity	Heating or cooling	Ground, water, air heat pumps	√	√	E, H

* Technically possible but not not commercially widespread

1 Availability of resource depends on location

2 EED, Annex I Part II

As can be seen in Table 18, depending on the technological solutions, centralized and decentralized systems could be applied:

a) Decentralized (or individual) systems in which the heat and cold is produced *in situ,* so basically, each consumer produces its own heat or cold, following a distributed model of production. Decentralized systems can be installed within system boundaries that have been

characterised as high demand density (according to section 2.2.1) and that have been characterised as low demand density.

b) Centralized systems, which use district heating/cooling systems to distribute thermal energy from a central heat source to consumers. Centralized systems can be used to supply heating and cooling to system boundaries that have been characterised as high demand density as well as large scale consumers, e.g. an industrial plant. Centralized systems could, technically speaking, be used also to supply low demand systems, but it would normally not be economical. Therefore, it could be excluded from the analysis based on the statement on the CSWD (Paragraph 36), which says that 'only realistic scenarios need to be examined.

Energy can be distributed by hot water or steam (for both heating and cooling needs) or cool water (cooling needs) lines. With regard to the types of energy supplied, DHC networks can be divided into two main categories:

1) District heating networks, which can operate in different modes:

- Heating only network – it is used to supply heat for space heating and domestic hot water preparation. Such mode of operation is typical in colder climate countries with low or relatively short duration of cooling demand;
- Heating and cooling networks – it is used to supply heat for space heating during the cold season and heat for absorption chillers during the warm season. Absorption chillers might be installed on site near the final consumers or they can serve as hubs of a secondary cooling network to which consumers of cooling are connected;

2) A dedicated cooling network, cold water might be produced centrally using absorption or electric chillers and then distributed to cooling consumers through dedicated cooling supply pipelines.

- Regarding the choice of heat source for the DHC network, there are many options. In order for the DHC network to be qualified as an "efficient district heating" network, they have to meet the criteria, set in EED Article 2 (41). This article states, that an efficient DHC network should use at least:
- 50 % renewable energy. This category covers many different sources and technologies, including: biomass boilers; solar thermal; geothermal; heat pumps (for DHC applications water source might be the only option) and waste-to-energy plants. Thermal storage is an additional option to use with renewable technologies. Use of thermal storage might help to offset fluctuation of primary energy supply, which might occur due to, for instance, lower solar radiation during a cloudy day. Also, thermal storage might help to improve plant efficiency since it mitigates the requirement for heat production to closely follow heat demand. Large water tanks offer the least expensive solution. For more information on thermal energy

storage, see [22][29] and [23][30]. Use of renewables as energy sources is related with certain technological limitations, e.g. related to their supply of primary energy, or others with technological peculiarities of utilization of primary energy. These limitations and peculiarities should be taken into account when considering applicability of a particular technology for a particular heat demand system (see Example 17). See Annexes G and H for more information.

- 50 % waste heat. The sources of waste heat to be used in DHC networks will in most cases be industrial processes, as discussed in section 1.4, it can however be any other waste heat source, such as heat regained from waste water in cities.

- 75 % cogenerated heat. Cogeneration is the simultaneous generation of electrical or mechanical energy (power) and useful thermal energy from a single energy source. The definition of high efficiency cogeneration can be found in Annex II of EED. A list of possible high efficiency cogeneration technologies is presented in Table 18. Here only large size cogeneration technologies, which could supply DHC network are included. See Annex A for more information about Cogeneration.

- 50 % of a combination of such energy and heat.

It should be noted that since the definition of efficient DHC network does not indicate the need to cover 100 % of heat demand with CHP, waste heat and renewables, the DHC system might use conventional boilers using fossil fuel as supplementary heat source, which are not covered in this chapter of the methodology.

EXAMPLE 17 Identifying peculiarities of particular renewable technologies for inclusion into analysis
Different renewable technologies are associated with different peculiarities, for instance:
a) Biomass boilers can be sized to meet different heat demands, but in general they are most cost efficient when operating at constant load. Thus it is common to size them to cover a part of heat demand and supplementary heat sources (usually fossil fuel boilers) will cover peak heat demand. Also, it is advised to consider inclusion of condensing economisers as part of a biomass combustion system. Due to large moisture content in biomass the instalment of condensing

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[29] http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf

[30] http://iea-etsap.org/web/Highlights%20PDF/E17IR_TES_Hauer_Jan2012_AH_GS_rev3%20HL.pdf

economisers may lead to particularly large increases in efficiency (up to 30 % in some cases).

b) Use of heat pumps as heat sources for DHC networks is restricted to areas having sufficiently large heat sources. Such systems might be utilized by the DHC of, for instance, coastal towns utilizing heat accumulated throughout the summer in sea water[31].

c) Use of solar thermal panels is highly dependent on the climate zone. In colder climate zones, solar thermal panels are typically sized according to the heat demand which occurs in mid-summer when the panels produce most heat (e.g. sized to cover domestic hot water demand). In warmer climate zones solar panels can be used to cover hot water or cooling demands and in some instances can even provide heating during cold season.

3.2 Estimation of the technical potential

Once the technological solutions have been identified at system boundary level, the next step consists of identifying their technical potential. The following sub-sections provide guidelines on how to determine the availability of resources for those solutions whose technical potential is highly dependent in the availability of resource. These solutions are mainly solutions based on recovered resources, e.g., waste heat from industry, and solutions based on renewable resources.

3.2.1 Electrical installations

Here two cases should be considered at the system boundary level:

1. Existing power plant converted to CHP – the technical potential is the maximum heat demand supplied at typical heat to power ratios, see Section 1.4 and Annex A for more information.
2. New CHP – for fossil fuelled CHP the technical potential heat demand of high heat demand density areas that is not supplied with centralised heat supply today. For e.g. biomass CHP, there will be restrictions related to biomass availability, see Section 3.2.3.

3.2.2 Waste heat from industry

The technical potential for this technology would be treated for existing or planned industries only, as presented in Section 1.4.

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[31] See the example of use of heat pumps in Helsinki (Finland) DHC network on p.21 of presentation http://www.iea.org/media/workshops/2013/chp/markoriipinen.pdf

3.2.3 Identification of potential of renewable resources

This section is intended to describe the evaluation of additional potential of renewable resources, for utilisation of which suitable installations have yet to be built. Here only RES with the highest overall potential are described, although in particular locations other RES, such as biogas, might also make significant contribution to energy systems.

The preferred source of information for identification of renewable heat supply potential would be national studies on the subject matter, which are prepared in many MS. Another important source might be the reports of different scientific projects. In the absence of such information, the guidelines given here could also be used for identifying such potential.

The proposed sequence for identification of potential renewable heat supply is presented in Figure 16.
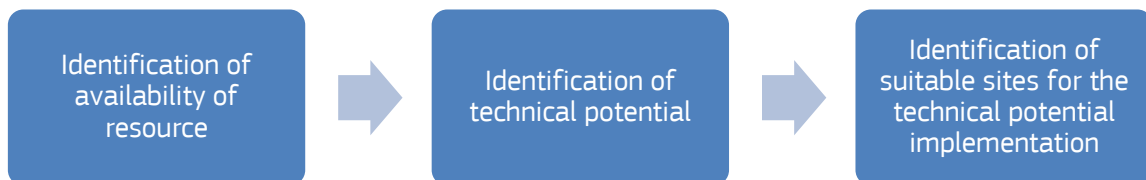
Figure 16. Proposed sequence for identification of potential heat supply from renewable energy sources.

The first step would involve identification of specific parameters of each RES, such as availability of that resource in a given territory (e.g. solar irradiation level, area and age of woods, presence of geothermal regions etc.) and location of that resource within the analysed territory in order to identify maximum or theoretical availability of given resources.

The second step would involve gathering data on technical characteristics of each RES, such as efficiencies of utilisation technologies, constraints for their use, such as availability of suitable land surface, level of sustainable annual cuttings, etc.). National renewable energy action plans[32], prepared within the framework of Renewable Energy Directive 2009/28/EC [24] could also be consulted. Table 11 of those plans contains an estimation of the total contribution of RES in heating and cooling till 2020. This information could be used to estimate the implementation rate of identified technical potential during the analysis period. Information contained in the National renewable energy action plans and statistical databases could also be used to identify the portion

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[32] http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

of theoretical RES potential which is already utilised, so that the expansion of a particular RES technology is not overestimated.

The final step would be the identification of most likely and suitable locations for installing RES systems. Although there are significant differences between different RES, in general such installations should be located as close as possible to individual energy consumers or high demand density system boundaries.

Solar thermal

For solar thermal systems, the theoretical potential depends on the yearly solar irradiation (kWh/m²) in the given locality. This information can be obtained from different sources, for instance PVGIS, created by the JRC Institute for Energy and Transport[33], HelioClim 3 databases[34], Pan-European Thermal Atlas[35] and other sources.

The next step would be the identification of technical potential taking into account restricting factors, such as technical factors or suitable land availability. Efficiency of solar panels is one restricting factor and it is dependent on the type of solar panel, difference between collector and ambient temperature, orientation of the panel and so on [25]. In general, solar panels are the most efficient when producing low temperature water, and therefore most suitable for sanitary hot water preparation, although they can be used for space heating and cooling purposes also.

Thus the amount of heat available at the particular site can be calculated according to the formula:

$$H_S = I \cdot r \cdot A \tag{20}$$

here H_S – estimated annual potential of heat supply from given solar thermal installation, kWh/a; I – yearly solar irradiation in a given region, kWh/m²·a; r – efficiency of the solar thermal system; A – available surface for installation of solar panels, m².

Solar energy availability throughout the year should also be taken into account due to the very fluctuating nature of this resource.

Solar panels can act as either individual heat sources for separate buildings or central sources for DHC systems. Due to that available surface for the installation of solar panels should be estimated in a different way for individual or DHC network related solutions.

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[33] http://re.jrc.ec.europa.eu/pvgis/countries/countries-europe.htm

[34] http://www.soda-is.com/eng/services/service_invoke/gui.php?xml_descript=hc1_month.xml#parameters

[35] http://maps.heatroadmap.eu/maps/31157/Renewable-Resources-Map-for-EU28?preview=true#

In case of individual installations available surface is related with the available area of the roofs and facades of the buildings. Suitable surface of the buildings taking into account construction, historical and shading elements is estimated to be equal to 60 % for the roofs and 20 % for the facades [26]. Other researchers give somewhat different numbers. Some studies estimate the available area of roofs and facades per capita, although such generalised numbers should be treated with care due to uncertainties associated with the roof areas per capita of different types of buildings.

Centralised solar collector systems are installed on land. The availability of land in such case should be estimated taking into account competing land uses, such as agricultural, recreational, urban, etc. Suitable location for centralised solar collector systems could be estimated based on the availability of unused land, or land not suitable for other purposes, located within a defined threshold distance from high demand density system boundaries. Information about different types of land can be extracted from different sources, such as general maps of municipalities or countries as well as Corine Land Cover database[36].

More information about solar thermal energy recovery technologies is presented in Annex G of this methodology.

Biomass

Biomass resources can be divided into different sub-categories, depending on its source: forestry activities, industry and agriculture.

For forestry biomass resources, information should be gathered about the area of forests in the analysed region (e.g. national, NUTS-3), type of woods and their age, their growth rates, amounts of wood residue left after felling operations, and calorific value of different types of wood biomass.

For agricultural biomass, such as straw, information gathered should include the area of crops in a given territory, yields of particular crops, ratio of grain to straw and straw calorific value.

Such information might be gathered from forest inventories, dedicated national studies and policy reports or reports of different studies, such as the Pan-European Thermal Atlas, Atlas of EU biomass potentials[37] [27], [28], etc.

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[36] http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2

[37] http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomass_futures_atlas_of_technical_and_economic_biomass_potential_en.pdf

The technical potential of heat from biomass could be based on identified technical, environmental and other restrictions. It could include a distance threshold for transportation of the biomass till identified heat demand areas and points, sustainability considerations (allowable removal of forest cuttings residues, minimum age requirement for felled wood, etc.), restrictions for the exploitation of particular areas (national parks, recreation zones, etc.). It should also be taken into account that not all available biomass can technically be gathered.

After estimating the technical potential, the next step would be to identify likely places for biomass combustion installations. One can assume that biomass combustion installations would be built near identified system boundaries in conjunction with the existing or potential DHC networks.

Biomass is a transportable resource, and therefore care should be taken not to allocate the same identified resource to several analysed systems boundaries. This can be achieved by identifying the resource available in the region and compare it to how much biomass that is allocated to the system boundaries of that region. If the resource is limited (lower than the sum of demand of all system boundaries) it could be assigned to the largest systems, or it could be assigned to system boundaries that needs a renewable resource to meet the high efficiency DHC requirement (see Section 3.1), e.g. systems that do not benefit from other sources like waste heat or geothermal energy.

Geothermal energy

Information about the temperatures at different depths in the ground can be extracted from national geothermal studies, the Geothermal DH (Geo-DH) atlas[38], the Pan-European Thermal Atlas, as well as other studies and reports.

In addition to the availability of suitable temperatures, other criteria should also be taken into account, such as the geothermal flow rate of the heat carrying medium (m³/h).

The technical potential for geothermal energy utilisation can be estimated by identifying suitable geological regions within a certain threshold distance from the System boundary. A threshold distance is needed because the geothermal extraction plant will be connected with a pipeline to a DHC network.

Similarly to other potential renewable energy sources, care should be taken not to assign the same geothermal resources to several System boundaries.

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38 http://loczy.mfgi.hu/flexviewer/geo_dh/

More information about geothermal energy recovery technologies is presented in Annex H of this methodology.

Waste-to-energy

The most accurate evaluation of energy recovery potentials from waste can most likely be found in national studies. In case such studies would be absent, the amount of recoverable energy could be estimated as explained below.

In order to estimate the amount of useful heat which can be obtained from the waste, it is necessary to estimate the amount of primary energy, which is contained in the waste. In order to do so, the following information needs to be collected:

a) total amount of the waste or the amounts of different waste types generated in the given country or region. This information can be obtained from Eurostat databases[39], national databases (for instance Statistics Netherlands[40] or dedicated reports [29]. In some countries energy recovered from waste and waste recycling are already widely used. This needs to be taken into account in the estimate of the potential for additional energy recovery.

b) calorific value of different types of the waste. These can be obtained from different sources of scientific literature and legislative documents. Table 19 provides an example of calorific values of different types of waste, as reported in Reference Document on the Best Available Techniques for Waste Incineration [30][41].

Table 19. Typical net calorific value ranges for some waste types [30].

Input type	Comments and examples	NCV in original substance (humidity included)	
		Range GJ/t	Average GJ/t
Mixed municipal solid waste (MSW)	Mixed household domestic wastes	6.3 - 10.5	9
Bulky waste	e.g. furniture etc. delivered to MSWIs	10.5 - 16.8	13
Waste similar to MSW	Waste of a similar nature to household waste but arising from shops, offices etc.	7.6 - 12.6	11
Residual MSW after recycling operations	Screened out fractions from composting and materials recovery processes	6.3 - 11.5	10
Commercial waste	Separately collected fractions from shops and offices etc.	10 - 15	12.5
Packaging waste	Separately collected packaging	17 -25	20
RDF-refuse derived fuels	Pellet or flock material produced from municipal	11 -26	18

[39] http://ec.europa.eu/eurostat/web/environment/waste/main-tables

[40] http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLEN&PA=7467eng&D1=0-25,76-86&D2=0&D3=a&HD=100215-1537&LA=EN&HDR=G1,G2&STB=T

[41] http://eippcb.jrc.ec.europa.eu/reference/BREF/wi_bref_0806.pdf

	and similar non-hazardous waste		
Product specific industrial waste	e.g. plastic or paper industry residues	18 - 23	20
Hazardous waste	Also called chemical or special wastes	0.5 -20	9.75
Sewage sludge	Arising from waste water treatment works	See below	See below
	Raw (dewatered to 25 % dry solids)	1.7 - 2.5	2.1
	Digested (dewatered to 25 % dry solids)	0.5 - 1.2	0.8

It is recommended to assume that energy recovery from waste stations would be region (NUTS-2 or NUTS-3 depending on the country specifics) based in order to optimise their operation. Thus primary energy, available from waste in region *x* can be calculated as follows:

$$B_{Wx} = \sum G_{xj} \cdot NCV_j \qquad\qquad (21)$$

here B_{Wx} – primary energy, recoverable from waste in region x, MJ/a (or similar unit); G_{xj} – amount of particular waste stream *j*, generated in region *x*, t/a,; NCV_j – net calorific value of particular waste stream *j*, GJ/t.

Since in some countries or regions energy recovery from waste and waste recycling are already widely implemented, G_{xj} should include only the amount of waste which currently is available in landfills and which is not already designated for other recycling processes.

If we would assume that there would be a single energy recovery from a waste station per region then B_{Wx} would correspond to a primary energy input of that station. In order to maximise utilisation of recovered energy, such stations should be placed near significantly large energy consumers, such as high demand density system boundaries.

In case CHP technology would be used, available heat can be estimated using default efficiency and power-to-heat ratios of particular CHP technologies. In case of heat only installations final energy supply could be estimated taking into account the efficiency of a particular energy recovery technology.

Another, simplified method for energy recovery potential estimation can be used based on the information provided in [30]. For instance, in case of municipal waste, in [30] it is stated that:

a) for a CHP plant, together with 0.6-1.0 MWh_e/tonne of waste, heat export of 1.8-4.5 GJ/tonne of waste can be achieved (based on an average NCV of 15.1 GJ/tonne);

b) for a heat only plant, the available heat export of 10.8 GJ/tonne of waste can be achieved (based on an average NCV of 15.1 GJ/tonne).

[30] also describes best available technologies for energy recovery from other types of waste.

4 Construction of scenarios

4.1 Setting the baseline scenario

Construction of the baseline is defined in Annex IX of EED is one of the steps of the CBA. Its purpose is 'to serve as a reference point, to which the alternative scenarios are evaluated'.

A more detailed description of the definition of a baseline scenario is provided in the CSWD. According to it, the baseline scenario should describe the present situation and its likely evolution as if no parameters of the existing situation are changed. The CSWD also calls this scenario business-as-usual (BAU) or reference scenario.

In most literature sources the baseline scenario is defined as the most likely development of existing energy demand, supply and transformation based on current knowledge, technological development and policy measures. In the context of the EED, the baseline scenario should consist of a realistic business-as-usual scenario. It should reflect already adopted policy measures with regard to existing national and EU legislation, for example the EPBD and RES[42]. The policy measures that are taken into consideration should be explicitly mentioned. Note, that although adopted policy measures should be taken into account, it does not necessarily mean that those policy measures will necessarily suffice to meet all policy targets. Should the baseline scenario fall short of important policy targets, it would indicate that additional measures may be necessary to reach the targets. A literature review is presented in Annex I.

Based on the forecasted demand assessed in section 1.7, the baseline scenario should include a description of the current supply and its likely evolution over time. This would include information on how the demand is met at present and assumptions about how it will be met in the future. In order to conduct these estimates, information on different aspects of the technologies that would satisfy the heating/cooling demand in the baseline, such as their performance, has to be gathered as it will be required later on for the economic analysis. These technologies do not necessarily have to be confined to conventional options. They might also include high-efficiency cogeneration or efficient DHC if such developments are expected also in the baseline.

The baseline scenario definition should allow determining the technology mix within each previously identified system boundary (as discussed in section 2 of this methodology).

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[42] EPBD: Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings; RES: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

The scenario construction also includes the determination, for each technology and each system boundary, of the size and number of the different installations allowing meeting the heat demand (following the process described in section 2.1). This is needed in order to be able to proceed with the economic valuation of the scenario.

4.1.1 Identification of heating and cooling demand and its development

The identification of heating and cooling demand is the first step of this process, see section 1.1. Results can be found in Example 16.

The second step consists of forecasting the heating and cooling demand. This task has been already described in previous sections of this document (see section 1.7).

4.1.2 Characterisation of the current mix of heating/cooling supply technologies

Characterising the current mix of heating and cooling technologies is the next step. The baseline scenario should include a description of the current mix of heating and cooling supply technologies for each of the segments of the heat demand, and within each system boundary. Bottom-up approach based on detailed information should be given priority (e.g. results of inquiries, statistics from technology suppliers etc.). In the absence of detailed information, one possible way to derive this information, for example, is to apply a top-down approach by using information on the current mix of fuel consumption and making assumptions about main technological solutions applied on the national context. This is the approach used within Examples 5, 8 and 10 to derive the current energy mix.

Since the heat supply technology mix is related to the heat demand source, information on the latter can be used to calibrate estimates for the former. For example, data on the number of houses or flats within the system boundary can be used to estimate the total number and size of individual heating units installed (i.e. assuming one installation per house). Likewise, data on the number and size of industrial installations can be used to approximate the number of heat generation units (and their sizes) in the industrial sector.

Some of the data sources and collection methods presented in section 1 can also be used to get information on the current technology mix.

4.1.3 Projecting the future technology mix and technology replacement rate

The result of this step of the methodology should be a picture of the heating/cooling supply technology mix during the entire time frame of the analysis for each end use category and within each system boundary.

One option is to make/use an estimate of the fuel mix in the final year and then determine the technology mix for that year and all years in between. This can be done by making assumptions of

different evolutions (linear, parabolic, stepwise, see Figure 17), depending on the technologies involved. Combining this information with the forecasts of the heating and cooling demand, allows determining the technology mix forecasts in the whole time frame.

EXAMPLE 18 Estimating technology replacement curves

Curve of technology replacement rate might have different profile and the decision on which curve shape to use in scenario will have an influence on financial performance results of that particular scenario. Assuming that total replacement of given technology will be realized after 20 years, some possible shapes of curves are presented in Figure 17.
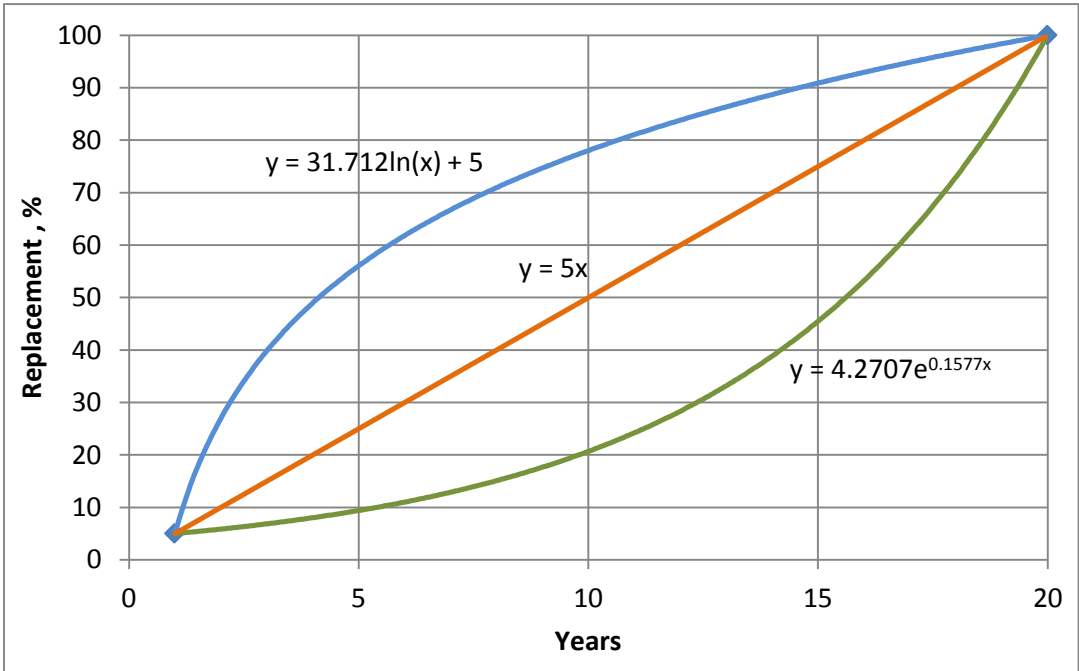
Figure 17. Examples of possible technology replacement curves.

It is recommended that a realistic approach is taken in terms of penetration of new technologies, and to appropriately stretch the anticipated evolution over time, e.g. the implementation of district heating in a whole a city is likely to take several years.

One other option is to take the technology replacement rate into consideration: currently used heat generation equipment will have to be replaced on a regular basis due to the fact that they reach the end of their technical lifetime. An assumption should be made about which technologies will continue to be used throughout the selected timeframe of the analysis and which will be replaced and by which technologies, also taking into consideration the likely evolution of the heating and cooling demand of the concerned demand areas or points, as determined in section 1. In these cases the replacement rate would represent the limit for the penetration of new technologies for the existing demand. The replacement rates for heating technologies in specific sectors can be

determined from market studies or other relevant sources, taking into account also the potential influence of existing policies in that replacement rate. Alternatively, an approximation of the replacement rate can be estimated on the basis of the average lifetime of the technology. So for a technology with a lifetime of 20 years, it can be assumed that 1/20 of the stock is replaced each year i.e. 5 % of the stock. However, where relevant, it can also be assumed that replacement rates will be affected by future policies and will lead to faster replacement rate than necessitated by the lifetime of the technologies. For new demand, e.g. new residential areas due to population increase or anticipated industrial developments, assumptions on which technologies will be used are needed.

Projecting penetration of different heat generation and supply technologies in the future might be based on: expert judgement; extrapolation of historical trends; national or EU projections of the energy system[43], modelling output, assessment of future evolution of fuels, etc.

As mentioned above, the impact of adopted policy measures should be taken into account when describing the future technology mix. Policies can influence the uptake of new technologies through a range of measures, including financial incentives, regulations and other mechanisms to overcome barriers to implementation (such as information campaigns).

Another issue which should be taken into account is the probability of full implementation of policy measures in practice. As was mentioned previously, the baseline scenario should include current policy measures, but it does not mean that those policy measures will be fully realised in practice during the selected timeframe. As such, the analysts might make an expert decision on the degree of implementation of different policy targets. This decision might be based on an assessment of the historical developments of previous policy measures and targets and other sources.

If it will be assumed that heat generation units will be replaced by units of the same type, it should be taken into consideration that a technology may evolve and this evolution might change their operational performance. In particular, the replacements might be expected to have an improved operational efficiency as a result of technology advancements. Likewise, the capital costs of the technologies may decline over time as a result of learning effects.

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[43] As, for example, the European Commission report on 'EU Energy, Transport and GHG Emissions Trends to 2050'.

4.1.4 Determination of the size and number of the installations

Once the technology mix is known for a specific year, within a given system boundary, and for a specific segment of the heat demand, then the size (installed capacity) and the amount of units of each technology can then be determined.

For example if the technology mix resulting from the baseline scenario stipulates that 10 % of detached houses will be equipped with heat pumps in 2040, and if there are 1640 detached houses with a nominal heat demand of 20 kW within one specific system boundary, then the number and size of the required heat pumps can be calculated, knowing the efficiency of those heat pumps.

The economic valuation will require calculating, for each year, the number of additional units of each type.

For district energy, the capacity and sizing of network hardware (pipes and interfaces) will also need to be estimated, see Annex B (Efficient District heating) for more information. Where district cooling is to be provided, the installation will be sized to provide the heat required by one or more absorption chillers. Some recommendations for sizing approaches of typical technologies are provided in Section 2.1 and in the Annexes attached to these Guidelines.

EXAMPLE 19. Data required for forecasting the technology mix in the BASELINE scenario

Following Examples 13 and 16, Example 19 shows a possible way of collecting information for the technology mix identification in the baseline scenario. This task consists of forecasting the technology mix evolution in the long term. It is suggested to collect this information per type of demand sector (households, service, etc.), as well as per type of sub-sector, e.g., single houses, multi-storey buildings, etc. An example of the data gathering for the period 2015-2050 (although not all the years are shown) can be found in the Table 20.

Table 20. Data gathering for technology mix forecasting for system boundary 1.

							2015	...	2030	...	2050
System boun-dary 1	Households	Multistore	Technology penetration (%)	Heating technology	Gas boiler		80%	...	65%	...	50%
					Heat		20%	...	20%	...	20%
					District heating	Gas boilers	0%	...	5%	...	10%
						CHP	0%	...	10%	...	20%
				Cooling technology	Heat		100%	...	100%	...	100%
				Hot water technology	Gas boiler		100%	...	90%	...	80%
					Solar		0%	...	10%	...	20%
		...	...								
	Service	Public buildings	Technology penetration (%)	Heating technology	Gas boiler		85%	...	71%	...	56%
					Heat		15%	...	19%	...	22%
					District heating	Gas boilers	0%	...	4%	...	7%
						CHP	0%	...	7%	...	14%
				Cooling technology	Heat		100%	...	100%	...	100%
				Hot water technology	Gas boiler		100%	...	93%	...	86%
					Solar		0%	...	7%	...	14%
		...	...				...	...	...	...	...

Finally, based on the heating and cooling demand forecasts (estimated in the Example 13) and the estimated percentage of each technology on the technology mix, the installed capacity in the BASELINE scenario can be assessed. The results for this Example for the system boundary 1101 are shown in the Table 21.

Table 21. Technology mix forecasts for system boundary 1.

							2015	...	2030	...	2050
System boun-dary 1	Households	Multistore	Technology penetration, MW	Heating techn.	Gas boiler		7,962	...	6,114	...	4,379
					Heat pump		1,991	...	1,881	...	1,752
					District heating	Gas boilers	0	...	470	...	876
						CHP	0	...	941	...	1,752
				Cooling techn.	Heat pumps		3,815	...	4,784	...	6,043
				Hot water techn.	Gas boiler		2,820	...	2,665	...	2,482
					Solar		0	...	296	...	620
		...	...				..	...	...	...	...
	Service	Public buildings	Technology penetration, MW	Heating techn.	Gas boiler		2,136	...	1,175	...	1,168
					Heat pump		377	...	308	...	459
					District heating	Gas boilers	0	...	59	...	148
						CHP	0	...	119	...	296
				Cooling techn.	Heat pumps		1,053	...	1,258	...	1,497
				Hot water techn.	Gas boiler		628	...	595	...	555
					Solar		0	...	46	...	92
		...	...				...	...	...	...	...

4.2 Construction of alternative scenarios

The aim of the Comprehensive Assessment is to estimate "*the potential for the application of high-efficiency cogeneration and efficient district heating and cooling*". Section 3 provides some guidelines on the identification of technical potential for different efficient heating and cooling solutions. As it is described in section 3.1 a 'solution' is a 'combination of three elements named: a resource (e.g. biomass), a technology (e.g. efficient boiler) and a distribution system (e.g. centralized system)', see Table 17.

Once the technical potential is identified, it is proposed to construct alternative scenarios to cover as much demand as is technically possible by each of the efficient heating and cooling solutions identified within the section 3. As shown in Figure 18. Input data required for the alternative scenario definition.18, the input data required to define alternative scenarios is the forecast of the demand and the information regarding the technical potential of each efficient solution. So, in the end, each scenario will be built to evaluate the effects of expanding each technical solution to their maximum extent (i.e. taking into account its technical potentials) with the aim of, later on, identifying the economic potential of that solution.

As a consequence, in each system boundary, there will be as much alternative scenarios as technically viable solutions are identified before, within the technical potential identification. As was mentioned on Section 3, Table 18 presents an extensive list of efficient heating and cooling solutions to consider. The aim of that list is to provide to the analyst with a broad list of technical solutions that should be considered within the analysis in order to fulfil the requirements of comprehensiveness derived from Art. 14 of the EED.
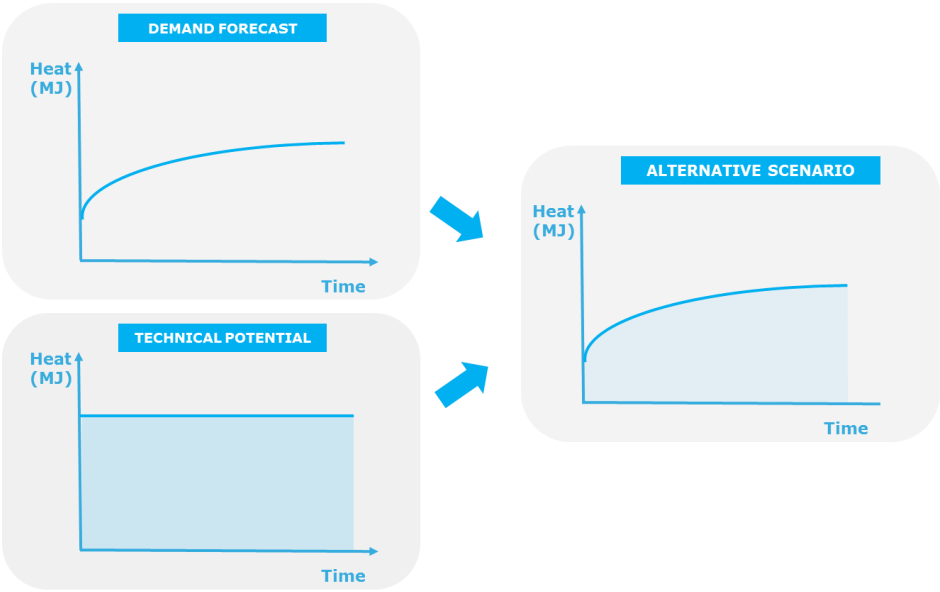
Figure 18. Input data required for the alternative scenario definition.

The procedures for defining the alternative scenarios are to a large extent similar to those used for defining the baseline scenario (see section 4.1). The corresponding technology penetration has to be determined for all years and the size and number of the installations has to be calculated. More details about sizing can be found in Section 2.1 The evolution of the demand should be taken into account, e.g. for the sizing of centralised equipment the capacity should be able to meet

the maximum demand throughout the lifetime of that asset, or for modular equipments capacity can be added as the demand increases.

The level of detail within the description of alternative scenarios will differ between individual solutions and centralized solutions:

- In the case of individual solutions, the technology penetration by 'segment' of the demand has to be determined. By 'segment' we mean a specific end use (space heating/cooling/hot water) and a specific sub-sector (e.g. detached residential houses).
- In the case of centralized solutions, the required capacity will be assessed based on the whole demand covered without making distinctions between demand segments (e.g. if a centralized solution supplies heating to households and service sector, the analysis should estimate the required capacity to cover the demand of both segments, without distinguishing by segment). The reason is that the decision of implementing the solution will affect all segments as a block.

In those cases where the technical potential of a solution is lower than the demand, the rest of the demand has to be covered by other technologies. This adjustment is required in order to make the baseline and the alternative scenario comparable, with the aim of assessing the economic potential of the solution later on. It is suggested to assume that the technical solutions used to cover the gap of demand are the ones used in the baseline scenario and with the same shares of those technologies. Nevertheless, when a technology that has been evaluated in the alternative scenario is also present in the baseline, the gap should be filled with the other technologies but without an additional contribution of the technology evaluated (because its technical potential has been already covered till its maximum extent). This situation is illustrated in Figure 19. Filling the gap of demand on the alternative scenarios.19. As can be seen, three different technical solutions supply the heating and cooling demand in the baseline scenario: technical solution 1 covers 60 % of the demand; technical solution 2, covers 20 % and technical solution 3, covers 20 %. An alternative scenario is built to evaluate the maximum expansion of the technical solution 1. Its technical potential allows covering 70 % of the demand. The gap of demand has to be covered considering the technologies present in the baseline. Nevertheless, the technology 1 cannot be used to fill the gap because the scenario has been built assuming its maximum technical potential so it is not possible to provide more energy with that solution.
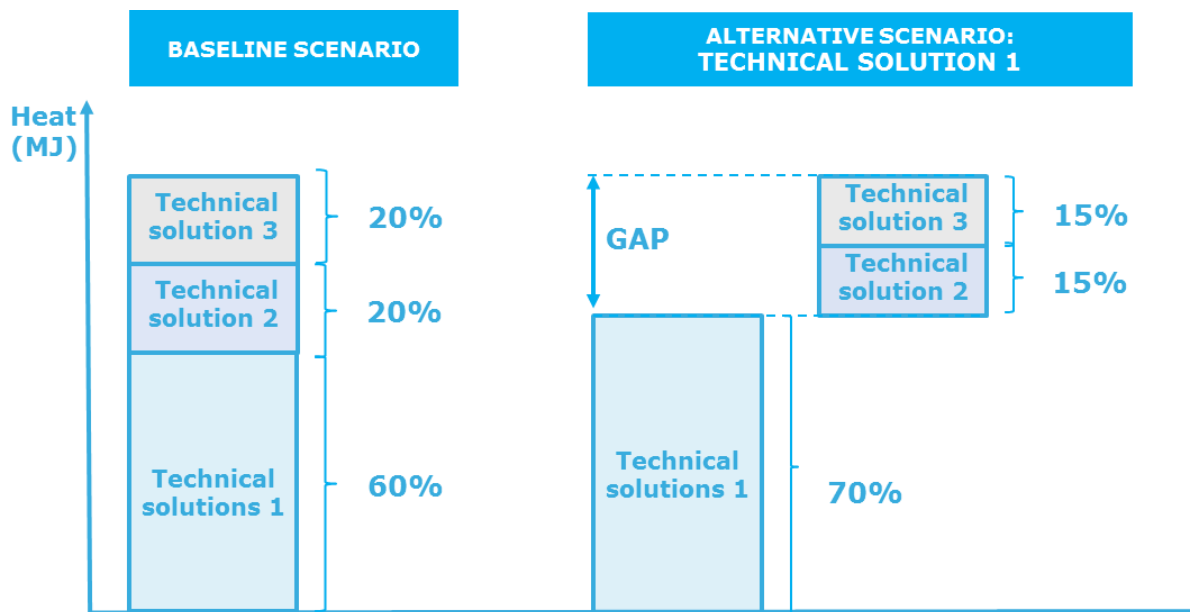
Figure 19. Filling the gap of demand on the alternative scenarios.

When evaluating the technical potential for renewable resources, it should be controlled that the resources are not accounted to several system boundaries. This is due to that the methodological approach proposed evaluates the technical potential of renewable resources within a certain perimeter around the system boundary. Hereby the technical potential could be overestimated due to that the same resource could be assigned to several system boundaries, e.g. the biomass of a forest could be assigned to two different system boundaries. To avoid this problem, it should be checked that the renewable resources required to cover the demand of the system boundaries within the same region are not higher than the available resources at regional level.

Once the alternative scenarios have been defined at system boundary level, it is possible to aggregate the output to determine which part of the heating and cooling demand at national level that technically could be satisfied by each of the efficient heating and cooling solutions.

EXAMPLE 20 Alternative scenario definition

After analysing the viability of different technological solutions applicable for the System boundary 1, the technical solutions that can be applied within the System boundary 1 are:

- Cogeneration, by installing new capacity, and distributing it by district heating and cooling system (new capacity, as well);
- Waste heat, from already existing industrial plants, distributed by district heating and cooling system (new capacity as well);
- Biomass boilers, using individual boilers; and

- Heat pumps.

Based on the forecasted heating and cooling demand (as indicated on Example 13) and the technical potential assessed, each of the four alternative scenarios has been designed to cover as much demand as technically is possible. As can be seen, in this example the solutions identified cover all the demand of the system boundary.

				ALTERNATIVE SCENARIOS (MWh)																			
				COGENERATION + DHC					INDUSTRIAL WASTE HEAT + DHC					BIOMASS BOILERS					HEAT PUMPS				
				2015	...	2030	...	2050	2015	...	2030	...	2050	2015	...	2030	...	2050	2015	...	2030	...	2050
Heat demand system 1	House-holds	Multi-store	Heating	9,952.8	...	9,405.4	...	8,758.5	9,952.8	...	9,405.4	...	8,758.5	9,952.8	...	9,405.4	...	8,758.5	9,952.8	...	9,405.4	...	8,758.5
			Cooling	3,815.2	...	4,784.3	...	6,043.3	3,815.2	...	4,784.3	...	6,043.3	3,815.2	...	4,784.3	...	6,043.3	3,815.2	...	4,784.3	...	6,043.3
			Hot water	2,820.0	...	2,961.0	...	3,102.0	2,820.0	...	2,961.0	...	3,102.0	2,820.0	...	2,961.0	...	3,102.0	2,820.0	...	2,961.0	...	3,102.0
		Terraced	Heating	68,482.1	...	64,715.5	...	60,264.2	68,482.1	...	64,715.5	...	60,264.2	68,482.1	...	64,715.5	...	60,264.2	68,482.1	...	64,715.5	...	60,264.2
			Cooling	26,251.5	...	32,269.6	...	46,005.4	26,251.5	...	32,269.6	...	46,005.4	26,251.5	...	32,269.6	...	46,005.4	26,251.5	...	32,269.6	...	46,005.4
			Hot water	19,403.2	...	20,373.4	...	21,343.6	19,403.2	...	20,373.4	...	21,343.6	19,403.2	...	20,373.4	...	21,343.6	19,403.2	...	20,373.4	...	21,343.6
		Single	Heating	107,727.8	...	101,802.7	...	94,800.4	107,727.8	...	101,802.7	...	94,800.4	107,727.8	...	101,802.7	...	94,800.4	107,727.8	...	101,802.7	...	94,800.4
			Cooling	41,295.6	...	50,762.7	...	62,686.8	41,295.6	...	50,762.7	...	62,686.8	41,295.6	...	50,762.7	...	62,686.8	41,295.6	...	50,762.7	...	62,686.8
			Hot water	30,522.9	...	32,049.0	...	33,575.1	30,522.9	...	32,049.0	...	33,575.1	30,522.9	...	32,049.0	...	33,575.1	30,522.9	...	32,049.0	...	33,575.1
	Service	Public buildings	Heating	1,795.0	...	1,186.4	...	1,479.1	1,795.0	...	1,186.4	...	1,479.1	1,795.0	...	1,186.4	...	1,479.1	1,795.0	...	1,186.4	...	1,479.1
			Cooling	1,053.1	...	1,257.5	...	1,496.8	1,053.1	...	1,257.5	...	1,496.8	1,053.1	...	1,257.5	...	1,496.8	1,053.1	...	1,257.5	...	1,496.8
			Hot water	448.8	...	457.7	...	462.2	448.8	...	457.7	...	462.2	448.8	...	457.7	...	462.2	448.8	...	457.7	...	462.2
		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		Other	Heating	598.5	...	592.5	...	565.0	598.5	...	592.5	...	565.0	598.5	...	592.5	...	565.0	598.5	...	592.5	...	565.0
			Cooling	319.2	...	452.1	...	571.7	319.2	...	452.1	...	571.7	319.2	...	452.1	...	571.7	319.2	...	452.1	...	571.7
			Hot water	149.6	...	164.6	...	176.5	149.6	...	164.6	...	176.5	149.6	...	164.6	...	176.5	149.6	...	164.6	...	176.5

5 Cost-Benefit Analysis

A CBA is an analytical approach used to appraise an investment decision in order to assess the welfare change attributable to it [31]. So conducting a CBA implies assessing the changes in cost and benefits between baseline and alternative scenarios and integrating them in a common framework analysis to compare them along time and arrive to conclusions about its profitability.

The CBA is based on the discounted cash flow analysis. Once the baseline and the alternative scenarios for each system boundary are defined, the analyst has to quantify and monetise the relevant effects, in terms of costs and benefits, derived from each scenario. This analysis has to consider also the distribution of those costs and benefits along the time horizon of the analysis. Quantifying the cost and benefits in both scenarios is required to assess the changes in cost and benefits between baseline and an alternative scenario. There are different categories of costs and benefits that will be described below. The assessment process consists of, for each cost category (i), to estimate the change of costs between the baseline and the alternative scenario, on a year basis (t), as indicated by the following expression:

$$Cost_{i,t} = \left[Cost_{i,t}\right]_{Alternative} - \left[Cost_{i,t}\right]_{Baseline} \qquad (22)$$

The total cost of each year is the result of summing the value of all those costs categories:

$$Cost_t = \sum_{i=1}^{n} Cost_{i,t} \qquad (23)$$

In the same manner, for each benefit category (i), to estimate the change of them between the baseline and the alternative scenario, in a year basis (t):

$$Benefit_{i,t} = \left[Benefit_{i,t}\right]_{Alternative} - \left[Benefit_{i,t}\right]_{Baseline} \qquad (24)$$

The total benefit of each year is the result of summing the value of all those benefit categories:

$$Benefit_t = \sum_{i=1}^{n} Benefit_{i,t} \qquad (25)$$

Those costs and benefits that remain constant in both scenarios do not have to be accounted as, when assessing its change between both scenarios, they will become null. That is the case, for example, of the value of heating and cooling used. Heating and cooling consumption is the same in both scenarios, so quantifying its value it not necessary.

Once the information on total cost and total benefit has been collected, there are different evaluation criteria to assess the return on the different alternative scenarios. Within these criteria, the Net Present Value is the one required by the EED. This measure integrates in a unique estimate the expected benefits minus the costs, both suitably discounted to allow aggregating

those that happen in different years, all along the time horizon considered. This indicator provides information about the "net benefit" of the different alternative scenarios considered.

$$NPV_x = \sum_{t=0}^{n} \frac{Benefit_t - C_{ost}}{(1+r)^t} = \frac{B_0 - C_0}{(1+r)^0} + \frac{B_1 - C_1}{(1+r)^1} + \cdots + \frac{B_n - C_n}{(1+r)^n} \qquad (26)$$

Where:

$NPVx$ is the Net Present Value of the alternative scenario x,

Bt is the net benefit of the alternative scenario at year t,

Ct is the net cost of the alternative scenario at year t,

r is the discount rate,

n is the time frame considered for the analysis

The time horizon of the analysis is an important parameter that has to be chosen before starting the CBA. When conducting a CBA of a single project, the time horizon of the CBA usually is equal to the lifetime of the project, in order to capture all relevant flows of benefits and costs associated to it. Following a similar approach, when analysing the penetration of efficient heating and cooling solutions, it seems reasonable to consider the lifetime of the different solutions considered. Estimates on technology lifetimes are available from international benchmarks, although local circumstances are also important to be taken into account The lifetime of technological solutions in the framework of the efficient heating and cooling varies from one technology to other and, in general, they are long, e.g. 30 years for district heating systems or 25 for gas-fired plants. When appraising the alternative scenarios, the time frame used should represent the lifetime of the longest living asset. When the lifetime of other assets fall short of the appraisal time horizon, the appraiser should assume that these assets will be replaced where appropriate. However, in a large programme with many investments, it can be difficult to select a time horizon based upon the lifetime of the longest living asset. So, in order to standardise the appraisals with respect to high efficiency cogeneration and efficient heating and cooling, a 35 year horizon can be recommended[44].

The CSWD of EED sets out[45] that MSs must ensure that the country level CBA has both an economic and a financial analysis included. The *financial analysis* tackles the analysis from an investor's perspective using the conventional discounted cash flow approach. The *economic*

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[44] Should assets last longer than the appraisal time horizon, the depreciated value of the asset should be included as a benefit in the final year.

[45] Paragraph 28.

analysis tackles the analysis from the point of view of the society, so the analysis must encompass the changes in the welfare of the society as a whole. Once the financial analysis has been done, some adjustments have to be introduced in the analysis to reflect a social perspective. These changes will be explained in the section 5.2.

The Cost-benefit analysis can be conducted both from a *financial* and an *economic* perspective:

- The financial analysis tackles the analysis from a private investor's point of view using the conventional discounted cash flow approach to assess net returns. In the context of the CBA for the purposes of Article 14 of EED, where different stakeholders are involved (from investors on centralised/individual technologies, promoters of distribution networks and individual consumers), the implementation of the financial analysis proposed within this methodology is set out from the perspective of heating and cooling consumers.

- The economic analysis tackles the analysis from the point of view of the society, so the analysis encompasses the changes to the welfare of the society as a whole. The welfare of the society is the level of prosperity and standard of living of the society. Changes to the welfare of the society mean gains or losses on the level of satisfaction of the society. The economic analysis has been generally used to support policy-making processes [32].

Both perspectives, the economic and financial analyses, can be applied to assess the same initiative (a project; a policy, etc.). When both analyses are carried, once the financial analysis has been done, some adjustments have to be introduced into the analysis to reflect the social perspective. These changes will be explained in the section 5.2. The usefulness of conducting the analysis from both perspectives is to identify potential areas for policy influence based on gaps between the financial suitability of an initiative and its convenience from a society's perspective. Based on that gap, public deciders can adopt measures to support or promote (by difference mechanisms as obligations, economic incentives, etc.) those initiatives, as well as removing existing or planned support mechanisms when the evaluation shows that are not justified in social terms.

Within the frame of the Comprehensive Assessment, the EED (Annex IX) explicitly states that '*the Cost-benefit Analysis shall include an economic analysis covering socio-economic and environmental factors*'. So, it can be interpreted that, at least, it is required to conduct the analysis from the economic perspective. On the other hand, the CSWD of EED goes further when sets out[46] that MSs must ensure that the country level CBA has both an economic and a financial analysis included. Broadening the scope of the analysis to incorporate both types of analysis can provide

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[46] Paragraph 28.

some useful information, as is explained later (see Section 6.3). MS have to fulfil the EED requirements. Whenever possible, it is advisable to take into consideration the guidelines provided by the CSWD as well, as they are justified on their potential usefulness by having a broader approach.

As described in the previous expression, the NPV estimation requires the use of a parameter known as 'discount rate'. The discount rate is a parameter that reflects the value for the society of future cost and benefits compared to the present ones. Using the discount rate, future costs and benefits are converted into their present value allowing a comparison between costs and benefits that happen in different moments of time. The financial analysis uses a financial discount rate (FDR), while the economic analysis will use a social discount rate (SDR). The selection process of discount rates is described below:

5.1 Financial analysis

The financial analysis must be done following some rules that are summarized below [31]:

- Only cash inflows and outflows are considered in the analysis. Those accounting items which do not correspond to actual flows are disregarded, i.e. depreciation, reserves, etc.

- The financial analysis should usually be carried out in constant (real) prices with prices fixed at a base-year. It is also possible to conduct the analysis using current (nominal) prices but it would involve a forecast of Consumer Price Index (CPI) that increase the uncertainty and complexity. When a different rate of change of relative prices is envisaged for specific key items, e.g. fuel prices, this differential should be taken into account in the corresponding cash flow forecasts.

- The analysis should be carried out net of VAT, both on purchase (cost) and sales (revenues), if this is recoverable by the project promoter. On the contrary, when VAT is not recoverable, it must be included.

- The analysis should be carried out including direct taxes on the prices of inputs, i.e., electricity, labour, etc.

The main costs and benefits to be considered in the financial analysis are described below. The different categories of costs and benefits do not apply to all technologies. Their value would be zero when they do not apply to a specific technology.

5.1.1 Costs

The costs that are taken into account in the financial analysis include the following categories:

- **Capital cost of heating and cooling supply**

The capital costs of heating and cooling systems comprise the amount of resources devoted for acquiring fixed assets. In the context of heating/cooling production, the equipment to be considered will vary in each case, comprising: heat production/recovery equipment; pumps (in the case of district cooling network); heat transfer line construction/modification (in the case of district heating/cooling); standby boilers, etc.

These costs take place when new additional capacity is added to the energy system or when existing capacity is replaced. That information is collected within the scenario definition. Knowing the construction time of the plants is also needed in order to distribute the cost along the time required for the completion of the project construction.

The information regarding capital cost is included in the techno-economic data of different technologies. Analysts should take into account the cost of technologies will be decreasing along time due to learning costs curves. Detailed techno-economic information of the main technologies considered in the analysis can be found in the Annexes A-H. Additionally, Box 1 shows a list of some other useful sources of information.

Box 1 – Techno-economic data sources of information
• Alberici et al., [33] Subsidies and costs of EU energy. Provides data on a wide range of technologies as well as country specific parameters, e.g. as load hours and efficiencies (which are relevant to adjust the reference technology dataset to the different climate regions in Europe). See Annex 4.
• JRC, [34], Energy technology Reference Indicator (ETRI) projections for 2010-2050. This report provides techno-economic information of existing and future electricity generation technologies.
• IEA – ETSAP Technology Briefs - ETSAP E-TechEd's provides a series of Technology Briefs, which provide basic information on process, status, performance, costs, potential and barriers for key energy technology clusters.
• The European Technology Platform on Renewable Heating & Cooling (RHC-Platform). This provides technology data for a range of renewable heating and cooling technologies
• AEA (2011) Review of technical information on renewable heat technologies. Report for the Department of Energy and Climate. This report provides a review of the technical cost evidence on renewable heat technologies.
• Sweet Group (2013) Research on the cost and performance of heating and cooling technologies. Report for the Department of Energy and Climate. This report collated data on the costs and performance of a range of Low and Zero Carbon (LZC) heating and cooling technologies.

- IEA (2011). Technology Roadmap. Energy-efficient Buildings: Heating and Cooling Equipment. This report includes technical and cost data for Active solar thermal, Combined heat and power, Heat pumps and Thermal energy storage
- SENTECH (2010) Commercial and Industrial CHP Technology. Cost and Performance Data Analysis for EIA. This report includes cost data from the U.S. for commercial and industrial CHP plant.

- **Operation and maintenance costs** (excluding fuel costs).

The operating costs are those associated to the consumption of materials; maintenance; administration; labour, etc. As mentioned before, the information regarding operating cost is included on the techno-economic data of different technologies. Detailed techno-economic information of the main technologies considered in the analysis can be found in the Annexes A-H. Box 1 shows a list of some other useful sources of information.

- **Fuel (and electricity) costs**

There are some technological solutions (as district heating/cooling or heat pumps) that also have associated fuel costs, which have to be taken into account in the analysis. There are countries that have their own forecasts of energy prices. For those that do not have them, some useful sources of information of long-term forecast of fuel and electricity prices are indicated in Box 2. There are some particular cases, as waste heat recovery and CHP, which require specific accounting rules that will be presented in more detail on Box 3.

Box 2– Sources of information about forecast on fuel prices
Existing data sources may provide default values of long term forecasts that can be used for the assessment: • **Conventional fuels** (natural gas, coal, oil) import prices can be found in the [35] report on EU Energy, transport and GHG emissions trends to 2050 (see Figure 20).
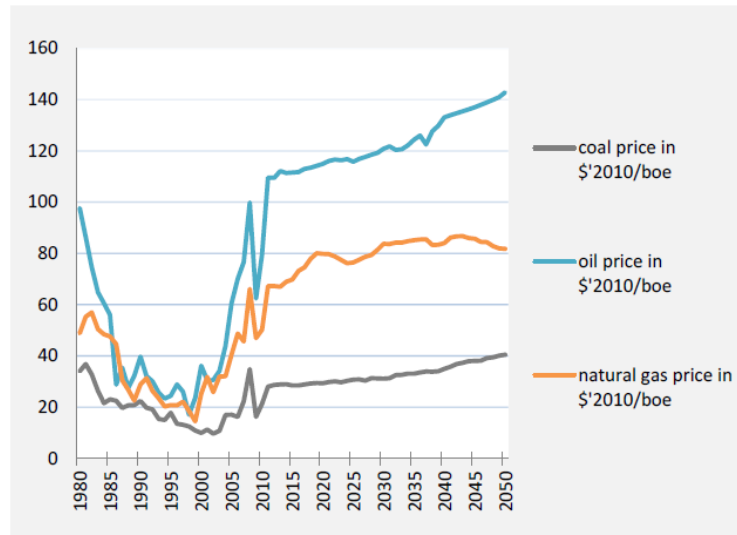
Figure 20. Fossil fuel import prices (EC, 2013b, p. 17).

- **Biomass prices** can have more variability between countries. Those countries without forecast on biomass prices, could use the price projections of the EU Energy system models assumptions, as for example the POLES model that assume import prices of biomass of approximately 6.5 euros 2005/GJ in 2006 and 8.3 euros 2005/GJ in 2050 [36].

- **Electricity prices** can also be found in [35] EU Energy, transport and GHG emissions trends to 2050, see Figure 21. The report provides forecast for price of electricity (pre-tax) by type of sector (industry, households, services) till 2050. The price chosen will vary with the type of consumer: for example, when the technology considered is individual heat pumps in houses, electricity prices for households should be chosen. Post-tax prices have to be considered in the financial analysis. In order to convert pre-tax into post-tax values, some figures regarding the magnitude of fiscal component in the EU-28 on electricity prices can be found in [3] report on Energy prices and costs.
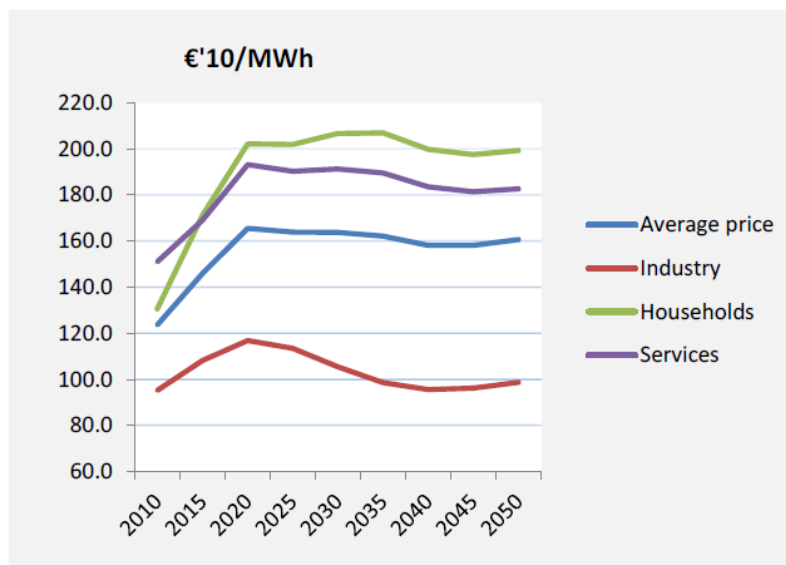
Figure 21. Price of electricity (pre-tax) by sector, EUR'10/MWh [35] p. 48)

- **CO₂ costs**

This cost category only applies for units that fall under the Emission Trading Scheme (ETS). There are different approaches to valuing carbon emissions. One option consists of valuing the damages associated with the impacts derived from climate change (known as the Social Cost of Carbon), and another option consists of estimating the marginal cost of CO_2 reduction of meeting specific reduction targets. These options are appropriate at policy appraisal level. Within the context of financial analysis, the tangible value of CO_2 for investors is the CO_2 prices of the ETS. Figure 22 shows long-term estimates of CO_2 prices of ETS that can be found in the [35] EU Energy, transport and GHG emissions trends to 2050. Some particular cases, as waste heat recovery and CHP, require specific accounting rules that are presented in more detail on Box 3.
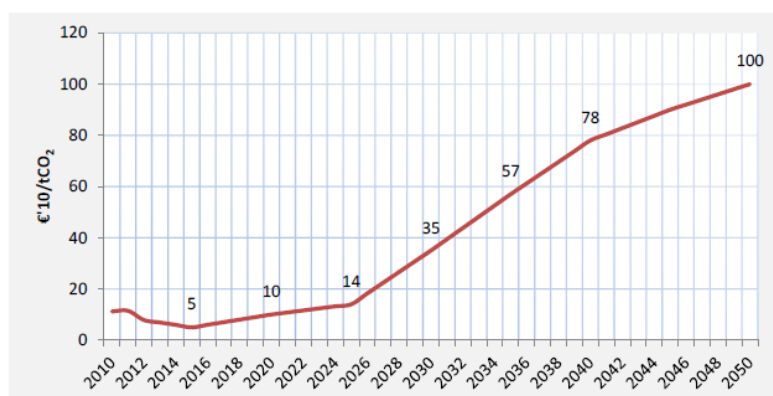
Figure 22. Projections of the ETS price [35] p.33

- **Loss of revenues from electricity production**

The baseline and alternative scenarios only account for heating and cooling supply/demand, whereas the supply of electricity is not included in the scenario definition. Nevertheless, due to the expansion of certain technologies, as CHP, changes in the electricity production generation happen. These changes have to be quantified and valued also in the analysis. The losses of revenues from electricity production only happen when power plants are converted into CHP in which the fuel consumption of the plant is maintained constant with respect to the baseline scenario. In that case, the plant experiences a loss in electricity production and the decrease of revenues from electricity sales have to be accounted for as a cost.

As mentioned before, those countries that do not have forecasted prices of electricity, can find some forecasts at EU level in the [35] EU Energy, transport and GHG emissions trends to 2050, see Figure 21. To assess the loss of revenues from electricity production, the wholesale prices of electricity that includes the cost incurred by companies to deliver the electricity on the grid[47] have to be used. In order to convert market prices into wholesale prices, some figures regarding the magnitude of transmission and distribution cost component in the EU-28 on electricity prices can be found in [37] report on Energy prices and costs.

EXAMPLE 21. Economic data collection for assessing the costs of heating and cooling
An example of the economic data collection for assessing the costs for DHC network components is presented in Table 22.

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[47] As described in EC (2014), the consumer price of electricity is the result of adding three components:

- The costs of energy, integrated by two subcomponents: the wholesale price, which covers the cost incurred by companies to deliver the electricity on the grid and the retail price, which covers the costs related to the sale of energy products to final consumers;

- The cost of the network, including the cost of transmission as well as the cost of distribution of electricity.

- The component related to taxation policy (taxes, levies, exemptions, etc.).

Table 22. An example of the economic data collection for assessing the costs for DHC network components.

Data	Value	Source
Large Reciprocating gas engine CHP (>2MWe)	850 EUR/kW$_e$	Eikmier *et al.*, 2011
Stand-by boiler	76 EUR/kW$_{th}$	Poyry and Faber Maunsell, 2009.
Primary distribution infrastructure	500-1,150 EUR/m	Ricardo-AEA own data.
Long-distance transmission pipeline	1 – 2.3 mEUR/km	Ricardo-AEA own data.
Domestic secondary distribution infrastructure	3,830-5,540 EUR/dwelling (depending on dwelling type)	Poyry and Faber Maunsell (2009)

Table 23 shows an example of data collection for standalone heating technologies:

Table 23. An example of data collection for standalone heating technologies.

Technology	Capital Cost	Annual Operating Cost [% of capex]	Plant Efficiency	Lifetime [Years]	Source / Notes
Oil Boiler	200 EUR/kW$_{th}$	5%	103% efficient (LHV basis)	15	http://www.idealo.de; November 2014
Gas Boiler	120 EUR/kW$_{th}$	8%	108% efficient (LHV basis)	15	
Biomass boiler	330 EUR/kW$_{th}$	3.50%	95% efficient (LHV basis)	15	
Ground-source heat pump	1,000 EUR/kW$_{th}$	1%	Coefficient of Performance – 5.0	20	
Air-source heat pump	800 EUR/kW$_{th}$	1.50%	Coefficient of Performance – 3.5	20	
Large Reciprocating gas engine CHP (>2MWe)	850 EUR/kW$_e$	4%	42% electrical efficiency 44% thermal efficiency 86% overall efficiency (LHV basis)	25	Eikmier *et al.*, 2011

5.1.2 Benefits

- **Revenues from selling electricity.**

This benefit category only applies to CHP plants. The wholesale price of electricity has to be used. As mentioned before, in order to convert market prices into wholesale prices can be found in [37]. There are different situations that require specific accounting rules, which are explained in more detail the Box 3.

- **Subsidies**

Any potential existing subsidy or public support received by the technologies analysed should be taken into account.

- **Residual value**

When the lifetime of some assets is shorter than the lifetime of the appraisal time horizon, it should be assumed that these assets will be replaced where appropriate. At the end of the time horizon of the CBA, the value of those assets should be taken into account among the revenues.

Residual value should be understood as the market value for the fixed assets or liquidation value of assets in the case they are sold out at end year.

<table>
<tr><td>Box 3 – Specific accounting rules for waste heat recovery from industries and CHP units</td></tr>
</table>

Waste heat recovery

When the alternative scenario considers the installation of waste heat recovery units in industrial plants[48], the consumption of fuel, as well as the CO_2 costs, does not change with respect to the baseline scenario. Consequently, in that case neither fuel costs nor CO_2 costs have to be taken into account in analysis of the alternative scenario.

CHP plants

In the alternative scenario, three different situations, which imply different accounting rules for fuel costs; CO_2 costs and revenues from electricity can take place:

1. Conversion of a power plant into a CHP plant, while maintaining the fuel consumption of the plant[49]. In that case, the fuel consumption, as well as the CO_2 emissions, does not change with respect to the baseline scenario. Consequently, in that case the fuel cost does not have to be taken into account in the analysis. In the case of CO_2 costs, if the plant receives free EU ETS allowances, their value should be accounted as revenue. As mentioned before, the decrease of revenues from electricity sales have to be accounted as a cost.

2. Conversion of a power plant into a CHP plant, while increasing the fuel consumption of the plant[50]. In this case, only the costs associated to the additional fuel and additional CO_2 emissions (compared to the baseline scenario) minus the revenues from the free allocation of EU ETS allowances has to be taken into account. The production of electricity of the plant does not change with respect to the baseline scenario. Consequently, in that case the revenues from electricity of the plant do not have to be taken into account in the alternative scenario

3. Construction of a new CHP plants. In that case, the fuel cost; CO_2 costs minus the revenues

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[48] It is referred to plants that operate without the heat recovery units in the baseline

[49] So experiencing a reduction on electricity production.

[50] In order to maintain the electricity production of the plant.

from the free allocation of EU ETS allowances, as well as revenues from electricity sales, associated to the whole plant have to be taken into account.   .

Table 24. Summary of fuel costs, CO_2 costs and revenues from electricity accounting rules for waste heat recovery and CHP.

Situation in the alternative scenario			Elements to be accounted			
			Fuel costs	CO_2 costs	Loss of revenues from electricity	Revenues from electricity
Waste heat recovery from industry			×	×		
CHP	Power plant converted into CHP	Fuel maintained	×	×*	∇	×
		Fuel increased	Δ	Δ*		×
	New CHP plant		√	√*		√

Legend: √: account them for the whole plant;

×: do not take them into account;

Δ: account the increase with respect to the baseline scenario costs;

∇: account the decrease with respect to the baseline scenario revenues.

*: accounting for the revenues from the free allocation of EU ETS allowances

5.1.3   Financial discount rate

The financial discount rate reflects the opportunity cost of capital, which means the potential return that could have been obtained by investing the same capital in an alternative project[51]. There are different approaches to estimate the financial rate of return, which are described in more detail in Annex I of [15].

The financial discount rate can vary depending on the perspective of different decision makers. It can vary also between technologies as it is an indicator of risk perception. Different stakeholders, such as industries, service enterprises and household owners, may have different expectations and opportunity costs on their available capital. For example an industry may have much higher return

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[51] There are different approaches to estimate the financial rate of return, which are described in more detail in Annex I of EC (2014).

of investments expectations than a private household and this should be reflected in the selected discount rate.

As mentioned before, the financial analysis should usually be carried out in real terms (using constant prices), although the analyst is free to carry it out in nominal terms (using current prices[52]. When a CBA is conducted in real terms, a real FDR has to be used. On the contrary, when a CBA is conducted in nominal terms, a nominal FDR has to be used. The FDR suggested by the [31] is expressed in real terms.

5.2 Economic analysis

As indicated by the [31] on its Guide to Cost Benefit Analysis of Investment Projects, once the financial analysis has been done, some adjustments have to be introduced in the analysis to reflect a social perspective:

- Fiscal corrections have to be applied as they are mainly transfers between agents within the economy and do not reflect real impacts on the economic welfare. The prices of inputs (including labour) are gross of direct taxes in the financial analysis but should be net of taxes within the economic analysis. On the contrary, the economic analysis has to be conducted gross of subsidies because they are a cost for the society that should be accounted for.

- It is required to estimate and include in the analysis the externalities or impacts on society welfare. These are not taken into account in the financial analysis as they do not generate a real cash flow for investors. In the context of the CBA, the main externalities to consider are derived from the environmental and health impact associated with the combustion of fuels, as well as the macro-economic impact related to the economic activity generated by the investments in the energy system and the saving on the energy bill, but also, whenever possible, others as a more optimal operation of the electricity network [38–41]. The nature of the impacts is different in each case, so different valuation techniques would be applied to assess their value for society. These valuation techniques to assess these externalities are explained below.

Some of the main costs and benefits to be considered within the economic analysis are described below. The methodological approach used for valuing externalities is more robust and accessible in some categories than in others. The analyst are free to incorporate other potential costs or

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[52] The following expression is usually used to convert nominal discount rate (i) into real discount (r) rate, by taking into account the inflation rate (π) is: $r = \frac{1+i}{1+\pi} - 1$

benefits considered relevant, as for example, additional transmission costs of increases on electricity transport or gas networks as a consequence of a large expansion on some technologies, e.g. heat pumps, CHP, etc.

5.2.1 Costs

- **Capital cost**

Capital cost of heating and cooling supply are the same that were accounted for in the financial analysis but considering them net of direct taxes.

- **Operation and maintenance costs**

Operation and maintenance costs of heating and cooling supply are the same that were accounted for in the financial analysis but considering them net of direct taxes.

- **Fuel (and electricity) costs.**

Fuel and electricity costs are the same that were accounted for in the financial analysis but considering them net of direct taxes.

- **Loss of revenues from electricity production**

They are the same that were accounted for in the financial analysis.

- **Environmental and health externalities.**

Energy production causes different types of environmental impacts as a consequence of the emission of pollution; land occupation and resources consumption (fuels, water, etc.) during the energy production process. These kinds of impacts generate a loss of welfare on society. Some methods have been developed to estimate the monetary value of environmental impacts in order to take them into account and integrate them in the decision making process.

The general approach of the environmental valuation methods is based on the "Impact pathway approach"[53], that aims at modelling the causal relationships from the pressure induced on the environment (e.g. emission of pollutants) to the impacts generated on different receptors, by assessing the changes in environmental quality. Once these impacts are assessed in physical units, the following step consists of calculating the damages or value of the impacts using economic valuation methods [42].

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[53] The 'Impact Pathway Approach' was designed within the context of the ExternE project. This project was launched in 1991 by the European Commission and the US Department of Energy. Since then, the European Commission has continuously supported this research field through several projects.

The whole implementation of the environmental valuation process is data demanding and resource consuming. Nevertheless, as a result of the implementation of some initiatives and projects[54,55], there are several databases that provide '*environmental damage factors*'. The damage factors provide information on the environmental damages produced by, for example, an additional unit of energy produced by different technologies (expressed, e.g., in EUR/MWh). These damage factors can be used to assess the environmental and health impact in each scenario. When damage factors are expressed per additional unit of energy produced by different technologies, the environmental damage of the scenario (*ENV*) would be the result of multiplying the energy production per technology (*E*)[56] by the damage factor (*DF*) per unit of energy produced by each technology, as indicated below:

$$[ENV_{y,t}]_{Scen.} = [E_{y,t}]_{Scen.} \cdot DF_y \tag{27}$$

Where,

$[ENV_{y,t}]_{Scen.}$ is the environmental damage associated to energy produced by technology *y*, in year *t*, within a specific scenario [EUR]

$[E_{y,t}]_{Scen.}$ is the energy produced by technology *y*, in the year *t*, within one scenario [MWh].

DF_y is the environmental damage per unit of energy produced by technology *t* [EUR/MWh]

The environmental damage of each scenario in one specific year will be the sum of the environmental damage generated by the production from all the technologies used in that scenario that year, as indicated below:

$$[ENV_{Total,t}]_{Scen.} = [\sum_{y=1}^{n} ENV_{y,t}]_{Scen.} \tag{28}$$

One of the sources of information that provides environmental damage factors per unit of energy produced for different heat and electricity technologies is the report on 'Subsidies and costs of EU energy' [33]. This report provides environmental damage factors that were estimated considering the Life cycle emission data[57] and considering the following environmental impact categories: Climate change; ozone depletion; terrestrial acidification; freshwater eutrophication; marine eutrophication; human toxicity; photochemical oxidant formation; particulate matter formation; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; ionising radiation; agricultural

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[54] Some examples are the projects supported by the European Commission as, e.g. NEEDS Project (New Energy Externalities Development for Sustainability) and CASES project (Cost Assessment for Sustainable Energy Systems).

[55] Life cycle emission data were provided by Ecoinvent database.

[56] The information regarding the energy production by technology comes from the scenario definition.

[57] Life cycle emission data were provided by Ecoinvent database.

land occupation; urban land occupation; natural land transformation; water depletion; metal depletion and depletion of energy resources.

Table 25 shows the damage factors obtained for different heat technologies. Figure 23 shows the relative contribution (%) to the total damages of the different impact categories considered within the study of [33], by technology[58].

Table 25. Environmental external cost for heat technologies at EU 28 level [EUR2012 / MWhth] [33].

Technologies	Environmental damage (EUR$_{2012}$ / MWh$_{th}$)
CHP–Bio (Heat)	4.3
CHP –Natural gas (Heat)	11.7
CHP – Hard coal (Heat)	24.1
CHP – Waste (Heat)	10.1
Domestic natural gas – fired boiler	17.9
Domestic wood pellet boiler	11.2
Domestic heat pump	12.5
Domestic solar thermal	9.6
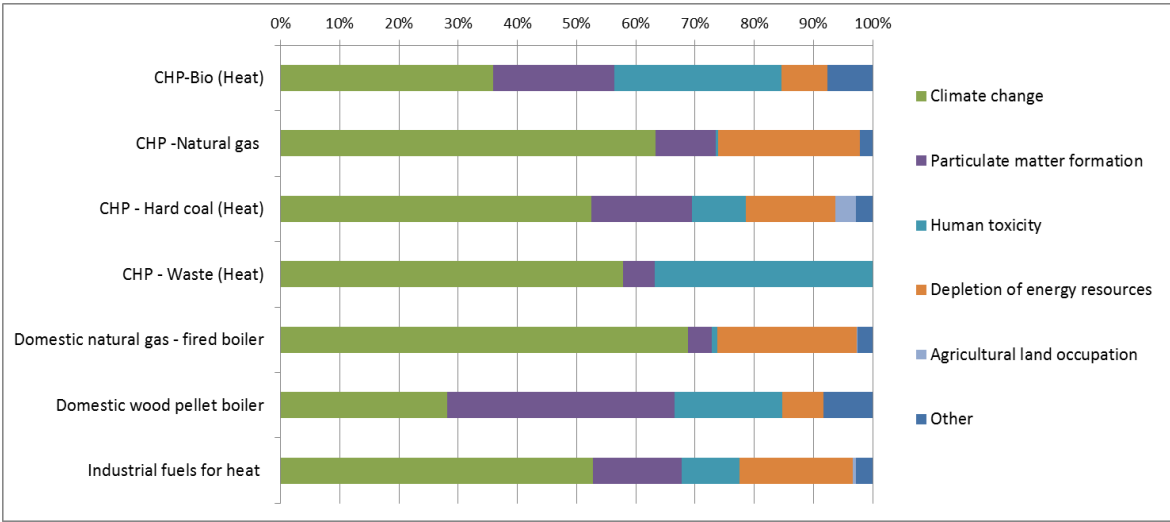
Figure 23. Percentage of damage of the different impact categories considered (%) [33].

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[58] See Annex 3 of the document.

These values could vary over the years due to changes in different parameters (population density, overall pollution load of the atmosphere). As shown by [43], the changes of health and environmental damages could be significant for certain pollutants as ammonia and NMVOCS[59]. Nevertheless, there is no information on the evolution of damage factors over time in [33]. The sensitivity analysis could be used to assess the impact by changing parameters.

Within the financial analysis, the costs of CO_2 emissions were taken into account for those installations falling within the scope of the EU Emissions Trading System (ETS) as they have already been internalised through the CO_2 market prices. The valuation approach of climate change impact used in [33] is based on a damage cost approach that provides higher values per tonne of emissions. Independently of the approach used, when going from the financial to the economic analysis, the costs of CO_2 emissions have to be removed from the analysis to avoid double counting.

Alberici *et al.* [33] do not provide environmental damage factors for geothermal energy. For this technology, the analyst could replicate the valuation assessment process used in the report [33], that consists of estimating the Life Cycle Emissions (by using EcoInvent database) and then applying damage factors to obtain the value per impact category.

As was mentioned before, when assessing the environmental impact of additional capacity of CHP in the alternative scenario, changes in the electricity production will take place and its effect on the environment should be taken into account. The different situations could be:

- Construction of new CHP plants. In this case, the damage caused by both energy products obtained as an output (so, heat and electricity) has to be accounted for. Damage factors in [33] provide the information required. Additionally, the avoided environmental damage costs of producing the same amount of electricity by another technology on the power system have to be taken into account.

- Conversion of already existing power plants into CHP. In this case, it can be assumed that the fuel consumption of the plants will remain constant. In this case, the environmental impact of the plants with respect to the baseline scenario will remain constant so it is not necessary to account for it. Only the environmental impact of the additional electricity that has to be supplied by other technology to cover the electricity demand has to be assessed.

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[59] Non-methan volatile organic compound.

For assessing the environmental impact of electricity production, environmental damage factors for electricity technologies provided by [33] can be used. The assessment can be based on two different approaches:

- Considering the emissions expected from the electricity generation mix in the future. This approach assumes that changes in electricity consumption derived from different scenarios will come proportionately from each of the generation technologies in the grid mix. Forecasts about the changes in MS power mix can be found in [35] report on EU Energy, transport and GHG emissions trends to 2050.

- Considering the emissions expected from the marginal technology of the power system on the long run. This approach refers to which technology is expected to increase or decrease when there are marginal but sustained changes to energy demand or supply. The use of a marginal plant in the appraisal generally reflects more accurately how the electricity generation market works in practice, and therefore which plant are most likely to reduce output in response to any sustained reductions in energy consumption. Nevertheless, the implementation of this approach requires more sophisticated models to obtain the required information. As a simplification, for example, [31][60] considers that the next best alternative plant for producing electricity would be a CCGT (combined cycle gas turbine). This assumption could be considered representative for those MS without more detailed information.

- **Impact of energy dependency**

In the context of the ExternE project, which is one of the main projects on energy externalities assessment, *Arnold et al.* [44] concluded that assessing externalities derived from energy dependency would consist of estimating the impact on the economy caused by increases of imported fuel prices. A rise in fuel prices has direct impact on prices in the economy, leading to a higher inflation. A deterioration of foreign exchange relations occurs due to higher prices of imports and reduced export competitiveness. On the other hand, a reduction of consumption and investment due to inflation will take place.

The approach to assess this externality would consist of determining the impact on the economy (GDP) associated to a rise in the price of imported fuels. This requires determining, firstly, the elasticity of the economy to increases in imported fuel prices:

$$\varepsilon_{PIB} = \frac{\Delta GDP/GDP}{\Delta P/P} \tag{29}$$

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[60] See pages 194-195.

Where,

ε_{PIB} is the GDP elasticity of imported fuel prices,

$\frac{\Delta GDP}{GDP}$ is the percentage change in GDP (%),

$\frac{\Delta P}{P}$ is the percentage change in price of imported fuels (%)

Thus, the impact on the economy per unit of imported fuel consumed, associated to an increase of 1 % in fuel price, can be measured as:

$$\Delta GDP_{per\ unit} = \frac{\varepsilon_{PIB} \cdot GDP}{F} \qquad (30)$$

Where,

$\Delta GDP_{per\ unit}$ is the impact on GDP per unit of fuel consumed (EUR/MJ);

ε_{PIB} is the GDP elasticity of imported fuel prices;

GDP is the GDP of the economy of one year (EUR);

F is the consumption of fuel of one year (MJ).

Having information regarding the amount of imported fuel consumed each year in each scenario, as well as the forecast about fuel prices evolution, it would be possible to assess the cost associated to energy dependency in each scenario:

$$[\Delta GDP_t]_{Scen.} = \Delta GDP_{per\ unit} \cdot \left[\left(\frac{\Delta P}{P}\right)_t\right]_{Scen.} \cdot [F_t]_{Scen,} \qquad (31)$$

As well as the rest of the costs and benefit categories, this impact is measured in both scenarios so the final step would consist of estimating the difference in costs between the alternative and baseline scenarios.

The final step would consist of transforming the GDP into a measure of welfare. In the context of a Cost-Benefit Analysis, it is suggested to use the Net Domestic Product (NDP). This indicator is obtained by reducing the depreciation (or consumption of fixed capital) from the Gross Domestic Product (GDP). The main reason to propose this indicator is that it provides information related to the changes on disposable income at domestic level. Weitzman [45] established the link between income and welfare. So, once the impact on GDP of each technology is known, the next step consists of discounting the consumption of fixed capital[61]. The resulting value would be the one computed as a cost of energy dependency in the economic analysis.

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[61] The information regarding the Consumption of Fixed Capital (CFC) can be found in the National Accounts. Estimating the percentage of the CFC with respect to the GDP ($\delta = \frac{CFC}{GDP} * 100$) allows transforming the impact on GDP derived from

The complexity of the relationship between fuel prices and economic activity requires the development of consistent macro-economic models that are able to account for all the transmission mechanisms, as well as adaptation mechanisms. MS with proper tools and information will be able to include this impact category in the context of the Cos-Benefit Analysis. Otherwise, it could be matter of assessment in future revisions of the Comprehensive assessment.

5.2.2 Benefits:

- **Revenues from selling electricity.**

They are the same as in the financial analysis.

- **Residual value**

They are the same as in the financial analysis but, if there is any direct tax, it should be accounted before taxes.

- **Macroeconomic impact.**

There is substantial literature evidence of the positive outcome for GDP growth and employment derived from increases on energy efficiency[62]. The Impact Assessment of the Energy Efficiency Directive [16], for example, analyses the impact of realising the economic potential of high–efficiency CHP and district heating/cooling at EU level[63]. Results show that such a scenario would yield an increase of 1,296 $MEUR_{2000}$ on the GDP in 2020 (0.01% of the GDP).

When assessing the macro-economic impact of energy efficiency measures, two kinds of effects have to be taken into account:

- First order effects are those derived from the investment and operation of heating and cooling solutions. There will be a *direct impact* on those sectors of the economy that provide goods and services for the installation and operation of energy supply projects, as well as an *indirect impact* on those sectors that provide intermediate supply to the previous ones. *Induced effect* is derived from the expenditures in final demand from income earned by employment, directly

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the heating and cooling options into an impact on NDP derived from the heating and cooling options by discounting it: $\Delta NDP = \Delta GDP * (1 - \delta)$.

[62] IEA (2014) provides an overview of several studies: at the EU level, the Impact Assessment of the Energy Efficiency Directive (EC, 2011), as well as the energy efficiency renovation of buildings (Copenhagen Economics, 2012); at national level, some studies in UK (Baker and Foxon, 2008; Allan *et al.*, 2008) and Germany and at global level, the implementation of the efficient Worldwide Scenario defined by the IEA in *The World Energy Outlook* (OECD, 2013).

[63] This scenario is called *Option D3* in the Impact Assessment report (EC, 2001).

or indirectly, involved in the production process. This impact will take place both in the baseline and the alternatives scenarios.

- The second order effects take place as a consequence of a redirection of the savings derived from reductions in the energy bill. They will have a positive impact on the economy through an increase of final consumption of households, or for example a reinvestment in productive sectors.[64].This impact will take place in the alternative scenarios so the savings on the energy bill have to be accounted for in order to assess its impact.

MS can use different methodological approaches to assess the macroeconomic impact associated to the expansion of efficient heating and cooling technologies:

- The Input-Output methodology[65], which uses the Input-Output tables to analyse the relations between the different economic sectors in a systematic way. The Annex J describes the basis of the I-O methodology. The Input-Output approach has been widely used because its simpler implementation but it has some weakness as it is based on rigid and static relation between sectors, reducing its capacity to capture dynamic and complex reactions on the economy.
- Using Computable General Equilibrium Models (CGEM) or macroeconomic models, sometimes combined with energy-system models, which are capable of capturing more complex relations and effects on the economy. MS that already have these kinds of models could use them for assessing the macro-economic impact assessment. Nevertheless, the implementation of those models makes sense at large-scale policies so, when the scale of system boundaries is small, the analyst should evaluate the suitability of its application.

There are different indicators to measure the impact on the economy derived from energy efficiency projects: GDP, employment, export increase, etc. As mentioned before, in the context of a Cost-Benefit Analysis, it would be suggested to measure the macroeconomic impact by using the Net Domestic Product (NDP). This indicator is obtained by reducing the depreciation (or consumption of fixed capital) from the Gross Domestic Product (GDP). The main reason to propose this indicator is that it provides information related to the changes on disposable income at domestic level. Weitzman [45] established the link between income and welfare. Besides this, the NDP is expressed in monetary units and encompasses the benefits associated to the rest of macroeconomic indicators (employment, export increase, etc.).

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[64] Beside this, when the improvement in energy efficiency is enough big there is a reduction in energy prices, the whole economy would experience additional positive effects. Nevertheless, as fuel prices depend on international markets, experiencing reduction in fuel prices is not expected to be relevant in this case.

[65] Developed by Leontief on the 1930's [46,47].

For those MS that do not have Computable General Equilibrium Models to assess the socio-economic impact, it would be suggested to use the Input-Output Methodology. More details about the practical steps can be found in Annex K.

- **Impact on reliability of the system operation**

One of the benefits derived from the expansion of CHP production is its contribution to the reliability of the electricity network. The reliability measures the ability of the electricity system to meet the electricity needs of customers. CHP, as a Distributed Generation (DG) source of electricity, can contribute to avoid or reduce the power outages. As described by DOE [48], DG can contribute to the reliability by different ways: by using DG to support local voltage levels and thus avoid outages; by increasing the diversity of power supply options; or by reducing stress on grid components.

The benefits of CHP to increasing the reliability of the system can be valued by different ways: one option is to estimate the avoided cost of increasing power reliability by other technical solutions and, other option is to estimate the avoided costs derived from outages. The second approach is the one proposed by ENTSOE (2013) in its guidelines to conduct cost-benefit analysis of grid developments. The work consists of:

- Firstly, estimating the impact on the reliability of the system from a CHP unit. Modelling tools have to be used for the assessment to simulate the impact on reliability of a new element on the system. Different indicators can be used for the assessment, as the Expected Energy not Supplied (EENS)[66] or the Loss of Load Expectancy (LOLE)[67].
- Secondly, assessing the benefit of that improvement by using the value of the unserved energy for customers. The indicator commonly used to value the real costs of interruptions in power supply to customers is the Value of Lost Load (VOLL)[68]. The VOLL is the weighted average of the costs of an outage for the different kind of consumers and it is usually expressed in terms of EUR/kWh. VOLL values vary from country to country as it depends on several factors (sectoral composition of the economy, level of dependency on electricity consumption, etc.). CEER [49] provides the guidelines on how to estimate the costs due to electricity interruptions at national level for EU-MS. ENTSOE (2010)[69] provide result of VOLL for some EU-MS, although not all follow the methodology suggested by CEER [49].

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[66] Expressed in MWh/year.

[67] Expressed in hours/year.

[68] More detailed information about the VOLL can be found in van der Welle and van der Zwaan (2007).

[69] See Annex 8.

The rigorous implementation of this approach requires in-depth engineering analysis. This could be a weakness that reduces its applicability in the context of the Cost-Benefit Analysis of efficient heating and cooling solutions. MS with proper tools and information will be able to include this impact category in the context of the Cos-Benefit Analysis. Otherwise, it will be not possible to assess it.

5.2.3 Social discount rate (SDR)

The Social Discount Rate (SDR) reflects the social view on how future benefits and costs should be valued against present ones[70]. For the programming period 2014-2020, the European Commission [31] suggests using two benchmark social discount rates: 5 % for the Cohesion countries and 3 % for the others. The Commission also encourages MSs to provide their own benchmarks for the SDR. Those MS with their own values can use them for the CBA of efficient heating and cooling solutions. Alternatively, those without own estimates can use these reference values for the CBA. As mentioned before, these values are provided for the programing period 2014-2020, so the impact of a potential change in the SDR post-2020 could be analysed in the sensitivity analysis. As an alternative source of information, Florio (2014) provides SDR estimates for 20 European countries.

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[70] There are different approaches to estimate the social discount rate, which are described in more detail in Annex II of EC (2014c).

6 Interpretation of results

6.1 Identification of the economic potential per technology

As indicated in the SWD (18), once the technical potential of the solutions has been assessed, the next logical step consist of conducting a Cost-Benefit Analysis to identify those parts of the technical potential that can economically be met by efficient heating and cooling solutions. This is the economic potential, which is defined as 'the subset of technical potential that is economically cost-effective as compared to conventional supply-side energy resources' [21]. Within the context of the Comprehensive Assessment, the conventional supply-side resources are those that constitute the baseline scenario. The alternative scenarios have been built to test the effects of realising the technical potential of various technology solutions to cover the heat demand. Once the effects have been quantified and valued in economic terms, those parts of the technical potential that provide positive NPV, when compared to the baseline scenario, indicate that they are cost-effective and so constitute the economic potential of that technology. To conduct this analysis it is suggested to use the output of the economic analysis, so the economic NPV (ENPV).

In the context of the EED, the NPV has to be calculated for the different alternative scenarios. The level of detail of the output of the analysis depends on the type of distribution system considered:

- In the case of individual solutions, the NPV has to be calculated per demand segment supplied, e.g., if a technology supplies heating to households and there are three categories of households, the analysis should provide a NPV for each of the three categories. Within the same alternative scenario, there can be some demand segments with positive NPV but other demand segments with negative NPV, e.g., installing individual CHP can be competitive for hospital but not for single households.

- In the case of centralized solutions, the NPV has to be calculated for the whole heat demand system without making distinctions between demand segments, e.g. if a centralized solution supplies heating to households and service sector, the output of the analysis would be a single NPV although there are two segments of demand. The reason is that the decision of implementing the solution will affect all segments of demand as a block.

Example 22 illustrates the kind of information that could be obtained as an output of the analysis.

EXAMPLE 22. NPV results for assessing the economic potential

Table 26 shows an example of results obtained for the System boundary 1. As can be seen, the NPV for the solutions with centralised systems (cogeneration+DHC and waste heat+DHC) are provided for the whole scenario, while the results for individual systems (biomass boilers and heat

pumps) are provided by demand segment. Cogeneration, industrial waste heat and biomass boilers provide positive NPV for all demand covered so its whole technical potential is considered cost-effective compared to the baseline scenario. In the case of heat pumps, the potential is cost-effective when supplying multi-storey buildings and other service buildings. Nevertheless, its potential is not cost-effective when supplying terraced, single houses and public buildings.

Table 26. NPV (EUR) for different alternative scenarios within the System boundary 1

			COGENERATION + DHC	INDUSTRIAL WASTE HEAT + DHC	BIOMASS BOILERS	HEAT PUMPS
System boundary 1	Households	Multistore	27,459,757	18,929,237	288,674	1,360,605
		Terraced			611,952	-2,274,339
		Single			959,785	-2,793,263
	Service	Public buildings			766,230	-1,110,870
		...			...	...
		Other			90,793	232,630

Once the economic potential of the solutions have been identified at system boundary level, all of them can be aggregated to determine the economic potential of each technology solution at national level.

6.2 Identification of the cost-efficient potential

Once the economic potentials have been estimated, the cost-benefit analysis is further used in order to identify the combination of solutions that provides the most cost-efficient way of supplying heating and cooling needs (see EED, 14.3). The analytical approach usually used to identify the most cost-efficient solutions is based on the cost supply curves of energy. In the context of the Comprehensive Assessment, the work would consist of building the heating and cooling supply curves based on the NPV per unit of energy (EUR/MWh) for different technology solutions within a system boundary level (also distinguishing the demand segment supplied, in the case of individual solutions). The curve will present those parts of alternative scenarios, each representing a specific technical solution, with highest NPV per unit of energy provided, then the second highest and eventually to the lowest ones, considering only those parts of each scenario with positive NPV, see Figure 24. The height of each box provides information on the average NPV of the solution and the width, of the amount energy provided. Each segment of demand is represented by a different colour. As can be seen, it is possible that the technical solutions do not cover the demand of a segment so several solutions are required to fill it. Knowing the total

energy demand, the most cost-efficient solutions will be those on the left side of the demand threshold.
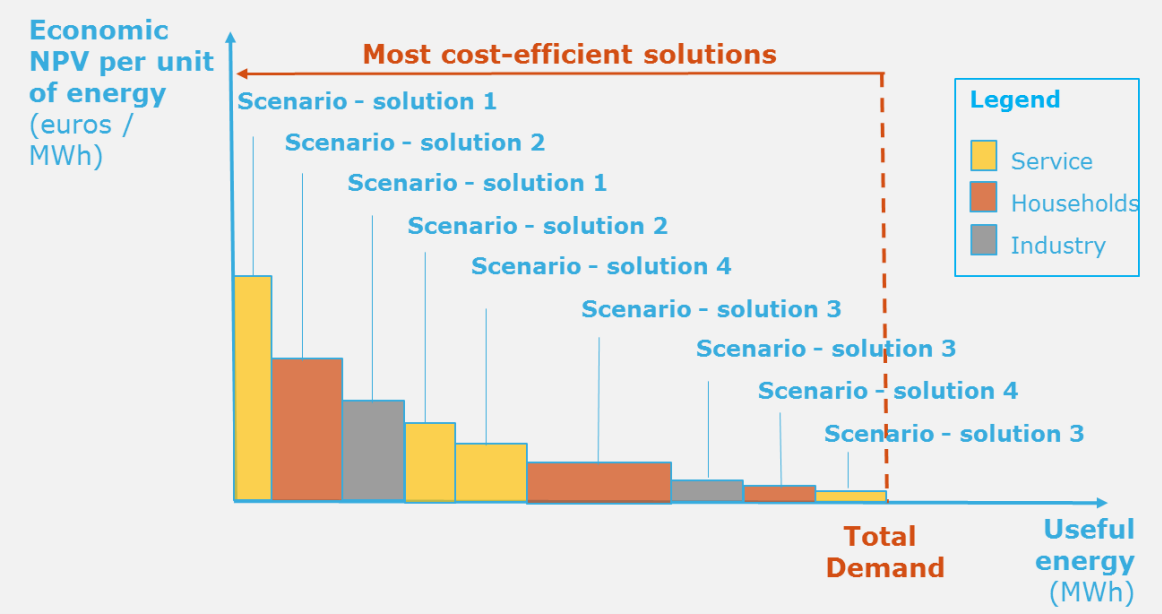
Figure 24. Heating and cooling supply curve at system boundary level.

In the context of the heating and cooling solutions some precautions have to be taken into account when implementing this approach, mainly because of the presence of different demand segments and different types of distribution systems (individual and centralized):

- Within the construction of the curve, the presence of mutually exclusive solutions has to be considered. In this sense, when the supply of a specific demand segment, e.g., service sector, has been totally covered by previous solutions, other solutions that cover that demand segment should not appear in the curve anymore. Figure 25 shows an example of a case in which a technology should be avoided. As can be seen, the solution with the highest NPV is the technical solution 1 that provides energy to cover 100 % of the service sector demand (in Figure 25 this information is indicated in parenthesis). Nevertheless, on the right, another technical solution (Technical solution 2) that also provides energy to the service sector appears. Some restrictions have to be incorporated in the analysis to avoid potential overlaps.

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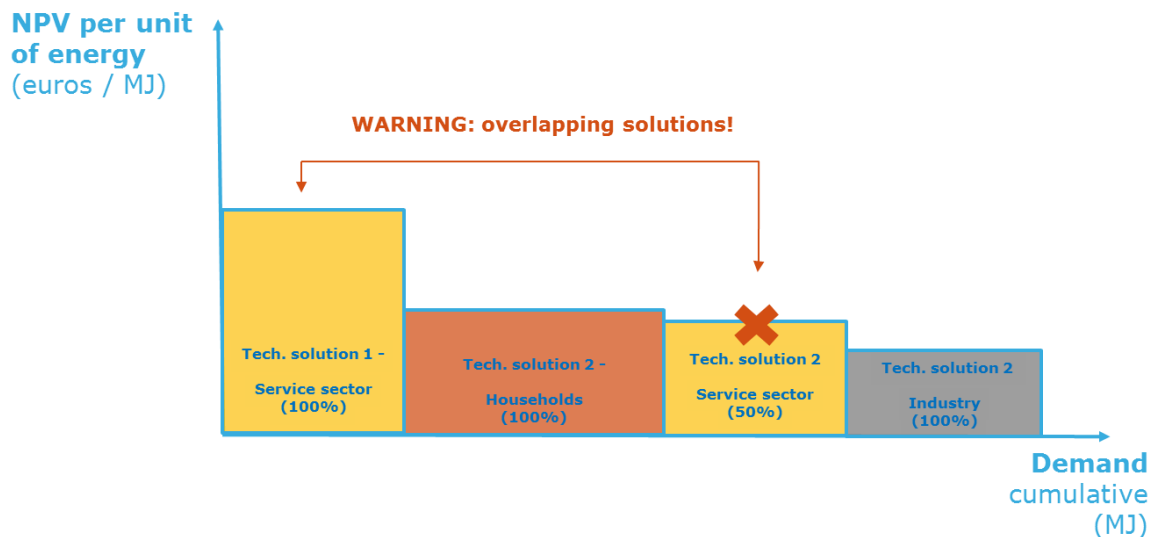
Figure 25. Heating and cooling supply curve not valid due to overlapping solutions.

- When there are centralised solutions and individual solutions within the same system boundary, it is suggested to conduct the analysis gradually:

1. Firstly, analysing the individual solutions separately. The aim is to identify the best individual solution by segment of demand.

2. Secondly, assessing NPV of the combination of all the best individual solutions by segment of demand.

3. Thirdly, comparing the best combination of individual solutions with centralized solutions. When any of the centralized solutions do not cover the whole demand of the system boundary, a previous process of selection has to be done to identify which is the best combination of resource to supply the district heating network, e.g. if there is a waste heat source that cover the 40 % of the demand and is more competitive than supplying heat by new CHP plants, the best option would be to use the waste heat as much as possible and cover the rest of the demand by using for example CHP plants or boilers.

This approach is illustrated on Example 23.

EXAMPLE 23. Identification of the most cost-efficient solutions
Table 28 shows an example on how to identify the most cost-efficient solutions within the System boundary 1, where centralized and individual systems coexist. The first step consists of analysing the individual solutions separately to identify the best individual solution by segment of demand. The best combination of individual solutions by segment is highlighted in green in Table 27.

Table 27. NPV per unit of the different technical solutions within System boundary 1.

			BIOMASS BOILERS	HEAT PUMPS
System boundary 1	Households	Multistore	17	82
		Terraced	5	-20
		Single	5	-16
	Service	Public buildings	205	-297
		…	…	…
		Other	75	192

Later, the best combination of individual solutions has to be compared with the rest of centralized solutions. Table 28 provides information on the average NPV of the combination of best individual solutions as well as the other centralized solutions (cogeneration and industrial waste heat). The solution that has the highest NPV is the Cogeneration+DHC.

Table 28. NPV per unit of energy for centralized solutions and the best combination of individual solutions.

	COGENERATION + DHC	INDUSTRIAL WASTE HEAT + DHC	Most cost-efficient combination of individual solutions
Total	87	60	12

When there are alternative scenarios with very similar results, using other kind of indicators as, for example, reduction of CO_2 emissions or Primary energy savings, could be used as an additional criterion to help in the decision making process.

Once the most cost-efficient solutions have been identified at system boundary level, all of them can be aggregated to determine the most cost-efficient potential at national level

6.3 Identification of areas for policy influence

As stated on Article 14 (4), based on the output of the cost-benefit analysis, MS will have to define adequate strategies, policies and measures. The CSWD Guidance on EED suggests conducting the CBA both from the economic and financial perspectives. So, at the end of the CBA, two kinds of indicators will be obtained: [i] the financial rate of return (FNPV) and [ii] the economic rate of return (ENPV). The usefulness of conducting the analysis from both perspectives is to identify potential areas for policy influence based on gaps between the financial suitability of a solution and its convenience from a society's perspective. Based on that gap, public deciders can

adopt strategies, policies and measures to support or promote those solutions, as well as remove existing or planned measures when the evaluation shows that are not justified in social terms.

The results of these two indicators should be analysed in order to obtain useful information to design policy measures:

- Those technical solutions that have a negative financial result (FNPV<0) but a positive result from a society point of view (ENPV>0) and are solutions that are within the cost-efficient potential, are solutions that require public support[71] that is justified in social terms.

- Those technical solutions that have a positive financial result (FNPV>0), as well as a positive result from a social point of view (ENPV>0), and are solutions that are within the cost-efficient potential, are solutions that do not require support. If those solutions are already receiving any kind of public support, public authorities should consider checking if the amount of public support received by this solution is appropriate or whether it should be reduced.

- Those technical solutions that have a negative result from a social point of view (ENPV<0) and are already receiving support, then it should be considered to remove the support, because it is not justified from a social point of view. However, there might be other conflicting energy policy targets (although out of the scope of this analysis), so an appropriate balance should be found.

6.4 Other indicators

The primacy of the NPV as an indicator for the appraisal is widely recognised [50]. Nevertheless, there are other complementary indicators that can provide additional information for the assessment:

[i] The internal rate of return (IRR), which consists of assessing the discount rate that would produce a NPV of zero. Once IRR is determined, the rule for accepting and ranking solutions is to adopt those alternatives which have a higher IRR than the predetermined discount rate [50]. There are some arguments in favour of using the IRR because it is an indicator familiar to decision makers but it has other disadvantages as it is sensitive to economic lifetime and timing of benefits.

[ii] The Cost-benefit ratio (CBR), which measures the rate of the present value of benefit with respect to the present value of costs. The usefulness of the CBR resides on its capacity to rank solutions that are not mutually exclusive, e.g., individual solutions that do not cover the total demand of a segment. Suppose a hypothetical situation in which there are three alternative

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[71] Or additional support in case that it is already receiving any kind of it.

scenarios with the characteristics described in Table 29 [50]. And imagine that there is a budgetary restriction of 200.

Table 29. Ranking independent projects.

Scenario	Cost (C)	Benefit (B)	B-C	B/C
A	200	400	200	2.0
B	100	220	120	2.2
C	100	240	140	2.4

When the solutions described in Table 30 are mutually exclusive, solution A should be the one chosen as it is the one with the highest NPV. Nevertheless, when alternatives are not mutually exclusive, choosing solutions B and C will allow maximizing the net benefits (260 when the net benefits of B and C are summed instead of 200 from the alternative A). So, this example shows that the Cost-Benefit ratio provides complementary information that can be useful depending on the situations. Nevertheless, the main disadvantage of the cost-benefit ratio is that all costs can be treated as negative benefits and vice-versa, so the final results can vary depending on how the effects are classified.

7 Sensitivity analysis

Annex IX of the EED requires that a sensitivity analysis is included in the Cost-Benefit Analysis. The aim of the sensitivity analysis is to assess which is the impact on the final results of calculations associated to changes in some relevant factors.

There are different approaches for taking into account the uncertainty in assumptions. Within the context of the EED, it would be enough to assess the changes of the NPV (in absolute terms) derived from a change in those parameters under uncertainty. This implies exploring a realistic range of key parameters based on prior modelling or analysis, e.g. high and low prices of fuels. It should be observed if there is any change in the final conclusions (economic potential and cost-efficient potential identification) associated to the change in any specific parameter (or even, a combination of parameters).

Other kinds of sensitivity analyses could provide useful information to identify some sensible parameters and values that could require special attention due to the risk associated to them:

- Measuring the elasticity of the NPV to changes in relevant parameters. It consists of measuring the ratio of the percentage change on NPV derived from a percentage change in one parameter. This allows identifying parameters for which a variation would have a higher influence on the results;

- Identifying switching values or values of a specific parameter for which the results turns from a positive outcome to a zero profit.

Based on some literature review[72], the parameters that can be explored in a sensitivity analysis can be:

- Discount rate;
- Changes in investment and operating costs (e.g. ± 25 per cent);
- High and low prices of fuels, electricity, CO_2 quotas, etc.;
- High and low values of effects on the environment, etc.;

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[72] Gulli, 2006; WYG, 2009; Eikmeier *et al.*, 2011; DEA, 2014.

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Annexes

The Annexes A-H describe a selection of relevant individual heating and cooling technologies that could play a significant role in the cost benefit analysis. The modules also indicate the steps, type and potential sources of information needed to carry out the analysis. It should be noted that the list of technologies is not exhaustive and that, as the EED indicates, the combination of different individual technologies should also be taken into account in the cost benefit analysis.

A.   Cogeneration

Introduction

Combined generation of heat and electricity, also known as cogeneration, is the combined production of electricity and heat from the same source of primary energy. With this method an important part of the waste heat from conventional electricity processes is utilized to cover specified end-use energy demand. Cogeneration is based on the thermodynamically efficient utilization of the fuel's energy content.

There are many energy production technologies that can be used under this definition. In this module only the technologies that are included in Annex I Part 2 of the EED and are relevant to the cost benefit analysis are going to be described.

Technologies

Cogeneration technologies can be used both in big centralized stations and in decentralized ones (distributed generation). The most popular prime movers are summarized below:

Centralized generation

Steam Turbines: They can be used either stand alone or as a part of a combined cycle. Steam turbines are the most common technology used in power plants and industries. Depending upon the exit pressure of the steam, steam turbines fall into two types: *backpressure turbines* and *condensing turbines*. Backpressure turbines operate with an exit pressure at least equal to atmospheric pressure, and are suitable for some sites with a steam demand of intermediate pressure. Condensing turbines have the advantage of changing electrical and thermal power independently and they work with an exit pressure lower than atmospheric pressure. In theory, steam turbines equipped with a suitable boiler can be run on any kind of fuel. As a mature technology, steam turbines have an extremely long life and, with proper operating and maintenance, are very reliable. However, several problems limit their further application, which include low electrical efficiency, slow start-up time, and poor partial load performance. As a result, steam

turbines are more popular in large central plant utilities or industrial cogenerations than in distributed energy applications.

Open cycle gas Turbines: frequently used prime movers in larger-scale cogenerations due to their high reliability and large range of power. They are usually found on peak load plants. Combustion turbines are easier to install than steam turbines and they have the added benefit of being less area intensive, with lower capital costs and very flexible in their operation.

Decentralized generations

Reciprocating engines: It is the most mature prime mover technology used in distributed CCHP systems which is mainly driven by natural gas. Reciprocating engines are a proven technology with a range of size and the lowest first capital costs of all CCHP systems. In addition to fast start-up capability and good operating reliability, high efficiency at partial load operation give users a flexible power source, allowing for a range of different energy applications—especially emergency or standby power supplies. Reciprocating engines are by far the most commonly used power generation equipment under 1 MW. However, full utilization of the various heat sources with diverse temperature levels in CCHP applications is difficult.

Micro-turbines: It is actually an extension of turbine technology in smaller scale. They are primarily fuelled with natural gas, but they can also operate with diesel, gasoline or other similar high-energy fuels. Research on biogas is ongoing. Micro-turbines have only one moving part; they use air bearings and they do not need lubricating oil, although they have extremely high rotational speed, up to 120 000 rpm. Small-scale individual units offer great flexibility and can be easily combined into large systems of multiple units. Micro-turbines can be used as a distributed energy resource for power producers and consumers, including industrial, institutional, commercial and even residential users of electricity in the future. Moreover, the heat produced by a micro-turbine can be used to produce low-pressure steam or hot water for on-site requirements.

Table A1 summarizes relevant data from the literature for the above-mentioned technologies.

Table A1. Techno-economic data for cogeneration [51-56]

	Steam turbines	Gas turbines	Internal Combustion Engines	Micro-turbines
Capacity range	50 kW - 500 MW	250 kW - 50 MW	3 kW - 6 MW	15 - 300 kW
Fuel used	Any	Gas, propane, distillate oils, biogas	Gas, biogas, liquid fuels, propane	Gas, propane, distillate oils, biogas
Efficiency electrical (%)	7 - 20	25 - 42	25 - 43	15 - 30
Efficiency overall (%)	60 - 80	65 - 87	70 - 92	60 - 85
Power to heat ratio	0.1- 0.5	0.2- 0.8	0.5 - 0.7	1.2 - 1.7
Output heat temperature (°C)	Up to 540	Up to 540	Different levels	200 - 350
Noise	Loud	Loud	Loud	Fair
CO_2 emissions (kg/MWh)	N/A	580 - 680	500 - 620	720
NOx emissions (kg/MWh)		0.3 - 0.5	0.2 - 1.0	0.1
Availability (%)	90 - 95	96 - 98	95	98
Part load performance	Poor	Fair	Good	Fair
Lifetime (years)	25 - 35	20	20	10
Average cost investment (EUR/kW)	1000 - 2000	600 - 950	900 - 1500	1100 - 1800
Operating and maintenance costs (EUR/kWh)	0.004	0.0045 - 0.0105	0.0075 - 0.015	0.01 - 0.02

Emissions associated with a steam turbine are dependent on the source of the steam. Steam turbines can be used with a boiler firing any one or a combination of a large variety of fuel sources, or they can be used with a gas turbine in a combined cycle configuration.

Guidelines to select and design a cogeneration plant

Selecting and sizing a CHP plant is dependent on the heat and electricity energy demand and on the coincidence of these loads. Heat-to-power ratio is one of the most important technical parameters influencing the selection of the type of cogeneration system. The heat-to-power ratio of a facility has to match with the characteristics of the cogeneration system to be installed.

The design and sizing of a plant based on the load duration curve of the heat demand is a commonly used rule of thumb approach subject to several limitations such as lack of load coincidence information, assumption of ideal operation etc. [58]. The most important considerations for the design of CHP in each sector are presented below:

Industry: Industry loads are usually easy to predict and simulate because they depend heavily on the production needs and planning. Energy is used mainly in production processes and less in HVAC or lightning systems. For that reason, ambient temperature has a smaller effect. Industries can be divided in two big categories in regards to their type of operation: continuous or batch. Those that have continuous operation have more constant loads, and the fraction between the energy kinds does not fluctuate a lot during the day. The latter one depends only on the kind of industry. It is clear that industries can be classified according to their energy priorities e.g. an aluminium industry is very power-intensive whereas an ice-cream industry needs large quantities of cooling energy. A very common problem that occurs on batch operation industries is the successive alternation of energy demand; e.g. a heat-intensive process is needed immediately after a power-intensive process is completed, thus making those industries unsuitable for CHP systems.

Commercial buildings have demanding thermal and cooling loads due to heating, ventilating and air conditioning (HVAC) systems. For that reason CHP technology and application matching in the commercial sector is more difficult than industrial complexes as: (a) it has more fuzzy profiles, (b) on average they are operating fewer hours per year so the payback period of the investment rises, and (c) are generally smaller than industrial sites which means that are less efficient having smaller economy scales. In contrast to industrial consumers, ambient temperature affects heavily the commercial buildings. Of course, the most important factor is occupation and activity frequency. Both seasonal and daily variations of energy need to be considered for a more precise design result. Electricity is usually distributed to office applications and cooling devices. Thermal energy is used for space heating and other processes, such as equipment sterilization, laundry, and kitchen general hot needs.

Residential buildings have the most unpredictable loads since they are based on human acts and needs. The cyclic variance of energy demand due to the operating nature of the residential equipment (e.g. fridge, boiler etc.) is important to be considered even on a half-hour basis. The most

important factors that affect occupation pattern and thus the energy demand are the following [57]: a) the number of residents, b) the time that the first resident stands that goes to sleep and c) the time that a house is unoccupied during the day.

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B.   District heating

Introduction

A heating system consists of three main components: heat generation in heat source, transportation of heat carrier and use of heat in heating system. District heating (DH) systems are used to transport and distribute thermal energy, generated in central source to residential, commercial and industrial consumers to be used in space heating, domestic hot water preparation and/or process heating. Heat is carried by a heat carrying medium running in pipelines, usually made of steel. Typical heat carrying mediums are water or steam, the former being the most prevalent in residential areas. Further, steam distribution networks are used for delivering of process heat in some large industrial zones.

District heating is traditionally prevalent in Central, Eastern and Northern European countries where due to colder climate (heating degree days in excess of 3000) there is high demand for heating. Share of citizens served by district heating in some countries is very high (more than 60 % of all citizens in Latvia and Lithuania) [59]. Yet, district heating systems are also operating in warmer climate zones, for instance Italy.

Application

District heating systems are more suitable to be implemented in areas with high heat density or high plot ratio and high annual load factor. High heat density is related to higher consumption and sales and therefore more favourable conditions for covering the investment costs. District heating systems require large initial investments, of which the largest part is usually the cost associated to pipes and their installation.

The annual heat load factor represents the distribution of heat demand of a given heat consumer over the year. The more even this distribution, the better utilization of district heating network's and heat sources' capacity. Ideally heat load would be represented by horizontal line but in reality it has a number of peaks when heat demand is very high and periods of low consumption, when heat demand might be very low. This makes the design and proper sizing of the networks a very complex task.

In order to expand the utilization and implementation of district heating systems, political will and favourable policies, which have proven their importance in the successful implementation of district heating, might still be needed.

Advantages and disadvantages

Most of the benefits of district heating are stemming from the fact that heat is generated in small number of large central heat sources rather than in a large number of small heat generators, located directly at the place of heat demand. District heating has many benefits:

- More efficient generation of heat and lower consumption of fuel due to the use of large well maintained and controlled equipment;
- Ability to increase efficiency even further by the employment of cogeneration;
- Lower air pollution. Lower air pollution is related not only to more efficient utilization of fuel sources but also to better control of pollution due to smaller number of pollution sources. Lowering of local air pollution is especially important in dense urban areas because central plants are usually designed to be located at the outskirts of town taking into account prevailing wind direction;
- District heating systems are flexible in their operation, i.e. they are able to utilize different heat sources and different primary energy streams. Heat to the network can be supplied by renewables, such as biomass or solar energy, by conventional boilers using fossil fuel or by waste heat recovery systems.

District heating has also significant deficiencies: large quantities of steel are needed for production of pipelines which have limited lifespan and need to be regularly replaced, damages of pipelines might lead to break-ups in heat supply (although this can be mitigated by careful design of the system), networks are costly and require large initial investment, pipelines are laid in urban areas so careful planning is required and heat losses in some networks might be significant.

Design considerations

District heating systems can be of very different sizes. They can supply large cities, such as Greater Copenhagen (Helsinki), Helsinki (Finland) or Vilnius (Lithuania) or small townships and villages with only a small number of houses. The capacities of district heating networks can vary significantly depending on the size of the area served. For instance, the annual demand in the Greater Copenhagen district heating system exceeds 30 PJ while small district heating networks might have an annual heat demand of less than 10 TJ [60].

Moreover, the design and configuration of district heating network is very much case-dependant. Typically district heating network consists of transmission pipelines and distribution pipelines. Transmission pipelines have larger diameter (up to 1200 mm) and transport heat carrying medium from heat source to distribution hubs. On the other hand, distribution pipelines distribute heat to consumers and are smaller in size (typically diameters do not exceed 300 mm). In some cases this distinction into two groups is arbitrary and it is difficult to establish where transmission pipeline

ends and distribution begins. In other cases district heating networks might have dedicated transmission pipelines with different parameters (temperature and pressure) of heat carrying medium than in distribution networks.

Usually a district heating network is made of two pipes laid side-by-side. One pipe is used to supply warm heat carrying medium from the heat source to the consumers and the second is used to return the cold medium back to the heat source. In water based networks diameters of pipelines are the same, but in steam networks the supply pipe is much larger in diameter than the return pipeline.

Some designs use twin pipelines when supply and return pipes are enclosed in the same casing in order to lower installation costs and heat losses but twin pipes are available in limited sizes – up to 219 mm [60].

It is common practice to construct district heating networks by using pre-insulated pipes. Such pipes are put in polyethylene (PE) casing in the factory. The empty space between external surface of service pipe and plastic casing is filled with polyurethane (PUR) insulation. Steel is the material of choice for service pipes but copper, PEX or aluminium/PEX might also be used. Such prepared pipes are shipped to installation sites in which are welded into continuous pipelines and the joints are insulated.

Pipelines with PUR insulation can be used for carrying medium of up to 140 °C temperature, but usually a lower temperature is maintained under operational conditions in order to avoid thermal damages to insulation and to lower heat losses. If higher temperature heat carrying medium is intended to be used, insulation should be made of mineral wool and installed on site.

The maximum pressure of typical district heating pipelines is up to 24 bar. Nonetheless, normal values of pressure in transmission pipelines are usually up to 20 bar and up to 10 bar in distribution network.

Although district heating pipelines are usually buried underground, pipelines might be, in some instances, laid in concrete small or walk-through tunnels for easier access. This method of installation is more expensive but it allows an easy access to damaged pipeline. Digging activities, which might be very costly and difficult to do in urban areas, are avoided. Pipelines can also be installed above ground on special retainers although using such method increases heat losses.

District heating pipelines can also cross rivers or water channels. This is done either by using bridges or pipes installed underneath the water body by directional drilling.

Technology data

Total costs of implementation of district heating system in given area consist of two parts: costs of pipelines and costs of district heating substations. The latter is related to the connection of heat consumers (i.e. buildings) to the network.

Overall, it is difficult to present precise data on installation costs of district heating networks due to the particularities of each demand area. Nonetheless and as an illustrative example, the report published by the Danish Energy Agency [60] includes projections of parameters of different types of district heating systems up to 2050 (see Table B1).

Table B1. Techno-economic data for conventional district heating network constructed in existing building area [60].

	Year			
	2015	**2020**	**2030**	**2050**
Heat density an consumer (TJ/km^2 land area)[73]	120	120	120	120
Net loss (%)[74]	15	15	15	15
Heat density ab plant (TJ/km^2 land area)	141	141	141	141
Pump energy (MWh/TJ/year)	0.2-4	0.2-4	0.2-4	0.2-4
Technical lifetime (years)	30-50	30-50	30-50	30-50
Investment costs (1000 EUR/TJ)[75]	18-22	18-22	18-22	18-22
Fixed O&M (EUR/TJ/year)	250	250	250	250

Based on the data included in Table B1, the authors of the previously mentioned report [60], expect no changes in technical or economical parameters of district heating networks to occur in the foreseeable future. Although this might be reasonable assumption since district heating is a mature technology, district heating pipelines require large amounts of steel. Therefore, investment costs might be ultimately affected by changes in the price of key raw material.

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[73] Based on an area with 1400 (old and relatively large) single-family houses with a total heat demand of 229 TJ/year excluding network losses. Twin pipe network with a total length of 17500 m including branches.

[74] use of single pipes would lead to a higher heat loss.

[75] Excluding branch pipes. Including main network (twin pipes, earthwork and pipe work).

In case that the extent of a district heating network, for a particular heat demand area, could be estimated, investment costs of district heating pipelines might also be estimated based on the price Catalogue compiled by the Swedish District Heating Association [61]. The catalogue includes prices of pipes with diameters ranging from 18 till 1000 mm. The summary for pre-insulated pipes with PUR insulation is presented in Table B2.

TableB2. Costs of district heating pipeline installation [61][76].

Diameter (mm)	Cost of pipe (EUR/m)	Welding works (EUR/m)	Joint assembly (EUR/m)	Earth works (EUR/m)	Total costs (EUR/m)
20	19	19	5	150	193
25	20	21	6	176	223
32	22	22	8	206	258
40	23	24	8	241	295
50	28	27	8	284	347
65	33	31	8	302	374
80	38	36	8	343	425
100	55	39	10	387	492
125	66	42	10	443	560
150	82	52	10	532	675
200	113	74	16	563	765
250	173	83	16	617	888
300	203	101	16	671	990
400	233	119	25	744	1121
500	285	142	25	836	1289
600	358	174	29	928	1489

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[76] Prices in the Catalogue [61] are expressed in Swedish crowns. Exchange rate of 2013 (0.11581 SEK to 1 EUR) was used for conversion

700	426	223	29	1033	1711
800	489	260	41	1115	1904
900	571	309	41	1195	2116
1000	686	361	41	1289	2377

It should be mentioned that although the Catalogue [61] includes two different variations of prices i.e. one for street areas and other for green spaces, only costs for street areas are presented in Table B2.

Furthermore, the DEA project [60] establishes that the investment into district heating substations for one family house is 1500–3500 EUR/house and 70 EUR/kW for apartment buildings. The expected lifetime of substations is 20 years and the fixed O&M costs are 150 EUR/unit/year for single family buildings and 1250 EUR/unit/year for apartment buildings. The report also mentioned that these indicators will remain unchanged till 2050.

Guidelines to conduct the Cost-benefit analysis of district heating

Precise guidelines on the estimation of costs of DHC networks are difficult to provide due to a combination of factors; the actual cost is site specific and the result of complex network optimization calculations, which depends on the configuration of heating and cooling consumers, plot ratios, parameters of available heat etc. This implies that the length of the DHC network has to be estimated in most cases. The estimation can be based on different considerations, but a reasonable approximation could be to use the relationship between linear heat density demand and the total heat demand. As pointed out in CSWD (footnote 24), an area with plot ratio of 0.3 currently corresponds to a linear heat density of 2.5 MWh/m (this was based on the assumption that the current specific heat demand is 130 kWh/m^2). The linear heat density is the ratio of heat supplied annually into the district heating network to the trench length of the pipelines of the network. Thus, by dividing the calculated heat demand of a given heat demand area by the linear heat density, the total length of DHC network needed to serve that area can be estimated. For instance, a heat demand area with plot ratio of 0.3 and a heat consumption of 20000 MWh/a would need 20000 MWh/2.5 MWh/m = 8000 m length DHC network to serve it. It should be noted that linear heat density depends on the plot ratio. A higher plot ratio corresponds to higher linear heat density. Based on experience of existing DHC the linear heat density can range from 2.5 to 6.5 MWh/m, the first number corresponding to lower plot ratio areas (around 0.3) and the second number corresponding to areas with high plot ratio (around 1.0).

Another method to estimate the length of district heating network might be based on the length of streets in a given demand area.

Further, the second parameter influencing the capital cost of a DHC network is the diameter of its pipelines. The pipes leaving the central plant serve all demand and therefore have the largest diameter. These are at maximum being 1000-1200 mm with smaller diameter pipes branching off to serve smaller groups and individual consumers. The diameters of pipelines serving individual consumers may be as low as 20-32 mm. The estimation of the DHC network cost can be based on the average diameter of pipelines needed to supply heat. An analysis of existing DHC networks shows that the average diameter of pipelines in many cases ranges from 80-150 mm, but may be somewhat larger or smaller depending on the network configuration and operational conditions.

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C.   District cooling

Introduction

Chilled water for space cooling or industrial processes might be produced by vapour compression machine or by an absorption refrigeration machine driven by electric, turbine or internal combustion engine. District cooling (DC) can be achieved using four general options:

1. Heat from central source can be distributed to absorption machines located directly at the place of cooling demand by using pipelines of district heating system. In this case no separate pipelines for chilled water transportation might be needed and the system is essentially district heating network with different load profile.

2. Dedicated district cooling (DC) system might be installed for transport and distribution of chilled water to consumers. Chilled water would be prepared centrally in absorption chillers or vapour compression machines. Chilled water is carried by heat carrying medium running in pipelines which are of the same basic construction as district heating pipelines.

3. Heat from central heat source can be distributed through district heating network to cooling hubs, located near concentrations of cooling consumers, such as office buildings, complexes of service buildings, etc. Absorption chillers, located in these hubs, produce chilled water using heat from district heating network and supply chilled water to cooling consumers through a series of smaller local district cooling networks.

4. A free cooling system uses low external air temperatures in order to reduce the temperature of a water source i.e. it utilizes the cool outdoor air as a free cooling source.

Application

District cooling systems are most suitable to be implemented in areas with high building density (especially offices and service buildings) and high annual cooling load factor. District cooling systems require large initial investments, of which the largest part is usually the cost of pipes and their installation, a trend that district cooling shares with district heating systems.

Chilled water supply temperature needed for conventional cooling and air conditioning systems usually range from 6 to 7 °C. A lower water temperature might be used in order to lower flow rate of coolant per kW of refrigeration thus resulting in smaller diameters of district cooling pipelines and lower investments. If chilled water storage is used, the lower limit is around 4 °C and ca. 1 °C in the case of ice storage systems. Typical temperature values in return pipelines range from 12 to 17 °C [62].

Advantages and disadvantages

Since the systems are very similar, most of the benefits of district cooling are similar to the ones of district heating. Benefits are related with the fact that cooling is generated in small number of large central cooling sources rather than in a large number of small air conditioners or coolers. Most important district cooling benefits are:

- more efficient generation of cooling and lower consumption of primary energy due to the use of large well maintained and controlled equipment
- lower air pollution
- district cooling systems are flexible in their operation, i.e. they are able to utilize different heat sources and different primary energy streams
- cooling might be generated from waste heat. Using district cooling allows for better utilization of cogeneration plants, especially if they serve both heating and cooling needs of given demand area

One of the biggest disadvantages of district cooling is the large initial investment associated to the installation of the system.

Design considerations

The design and configuration of district cooling network is very case dependant and all district cooling systems are somewhat different. Usually district cooling networks consist of two pipes laid side-by-side. One pipe is used to supply chilled water from a central chiller to the consumers and the second is used to return warm water back to the cooling source. In most networks the supply and return pipes present the same diameter.

In order to lower installation costs and heat losses, some designs use twin pipelines in which supply and return pipes are enclosed in the same casing. Nonetheless it should be noted that twin pipes are only available in limited sizes – up to 219 mm [64].

It is common practice to construct district cooling networks by using the same technology as in the case of district heating, for instance by using pre-insulated pipes. Such pipes are put in polyethylene (PE) casing in the factory. The empty space between external surface of service pipe and plastic casing is filled with polyurethane (PUR) insulation. Although other materials can be used, steel is usually the material of choice for service pipes. Such prepared pipes are shipped to the installation place where they are welded into continuous pipeline and the joints are insulated.

Common practice in the installation of district cooling pipelines is to bury them directly underground. In some instances pipelines might be laid in concrete small or walk-through tunnels for easier access. Although this method of installation is more expensive, it allows easy access to a

damaged pipeline without digging it out, which might be very costly and difficult to do in urban areas. Pipelines can also be installed above ground on special retainers although using such method increases warming rate of coolant.

Technology data

Total costs of implementation of district cooling system in a given area consist of two parts: costs of pipelines and costs of district cooling substations. The second part of investments is needed to connect cooling consumers (buildings) with the network.

In general, it is difficult to present precise data on installation costs of district cooling networks due to specifics of each demand area and general lack of reliable data. Since district cooling networks are very similar to district heating systems, some of the data can be used for both of these systems.

In case that the extents of district heating cooling for a particular heat demand area are estimated, investment costs of district cooling pipelines could be estimated based on price Catalogue compiled by the Swedish District Heating Association [63]. The Catalogue includes prices of pipes with diameters ranging from 18 till 1000 mm. The summary for pre-insulated pipes with PUR insulation is presented in Table C1.

TableC1. Costs of district heating pipeline installation [63][77].

Diameter (mm)	Cost of pipe (EUR/m)	Welding works (EUR/m)	Joint assembly (EUR/m)	Earth works (EUR/m)	Total costs (EUR/m)
20	19	19	5	150	193
25	20	21	6	176	223
32	22	22	8	206	258
40	23	24	8	241	295
50	28	27	8	284	347
65	33	31	8	302	374
80	38	36	8	343	425

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[77] Prices in [63] are expressed in Swedish crowns. Exchange rate of 2013 (0.11581 SEK to 1 EUR) was used for conversion

100	55	39	10	387	492
125	66	42	10	443	560
150	82	52	10	532	675
200	113	74	16	563	765
250	173	83	16	617	888
300	203	101	16	671	990
400	233	119	25	744	1121
500	285	142	25	836	1289

Moreover, The Catalogue [63] contains two different variations of prices, one for street areas and the other for green spaces (costs are presented only for street areas in Table C1).

In addition, results published by the Danish Energy Agency [64] establish that the investment in district heating substations in the case of one family house is 1500-3500 EUR/house and 70 EUR/kW of demand for apartment buildings. Expected lifetime of substations is 20 years. Fixed O&M costs are 150 EUR/unit/year for single family buildings and 1250 EUR/unit/year for apartment buildings. It is also mentioned that these indicators will remain unchanged till 2050. Same or similar figures can be used to estimate the installation costs of district cooling substations.

Guidelines to conduct the Cost-benefit analysis of geothermal potential

In order to conduct the cost benefit analysis the first step is to estimate the size of the district cooling network using different methods. One technique to estimate the length of district heating network is based on the length of the streets in a given demand area.

After deciding on the length of the district heating pipelines, a second decision, which will have a direct influence on the capital costs, should be made on the size of pipes. The distribution of pipe sizes by total length can be estimated by employing different methods, such as examples of existing district heating systems or based on sample district heating designs based on the conditions of country or region.

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D.   Waste heat recovery

Introduction

This module refers to the waste heat produced from industrial activities as part of unavoidable thermodynamic inefficiencies during the transformation of raw materials into more valuable products. Since the industry sector is very diverse, the sources quantity and quality of waste heat and consequently its recovery techniques differs greatly.

Waste heat sources from industrials processes can be categorized as follows [65]:

- Combustion exhausts: e.g. glass melting furnace, cement kiln , fume incinerator , aluminium reverberatory furnace , boiler;
- Process off-gases: e.g. steel electric arc furnace, aluminium reverberatory furnace, drying & baking ovens;
- Cooling water from: furnaces, air compressors, internal combustion engines
- Conductive, convective, and radiative losses from equipment and heated products:

EED refers mainly to the first three categories which incorporate a stream (gas or liquid) coming out of a process. The waste heat from a process can be categorized by its quality temperature. Most of the waste heat losses identified in industries are usually at temperatures below 230 °C. The type and quality of waste heat will define the heat recovery technology that will be used. Depending on the quality and quantity of recovered heat, it can be used either inside the industry for other processes, off-site for any other heat consumers, for electricity generation or for any other use by transforming/upgrading it (e.g. via a heat pump) to suitable conditions.

Technology data

Most of the time, waste heat will be recovered by a heat exchanger of the type specific for this application. The following Table summarizes the most important data needed for the design of such system.

TableD1. Most important design parameters of heat exchangers [66].

Parameters	Plate Heat exchanger	Plate-fin heat exchanger	Shell & tube heat exchanger (condensing)	Shell & tube heat exchanger (convective)
Applicable temperatures (°C)	100–650	60–90	100–500	40–500
U value (kW/ m^2 K)	0.06–0.28	0.06	0.1–0.85	0.1–0.6
Capital costs	10	5	3	5

(EUR/m²)				
Media	Steam to steam Water to water	Steam to water	Steam to steam Steam to gas Steam to water Gas to steam Gas to gas Gas to water	Water to gas Water to water Water to steam Steam to steam Steam to gas Gas to gas Gas to steam

Guidelines for designing a waste heat recovery equipment

Estimating the waste heat available in an industry includes a whole analysis of the energy balances of all processes. Given the stream's physical properties, mass flow rate, process stream source and target temperatures, the proper design can be identified, sized and costed. The selection of the heat exchanger type will also be affected by the composition of the waste heat source as the source fluids can be corrosive and modify the heat transfer rates. Denser fluids have higher heat transfer coefficients and so enable higher heat transfer rates for a given heat exchanger area and temperature drop. Fouling of heat exchangers can occur if the stream has a corrosive composition.

The most important costing parameter as it can be identified from the above Table D1 is the required heat exchange surface (m²). A simple application of energy balances and heat transfer equation can give a good estimation of it. Indicatively the following equations can be used for the design of a waste heat recovery system [67]:

$$q = m_c cp_c (Tc_{ou} - Tc_{in}) = m_h cp_h (T_{h,out} - T_{h,in})$$

where q, is the heat transferred, m the mass flow, Cp the heat capacity subscripts and T the temperature. c and h refer to cold and hot streams.

The Log Mean Temperature Difference can be found by means of

$$LMTD = \frac{(Thi - Tco) - (Tho - Tci)}{\ln \dfrac{(Thi - Tco)}{(Tho - Tci)}}$$

The required surface can be found by means of:

$$A = \frac{q}{U \cdot LMTD}$$

Based on that the capital costs can be identified. The most important operating cost of such system is the pumping water cost which is a related with the mass flow (m) of fluid that need to be

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pumped through the waste heat recovery device. The electricity consumed in the pumping can be estimated by means of:

$$Ep = \frac{m \cdot DP}{\eta \, \rho}$$

where E the electric power, m the mass flow, n the efficiency of the pump and ρ the density of the fluid.

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E.   Heat pumps

Introduction

Heat pumps are based on technology that transfers thermal energy from a heat source (i.e. aero-thermal, geothermal and hydrothermal) to a heat sink using a compression cycle that takes advantage of temperature gradients. They can be used to provide space cooling, space heating and hot water. It should be mentioned that reversible heat pumps can provide both heating and cooling.

Moreover, they can be driven by electricity or by thermal energy. The main difference between conventional compression heat pump technology and thermally activated heat pumps is their approach towards compression; compression heat pumps employ a mechanical compressor[78] while thermally activated heat pumps achieve compression by thermal means [68].

It should also be mentioned that thermally driven heat pumps can further be differentiated into absorption[79] and adsorption heat pumps[80] and are usually fuelled by fossil fuels.

Heat pump efficiency is characterised by the coefficient of performance (COP[81]), which is defined as the ratio between energy delivered and energy consumed, or by the seasonal performance coefficient (SPF), which also takes into account the real operating conditions [69]. Additionally, cooling efficiency is measured using the energy efficiency ratio (EER) or the seasonal energy efficiency ratio (SEER).

TableE1. Typical efficiency factors in heat pumps [68-72].

	COP/EER	SPF/SEER
Electrical-driven heat pumps		
Ground-source HP (GSHP)	2.5 - 5	2.4 - 6

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[78] Driven by an electric motor or combustion engine

[79] The principle of operation of an absorption heat pump is based on evaporation of a refrigerant and its absorption into an absorbing medium

[80] Based on the same principles as the absorption heat pump. It uses a solid instead of a fluid as absorption medium and are being increasingly used in small heat pump systems (70-500 kW), that are mainly used for cooling.

[81] COP values depend on the water temperature, humidity and ambient air temperature, set point temperature, hot water draw profile, auxiliary energy consumption and operating mode.

Air-source heat pump (ASHP)	2.5 - 3	2.2 - 5
(Reversible) air-source heat pump (r-ASHP)	3.5 - 4.5	2 - 6
Water-source heat pump (WSHP)	4	4 - 4.5
Thermally-driven heat pump		
Absorption heat pump	0.5 - 2.2	-
Adsorption heat pump	0.5 - 1.5	-

The information included in Table D1 also indicates that electrical-driven heat pumps have, in general, higher efficiency values than thermally-driven units. Moreover, ground-source heat pumps, which use underground heat exchangers, present higher efficiencies in cold weather than ASHPs.

In the commercial sector, the heat pump system can be a central installation connected to an air duct or hydronic system, or a multi-zone system in which multiple heat pump units are located in different zones of the building to provide individual space conditioning.

Lastly, it should be pointed out that heat pump technology can be used as the only heating and cooling system, in combination with other systems or as part of district heating and cooling and waste heat recovery installations.

Technology data

Detailed techno-economic data for heat pumps can be found, among others sources, in the European Heat pump association, the IEA heat pump center, IRENA [73] and the Heat pump & thermal storage technology center of Japan. Table D2 and Table D3 illustrate typical data that will be needed in order to carry out the cost-benefit analysis.

It should be noted that there exists a direct relation between the temperature of the energy source and the capacity provided by the heat pump (i.e. the lower the source temperature, the lower the capacity). Therefore, the efficiency of heat pumps depends on their technical specifications, mode of operation (increase/decrease temperature), selection of (partial/full) load mode, and differences between indoor and outdoor temperatures [69].

TableD2. Techno-economic heat pump data [69,71,72].

RESIDENTIAL SECTOR					
	HP #1	HP #2	HP #3	HP #4	HP #5
Technical data					
Thermal capacity (kWth)	15	20	35	10	3.5
COP (or SPF)	3.5	(2.6)	(3.4)	3.5	10
Heat source	Air-source (air to air)	Air-source (air to water)	Ground-source	Ground-source	Water-source
Fuel	Electricity	electricity	electricity	Electricity	Electricity
Technical lifetime (yr)	30	20	20	20	20
Economic data					
CAPEX (EUR/kWth)	1190	1657	1890	2832	2610
O&M excluding fuel (% CAPEX)	2	2	2	2	4

Water and ground configurations give, in general, higher operating performance compared to air due to less fluctuating water and ground temperatures. Nonetheless, air-source heat pumps have lower initial costs than water- and ground- source heat pumps due to a less expensive heat source/sink system and to the fact that ASHPs mainly consist of factory-built units which are easy to install. Furthermore, water-source heat pumps are in general cheaper than ground-source heat pumps since drilling operations are not usually needed.

TableD3. Techno-economic heat pump data [69, 72].

COMMERCIAL SECTOR				
	HP #6	HP #7	HP #8	HP #4
Technical data				
Thermal capacity (kWth)	>40	>40	43	40

COP (or SPF)	3.4	2.9		
Heat source	Ground-source	Air-source	Absorption	Adsorption
Fuel	Electricity	Electricity	Fossil	fossil
Technical lifetime (yr)	20	20	20	20
Economic data				
CAPEX (EUR/kWth)	3500	2000	22900	18000
O&M excluding fuel (% CAPEX)	2	2	4	4

Finally, investment costs per produced heat output are usually lower for absorption heat pumps than for the mechanically driven units.

Guidelines to conduct the Cost-benefit analysis of heat pump potential

In order to conduct the cost benefit analysis, the first step will consist of assessing the technical potential of the technology in the demand area. Among the factors that will have to be considered are the heating and cooling demand and supply profiles, characteristics of the area and primary fuel-mix.

In order to include the technology in the analysis it has to be assured that it also complies with the definition of ´efficient individual heating and cooling´ included in the European Energy Efficiency Directive [D2012/27] [75]. It should be pointed out that heat pump technology might also be considered in combination with other heating and cooling technologies. After the selection of the appropriate type of heat pump, the system has to be adequately dimensioned in terms of optimal configuration and capacity. Furthermore and in the case of ground-source heat pumps, the analysis also has to take into account costs related to drilling activities.

Finally, the environmental impact of the proposed technology has to be estimated. Therefore, data regarding potential emissions (to water, air and land) associated to the technology have to be included. In the particular case of heat pumps, environmental impacts will be mainly associated to the fuel and the working fluid, i.e. refrigerant.

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F.   Boilers

Introduction

Boilers can be used as the only heating unit in individual dwellings, as part of a district heating and cooling system[82] or in combination with alternative technology in hybrid configurations[83]. Nonetheless, it should be mentioned that the objective of this module is to only describe the use of standalone boilers for heating and cooling applications. Predominantly conventional boilers are nowadays being substituted by condensing units, which are high efficiency systems and require the use of less fuel. The fuels employed in boilers are mainly oil, natural gas[84], coal, electricity and renewable energy sources such as biomass. Table F1 includes efficiency values associated to different fuel sources.

TableF1. Efficiency in boilers [76].

Fuel	Actual efficiency (full load)	Actual efficiency (low load)
Coal	85%	75%
Oil	80%	72%
Natural gas	75%	70%
Biomass	70%	60%
Electricity	98%	95%

Electric boilers are used to produce space heating and hot water directly from electricity and can operate under a wide and flexible range of temperatures. In case of being integrated in district heating, they can utilise superfluous electric energy for heating at times of high electricity production.

On the other hand, gas units are the most commonly installed fossil fuel-based boilers. Besides, they can also be used in centralized systems for the production of comfort cooling in conjunction

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[82] Nowadays they are also frequently used for peak-load or back-up capacity

[83] The combination of a solar thermal system with a fuel-based boiler heating system can reduce fuel consumption by 10–20% (EHI).

[84] Condensing boilers running on natural gas are often the first choice both for new installations and for refurbishment across Europe.

with absorption machines. In residential gas boilers, the generated flue gas passes through a heat exchanger in which heat is transferred to another media, normally water the is then circulated to heat emitters in the space heating system and/or to the domestic hot water[85]. It should also be mentioned that low-sulphur heating oils have demonstrated advantages over conventional heating oils. Noxious substances in the flue gases are reduced to a minimum and the condensate does not need to be neutralised (EHI) [77]. Moreover, liquid biofuels (produced from biomass) are being added to conventional fuel. They offer a high energy density and with state-of-the-art combusting technology they can be burned without almost any residue or pollutants.

Finally, modern biomass-based boilers heating systems use wood in the form of pellets, wood chips or split logs. Wood-based central heating systems are capable of supplying an entire house with heat throughout the year and can easily be combined with other heating systems. Their main advantage is their high efficiency and a low or near-zero impact in terms of CO_2 emissions.

Technology data

Technical and economic data for boilers can be found in a large number of sources, including local manufacturers and Governmental Agencies technical reports. From a technical point of view, the capacity, efficiency, type of fuel, thermal output and technical lifetime are factors that will need to be taken into account in the cost-benefit analysis. Furthermore, CAPEX and OPEX information will also have to be included in the analysis.

For illustration purposes, typical data characterising a set of different boilers have been included in Table F2 and Table F3.

Table F2. Technical and economic data for selected fuel-based boilers [77-80].

	Boiler #1	Boiler #2	Boiler #3	Boiler #4	Boiler #5	Boiler #6
Technical data						
Nominal capacity (kW)	115	22	15	400	5	20
Nominal efficiency (%)	91	95	90	95	99	80
Fuel	Gas, oil, electricity	Gas, oil, electricity	Mineral oil	Mineral oil	Bio-oil	Bio-oil
Thermal output (kWh/yr)	42.2	7.5				
Technical lifetime (yr)	15-30	15-30	20	20	22	20

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[85] Gas boilers are also widely used in district heating systems and in industrial applications

Economic data						
Investment costs (EUR/unit)	315	630-1890	6600	32000	5000	11000
O&M (EUR/kW)	5	4	3	1.25	4	2

Table F3. Technical and economic data for selected biomass boilers [81].

	Boiler #7	Boiler #8	Boiler #9
Technical data			
Nominal capacity (kW)	6 - 12	107 - 970	100 - 5000
Nominal efficiency (%)	85	81	81
Fuel	Biomass	Biomass	biomass
Thermal output (MWh/yr)	5.4 - 23.3	187 - 3823	175 - 26280
Technical lifetime (yr)	20	20	20
Economic data			
CAPEX (EUR/kW)	833 - 1667	331 - 600	339 - 441
O&M excluding fuel (EUR/kW)	11.5 - 22.2	5.1 - 22.1	16.9 - 22.1

Boilers in the residential and commercial sectors usually have nominal capacities from 10 kW (for small applications) to 1000 kW (for a large sized building) and from 100kW to 5000 kW in the industrial sector [76,82,83].

In the case of biomass boilers, investment costs are frequently estimated to be from 0.3 to 0.7 M€/MW and operational costs to be ca. 5 % of the investment costs for heat generating capacities between 1 to 50 MW. Besides, in case of district heating applications, the typical heat generating capacity is between 0.5 to 20 MW.

Guidelines to conduct the Cost-benefit analysis of boiler potential

In order to conduct the cost benefit analysis, the first step will consist of assessing the technical potential of the technology in the demand area. Among the factors that will have to be considered are the heating and cooling demand and supply profiles, characteristics of the area and primary fuel-mix.

In order to include the technology in the analysis it is crucial to assure that it complies with the definition of ´efficient individual heating and cooling´ included in the European Energy Efficiency Directive (EC D2012/27). It should be pointed out that boilers might also be considered in combination with other technologies. Thereafter, the boiler unit(s) has to be optimally designed and dimensioned.

Finally, in order to conduct the cost-benefit analysis, the environmental impact of the proposed technology has also to be implemented. Therefore, potential emissions (to water, air and land) associated to the technology have to also be taken into account.

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G.   Solar thermal

Introduction

Active solar thermal technology provides heat that can be used for space and water heating and cooling in the residential, services[86] and industrial (in particular for processes with a heat demand up to 250 °C) sectors. Solar thermal systems collect the incoming radiation from the sun by heating a fluid in the collector unit. The heated fluid is then used either directly or indirectly with a heat exchanger transferring the heat to its final destination. The amount of heat energy provided per square metre of collector surface area varies with design and location[87]. Moreover, solar combi-systems[88], which provide both space and water heating, are generally larger units and can meet from 20% to 60% of the space heating and water heating needs of a (single-family) dwelling. It should be mentioned that combi-systems usually require an auxiliary heating system[89] to meet the balance of demand [84].

The deployment of technical potential is mainly limited by land and/or roof space availability and by the proximity of heating and cooling demand. According to the configuration of the solar thermal system, thermosiphon[90] (natural circulation) and pumped[91] (forced circulation) systems can be distinguished. Typically, solar thermal systems consist of a solar collector, a heat exchanger, storage, a backup system and a load. The installation of a storage unit would allow using the heat on demand rather than at the time of production. A broad variety of non-concentrating[92] solar thermal collectors are available. The two main types are flat-plate, which can be glazed or unglazed, and evacuated tubes. Furthermore, collector efficiency depends on the difference between the collector and the ambient temperature.[93]

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[86] Heat demand in the residential and services sectors mainly concern low temperature heat (<100 °C).

[87] It normally ranges from 300 kWh/m2/yr to 900 kWh/ m2/yr. Current solar water-heating systems for single-family dwellings are relatively small, with collector areas of 4 m2 to 6 m2 and a 150 l to 300 l storage tank

[88] Single-family household: systems typically have a collector area of around 12 m2 to 15 m2 associated with a 1 000 litre to 3 000 litre storage tank.

[89] Availability of low-cost compact thermal storage will remove the need for auxiliary systems in many applications

[90] Common in frost-free climates. A pumping system is not required but the heat storage needs to be placed on the roof above the collector, limiting its size because of its weight

[91] The collector and the heat storage can be separated

[92] Concentrating solar collector are used to produce high temperature heat

[93] Unglazed are best for 0°C to 10°C above ambient; evacuated tubes for more than 50°C above ambient and flat-plate for -10°C to 50°C above ambient [85]

Although the selection of collector technology depends on the application and the temperature at which heat is required (see Table G1), it should be noted that most of the installations in Europe comprise flat-plate collectors, evacuated tube collectors, unglazed water collectors and glazed/unglazed air collectors.

Furthermore, the technical development of solar thermal cooling systems, which can deliver cooling in the evening when using thermal storage, has progressed significantly in recent years. Cooling can be done with PV collectors and thermal collectors.

Table G1. Type of solar collector and optimal working temperature range for different applications [85].

	Working temperature (°C)	Application
Concentrating collectors	<0 – 400	Water and space heating and cooling, industrial processes
(Advanced) flat-plate	<0 – 150	Water and space heating and cooling, low temperature industrial processes
Evacuated tube collectors	<0 -150	Water and space heating and cooling, low temperature industrial processes
CPC collectors	<0 -150	Water and space heating and cooling
Plat-plate collectors	<0 – 90	Water and space heating and cooling
Unglazed collectors	<0 - 25	Water and space heating

It should be noted that solar cooling can help reduce electrical network peaks associated with conventional cooling. In addition, only high quality collectors are suitable for solar cooling [86]. There are two main processes involved in solar cooling i.e. closed cycles, in which thermally driven sorption chillers are used, and open cycles.

On the other hand, large-scale thermal solar installations have a large surface of solar collectors connected to dwellings, district heating schemes and industrial sites. Most of the plants in Europe have more than 500 m^2 of solar collector surface –one third have a nominal thermal power capacity of at least 1 MW$_{th}$– and operate between 30°C and 100°C [87]. There are different plant configurations, from the roof plants (roof-integrated and roof-mounted systems) and ground mounted collectors. Furthermore, the connection of solar plants to district heating systems can have

two different configurations: [i] connection to a main heating plant that has a seasonal heat store or [ii] direct connection to the district heating primary circuit on site.

Although the economics of large systems for thermal cooling are generally more favourable due to economies of scale, demand and limitations related to equipment availability for smaller capacities, the installation of small (<20kW) solar cooling ready-to-be-installed units for residential application has recently increased considerably.

Technology data

Data needed for the economic-benefit analysis include capital, operational and maintenance costs and environmental performance. Investment costs depend on the system design, complexity of the chosen technology, heat demand and climate and market conditions in the country of operation. Thermosiphon systems using natural circulation avoid the need for pumping and the associated equipment, installation and operating costs. Nonetheless, they are mainly limited to frost free climates. In other regions, higher-cost forced circulation systems will be required. Table G2 and Table G3 include factors to be taken into account and an estimation of solar systems costs, based on alternative technology, in different European areas.

Factors that will have to be included in the estimation of total investment costs for a solar thermal system are:

- Solar radiation on the site
- Cost of basic equipment, including the solar collectors, and their technical and operational characteristics
- Costs of additional equipment such as collector mounting components, storage vessel and plumbing
- In the case of cooling applications, cost and efficiency of the HVAC unit
- Labour costs

Table G2. Costs of solar heating and cooling [85].

	Costs (EUR/MWth)
Solar cooling	120 – 288
Large scale systems in Europe	32 – 120
Solar hot water northern Europe (forced circulation)	144 – 240
Solar hot water central Europe (forced	88 – 120

circulation)	
Solar hot water southern Europe (thermosiphon)	40 - 48

In general terms, solar cooling requires more expensive investment, but costs are reduced if a solar thermal collector is designed to be used for both summer cooling and winter heating. Furthermore, it should be mentioned that solar technology is characterised by higher upfront investment costs and lower operation and maintenance (O&M) costs than conventional systems.

TableG3. Typical solar and cooling system costs in the EU [85].

	Thermosiphon (southern EU)	**Forced circulation (central EU)**	**Forced circulation (northern EU)**	**Solar cooling**	**Large scale**
Investments costs (EUR/kW)	504	680 – 1 520	1 280- 1 920	1 280 – 2 560	280 – 832
Collector yield (kWh/m2a)	685	395	360	395 – 685	685
Lifetime (years)	15	20	20	20	20
O&M (% IC)	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5

It should be mentioned that technology for solar heating and cooling with a cooling capacity below 20 kW are often pre-engineered at a great extent, the entire system layout and the dimension of all components are usually pre-defined by the manufacturer.

Table G4. Typical Solar thermal system characteristics and costs for OECD Europe [85]

	Single-family dwelling	**Multi-family dwelling**
Typical size: water heating (kWth)	2.8 – 4.2	35

Typical size: combi system(kWth)	8.4 – 10.5	70 – 130
Useful energy: water heating (GJ/system/year)	4.8 – 8	60 – 77
Useful energy: space and water heating (GJ/system/year)	16.1 – 18.5	134 – 230
Installed costs: new building (EUR/kWth)	912 – 1 072	760 – 840
Installed costs: retrofit(EUR/kWth)	1 530 1 730	912 – 1 072

Furthermore, Table G4 includes average technical and costs data related to the installation of solar thermal systems in the residential and services sector, which are the main end-user of the technology up to date. It should be pointed out that solar thermal systems are highly modular, i.e. permutations of solar collector area and thermal energy storage, and systems can meet a wide range of demand profiles.

The SOLAIR project, financed under Intelligent Energy Europe, has developed best practise guidelines and an evaluation tool for assessing the cost performance of different solar cooling technologies and system designs. Furthermore, the European so-called Solar District heating project (SHD) has developed equivalent documentation for the case of large-scale installations [87,88]. The tool f-EASY [SOLAIR tool] allows conducting an initial feasibility study of solar thermal plants connected to district heating under diverse conditions.

Guidelines to conduct the Cost-benefit analysis of solar thermal potential

In order to conduct a cost benefit analysis, the first step consist s of assessing the availability of solar resources in the demand area. Apart from national solar maps generated by some MS, additional tools providing data at EU level are:

- Meteonorm application
- Photovoltaic Geographical Information System (PV GIS)

Based on the characteristics of the available resources, a second step comprises selecting and dimensioning the optimal technology for providing heating and cooling services. Finally, and although solar thermal systems are either carbon-free or have low GHG emissions, the environmental impact of the proposed technology has also to be evaluated and integrated in the costs-benefit analysis.

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H.   Geothermal

Introduction

Geothermal energy is derived from the energy stored in form of heat beneath the earth surface (in rocks and underground water or vapour reservoirs). Geothermal resources have different characteristics that influence its potential uses (more details can be found in [89-92]).

High temperature geothermal heat for electricity production and cogeneration

Resources with temperatures above 100 ◦C (and depth 1000-4000 metres) would be used for electricity production. The remaining hot water, after electricity generation, can also be used for heating services (through district heating), greenhouse and aquaculture applications. There are different types of geothermal plants for power production: direct dry steam; Flash cycle; binary cycle and Enhanced geothermal systems [93]. Within these options, the technologies used in combined heat and power systems are organic Rankine cycles and Flash cycle. The typical size of combined heat and power plants ranges from a few MWe up to 45 MWe [90].

Medium temperature geothermal heat for district heating

Reservoirs with medium temperatures, between 30-100 ◦C (and depth between 1000-3000 meters) can be used for district heating and cooling and in industrial process or industries (greenhouse and aquaculture). In order to be feasible, the source and demand should not be far from each other and the demand should be big enough[94]. The system consists of three main components[95]: the geothermal loop (composed of a production well and an injection well), the heat exchanger and the heating grid. Back up heating systems (heat pumps or boilers) could also be required. The use of geothermal resources for cooling services would require the use of adsorption chillers but other devices can also be used (fan coils and ceiling coolers) [94]. Relevant parameters that influence final costs are the reservoir depth and the permeability of the ground. Sometimes it is better to use heat pumps in order to reduce the depth of the wells [92]. Heat pumps can be adsorption heat pumps (driven by heat) as well as electric heat pumps (driven by electricity, which consumption is around 5-10% of the heat extracted from geothermal water). Typical capacities of these installations are 10-15 MW, without heat storage [92].

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[94] In Denmark, demands higher than 300-500 TJ are required (DEA, 2012).

[95] Investment cost structure of typical geothermal plants in Denmark is (DEA, 2012): exploration, 2%; wells, 46%; geothermal surface loop, 15%, heat pump plant, 29%; interest during construction, 7%.

Low temperature geothermal heat for direct use

Reservoirs with very low temperature (lower than 30 ∘C) or shallow depths (no longer than 250 meters), can be used for heating and cooling on the residential and service sector (individual house or buildings). The system consists of three main components [90]: the ground side to get heat out and into the ground; the heat pump to convert it into a suitable temperature and the equipment inside the buildings to transfer the heat or cold into the space. The system can be opened or closed depending on the characteristics of the underground, area, buildings, etc. Although closed systems can be designed in vertical or horizontal, depending on the available area, vertical configurations are more common. For the residential sector, typical capacities are 5-20 kW and for the commercial sector, 50 kW.

Technology data

There are different sources of information that provide general economic data on geothermal sources [95-98], but not all of them provide detailed and complete techno-economic data.

High temperature geothermal heat for electricity production and cogeneration

The additional cost of cogeneration plants compared to only power plants is around 10%. [98] provides techno-economic data for a Flash power plant (Table H1) and Organic Rankine cycle plants (Table H2). An additional 10% of investment cost would take place in the case of also using heat as an output.

Table H1. Techno-economic data for geothermal CHP plants [98].

	2010	2020	2030	2040	2050
Technical data					
Net electrical power (MW)	45	45	45	45	47
Gross electrical power (MW)	47	47	47	47	47
Thermal power (MW)	196	191	188	184	189
Net efficiency (%)	23	23.5	23.9	24.4	24.9
Max. capacity factor (%)	95	95	95	95	95
Avg. capacity factor (%)	95	95	95	95	95
Technical lifetime (years)	30	30	30	30	30

Costs					
CAPEX ref (EUR2013/kWe)	5530	4970	4470	4020	3610
CAPEX low (EUR2013/kWe)	2500	2500	2500	2500	2500
CAPEX high (EUR2013/kWe)	5930	5370	4870	4420	4010
CAPEX floor (EUR2013/kWe)	2000	2000	2000	2000	2000
Quality of CAPEX estimate	Medium	Medium	Medium	Medium	Medium
CAPEX learning rate (%)	-	-	-	-	-
FOM (% CAPEX ref.)	1.4	1.6	1.8	2.0	2.2
Environmental					
Direct CO_2 emissions (tCO2eq/GWh)	122	122	122	122	122
Indirect CO_2 emissions (tCO2eq/GWh)	92	92	92	92	92

Table H2.Techno-economic data for organic Rankine Cycle plants [98].

	2010	**2020**	**2030**	**2040**	**2050**
Technical data					
Net electrical power (MW)	7.3	7.5	7.7	8.0	8.2
Gross electrical power (MW)	9.0	-	-	-	-
Thermal power (MW)	54	54	54	54	54
Net efficiency (%)	13.3	13.8	14.2	14.7	15.1
Max. capacity factor (%)	95	95	95	95	95

Avg. capacity factor (%)	95	95	95	95	95
Technical lifetime (years)	30	30	30	30	30
Costs					
CAPEX ref (EUR2013/kWe)	6970	6600	6240	5870	5510
CAPEX low (EUR2013/kWe)	6470	6100	5740	5370	5010
CAPEX high (EUR2013/kWe)	7470	7100	6740	6370	6010
CAPEX floor (EUR2013/kWe)	-	-	-	-	-
Quality of CAPEX estimate	Low	Low	Low	Low	Low
CAPEX learning rate (%)	-	-	-	-	-
FOM (% CAPEX ref.)	2.1	2.2	2.3	2.5	2.7
Environmental					
Direct CO_2 emissions (tCO2eq/GWh)	4	4	4	4	4
Indirect CO_2 emissions (tCO2eq/GWh)	92	92	92	92	92
Water consumed (l/kWh)	1	1	1	1	1
Water withdrawn (l/kWh)	-	-	-	-	-
Evolution					
Max. potential (GWe)	-	-	-	-	-

Medium temperature geothermal heat for district heating

One of the sources providing a comprehensive view on techno-economic data is the Danish Energy Agency [92][96]. Table H3 collects techno-economic data for a district heating, considering two types of heat pumps: adsorption heat pumps and electric heat pumps.

Table H3. Techno-economic data for district heating from geothermal energy (based on DEA 2012) [92].

Technical data						
Type of heat pumps	Adsorption heat			Electric heat pumps		
Temperature of geothermal heat (C)	Approx. 70			Approx. 70		
Heat from geothermal source (%)	100			100		
Electricity demand, heat pump (%)	76			17		
Heat generation capacity (%)	176			117		
District heat forward temperature, winter (C)	80			85		
Electricity consumption for pumps etc. (%)	8			8		
Technical lifetime (years)	25			25		
Construction time (years)	4-5			4-5		
Economic data	2015	2020	2030	2015	2020	2030
Investment cost (MEUR per MJ/s geothermal heat)	1.8	1.8	1.8	1.6	1.6	1.6
O&M excl. electricity consumption (EUR/year per MJ/s geothermal heat)	47000	47000	47000	37000	34000	34000

Low temperature geothermal heat for direct use

One of the sources that provide detailed economic data is the Spanish Energy Agency [99]. Figure H1 shows the range of investment costs for individual heating systems depending

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[96] These data are based on Dansk Fjernvarmes Geotermiselskab (2011).

on the capacity of the plants and the drilling cost (the range depends mainly on the depth of the reservoir) and Figure H2 shows similar information for individual heating and cooling systems.

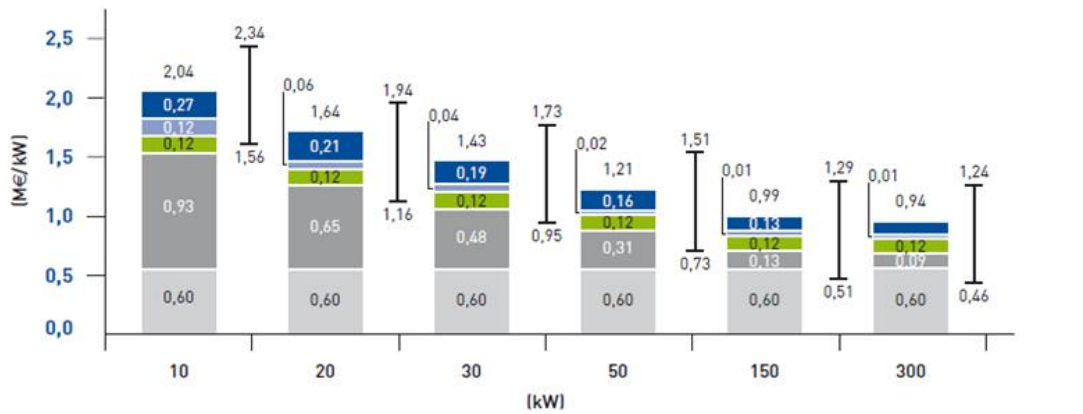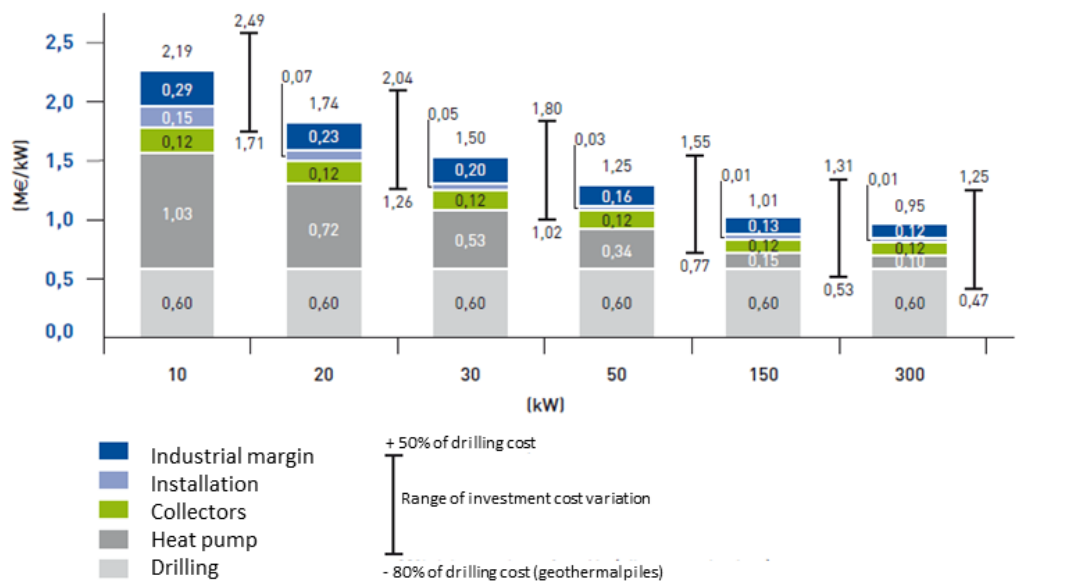Figure H1. Investment costs of installations with heat pumps for heating. [99]

Figure H2. Investment costs of installations with heat pumps for heating and cooling. [99]

Note: The industrial margin includes the cost of implementing the project (1,5% of investment cost)

Guidelines to conduct the Cost-benefit analysis of geothermal potential

In order to conduct a cost benefit analysis, the first step consists of assessing the geothermal potential available in the demand area. Some countries have datasets on geothermal resources and also, some other initiatives provide data at the EU level (see Table H4).

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Table H4. Existing datasets of geothermal potential, [100]

Coverage	Dataset
EU	Atlas of Geothermal Resources in Europe
Europe	GEODH project
Austria, Slovakia, Hungary, Slovenia	Transenergy
Bulgaria, Czech Republic, Romania, Slovakia and Ukraine	Database for Geothermal Resources of Eastern Europe
Germany	Geothermal information System of Germany
Herzegovina, Croatia, Madedonia, Slovenia, Serbia, Montenegro	Database for Geothermal Resources of the Balkans
Ireland	SEA Geothermal Mapping System
Italy	Italian National Geothermal Database
Netherlands	ThermoGIS (map of aquifers)
Poland	Geothermal Atlases for Poland
Spain	Geothermal Resources of Spain

Based on the characteristics of the available resources, the second step consists of choosing the technology or technologies that can be used for providing heating and cooling services. Afterwards, sizing the capacity to be installed would be required. Generally, the capacity is sized to cover the 80% of total heat demand. This approach considers that demand peak loads will be covered by back up technologies [101].

When deciding the configuration of the geothermal systems, combining them with different systems for heat storage could be an option to take into account. Different storage system can be considered: boreholes or aquifer thermal energy storage.

When assessing the environmental impact of the geothermal systems, the emissions associated to the electricity consumption of the pumps should be taken into account.

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100 IRENA (International Renewable Energy Agency) (2014) Geothermal strategy for the Global Renewable Energy Atlas.

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I.   Literature review on baseline scenario composition

In the report on European energy and transport development trends to 2030 (13) which was done using PRIMES model, baseline takes into account a high energy import price environment, the unsatisfactory economic growth of recent years and the more subdued growth prospects taking into account demographic developments and includes policies and measures implemented in member States. Baseline informs about development of policy relevant indicators, such as increase use of renewables, but it does not assume that specific targets, as set out in directives, will be necessarily met. For instance, authors of this report assumed that under baseline conditions the biofuels share in 2010 rises till 4 %, but this number is short of indicative target of 5.75. Authors also state that the baseline scenario provides projections of energy demand, supply and transformation on the basis of current knowledge, technology forecasting and policies.

In the national study for the UK (13) the cost-effectiveness of CHP was assessed for various industrial and building sectors. The baseline assumption was that the heat and electricity demands would be met by conventional gas boilers and grid electricity imports. Projected future energy demands were based on assumptions of expansion or contraction in industrial and service sectors.

Swedish Energy Agency (14) analysed the national potential for expansion in Sweden of efficient heating and cooling. The national baseline took into account that increased competition from heat pumps will lead to the total deliveries of district heating in Sweden decreasing towards 2025. However, it also assessed the potential for additional CHP and DHC, for both existing and new buildings. When assessing the CHP potential the baseline assumption was that the production of heat (hot water boilers) and electricity (in condensing power plants) used the same fuel source. However, it was noted that does not represent a realistic view of the energy system in practice (e.g. for a biofuel CHP, it is not necessarily realistic that it would replace electricity from a biofuel generation plant). With respect to District Heating, for existing buildings the baseline is taken as the weighted average of current heating provisions (including electric heat options biofuels, oil and gas), excluding buildings with heat pumps. For new buildings, district heating is assumed to compete with heat pumps, and a small amount of wood pellet heating. For industry, the baseline is assumed to be electricity. Finally, for district cooling, the baseline is assumed to be the use of individual compressor-driven cooling machines.

The paper by Danish Energy agency (15) on the Danish national approach, describes the baseline or "business as usual" as the current situation and its future development in the case that the new project is not completed. However, specific details of the baseline assumptions are not described.

In the study by Eikmeier et al (16) the baseline assumes that electricity would be purchased from the network, and the heat will be produced directly on-site. The baseline scenario also includes, for

buildings, assumptions relating to the impact on heat demand of building renovations, and expected developments in heating network expansion. For industrial sources, the study made assumptions with respect to future industrial low temperature heat demand in the region, and compared these assumptions with national projections.

In the Gulli (17) study, which provides an analysis at the installation level, there is no defined baseline either. However, option A (centralized electricity generation, condensing boilers for heat, compression chiller for cooling) and option B (centralized generation, heat pumps for heating and cooling) may be viewed as baselines in the sense of being the most likely alternatives to the decentralized generation options C (CHP following heat demand) and D (CHP following electricity demand).

J.   Basis of the Input-Output Methodology

The basis of input-output methodology was set by the Russian economist W. Leontief (1936) and it is based on the use of Input-Output Tables. The Input Output Tables provide a detailed analysis, sector by sector, of the process of production and the use of goods and services (products) and the income generated in that production over a period of time, offering the most detailed portrait of the economy (EUROSTAT, 2008). National Statistical Offices collect and provide periodically the Input-output Tables[97].

Figure K1. Input-Output Table Structure shows that Input-Output Tables structure comprises three matrices: [i] the matrix of intermediate consumption; [ii] the value added and [iii] matrix of final demand.

	Sectors	Final consumption		Gross capital formation	Exports	Final production (Demand)
		Households	Public sector			
Sectors	I. Matrix of intermediate consumption	III. Matrix of Final uses				
Wages & Salaries Operating surplus Taxes	II. Matrix of Value added					
Imports						
Final production (Supply)						

Figure K1. Input-Output Table Structure

The intermediate consumption matrix has a symmetrical structure, appearing in rows and columns all sectors of the economy with homogeneous activity. The information in columns informs about the intermediate consumption, which is the input used by one sector from the output of other sectors of the economy. The information in rows informs about the goods and services produced by one sector that are consumed by other productive sectors. The Added Value Matrix informs about the value added incorporated by the productive factors to the final production of the sector. These

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[97] If there is any exceptional case in which a MS does not have Input-Output Tables, the World Input-Output Database (WIOD) provides time-series of input-output tables for forty countries, covering the period from 1995 to 2011 (http://www.wiod.org/new_site/database/niots.htm).

primary inputs include salaries to labour, operating surpluses and taxes on primary factors. At the bottom of this matrix, there is information about imports by sector from abroad. Thus, the whole information in column provides a complete overview about the cost structure of the sectors and the information in rows, an overview about the revenues. The final demand matrix displays the final production (goods and services) that is consumed by final users, including households, government and exports. As the table is symmetrical, for each industry total supply equals total demand.

The structure of each sector's production activity can be represented by using a Matrix of Technical Coefficients (MTC) The MTC is composed of a series of ratios that reflect the percentage of input used per unit of final product, for each of the sectors of the economy. This MTC has to be built from the information contained in the matrix of intermediate consumption, as described below:

$$a_{i,j} = \frac{x_{i,j}}{x_j}$$

Where:

x_{ij}, is the output from sector i that is consumed by sector j

X_j, is the total output of sector j

a_{ij}, is the technical coefficient of production i consumed by j

Thus, it is possible to obtain a system of linear equations from the technical coefficients for describing the relation between the inputs used by each sector and final demand. Having this whole view on the structure of the economy it is possible to analyse the impact (direct and indirect) generated on the overall economic activity resulting from the implementation of a new project, in this case, construction, operation and maintenance of a plant or equipment for heating and cooling supply.

Intersectoral relations contained in the Input-Output Table can be described in matrix form by the following expression:

$$q = Aq + d$$

Where,

q is the vector of final production by sector,

d is the final demand vector and

A is the matrix of technical coefficients.

When there is an increase in the demand (Δd), the change in the total production in the economy (Δq) can be assessed by the following expression.

$$\Delta q = (I - A)^{-1}\Delta d$$

Where

    Δq is the increase in final production by sector,

    I is the identity matrix

    $(I-A)^{-1}$ is the Inverse Matrix of Leontief

    Δd is the increase in demand

The increase in demand associated to heating and cooling technologies (Δd) can be assessed following the next steps:

1. Collecting data on investment, O&M and fuel costs for each technology. The information has to be desegregated by the main cost components.
2. Determine, at cost component level, the import rates, which means the percentage of those expenses that correspond to goods and services that will be imported.
3. Determine which sectors of the economy (considering the classification of sectors provided by the Input-Output tables) provide each of the main cost components obtained at domestic level. The information is compiled in one vector that represents the increase of domestic demand (Δd). This has to be done for the investment as well as operation and fuel costs by separate.

An increase in total production on the economy derives in an increase in the value added, considering both the direct and indirect effect. The rate of value added per unit of production of each sector can be assessed trough this expression:

$$\gamma_j = \frac{AV_j}{x_j}$$

Where,

    γ_j is the rate of value added per unit of production of sector j,

    AV_j is the value added of sector j,

    X_j is the production of sector j.

Based on that rate, the impact on the GDP derived from a change in the total production in the economy (Δq) can be assessed by the following expression:

$$\Delta GDP = \sum_{j=1}^{n} \gamma_j \cdot \Delta q_j$$

Where,

ΔGDP is the change in GDP derived from increases in demand

Δq_j is the increase in final production by sector j,

γ_j is the rate of value added per unit of production of sector j,

The assessment of the induced impact requires the use of Social Accounting Matrices (SAM). The SAM is an extension of the Input-Output Table that allows describing the interrelationships of income and transfer flows between the different institutional units. The construction of the SAM is described by EUROSTAT (2008) and it implies a further break down of the household sector and a disaggregation of the persons employed. Thus, two parts of the use table of the input-output framework have to be more disaggregated: the components of net value added, shown in the third quadrant of the table, and the final uses which are presented in the second quadrant. MS that already have SAM, can also estimate the induced effect. Otherwise, building a SAM to assess this impact could be too demanding.

The secondary order effects (those derived from savings on the energy bill) can take place when a large scale expansion in efficiency causes changes at a wide economy level, including changes in demand, supply and thus, energy prices. As a first approximation, it can be used a similar approach for assessing them to the one used by Baer et al. (2013). In that study, the savings on the energy bill were estimated by taking into account the amortization schedule of the new investment[98]. As a simplifying assumption, it is considered that the energy bill savings are transferred to consumers and that they re-spent in direct proportion to the existing distribution of households expenditures. Using the Input-Output approach, it can be estimated the impact on GDP derived from an increase in household demand equivalent to the savings on the energy bill.

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[98] For the amortization schedule it was assumed a 20 years payback of new construction and equipment investments at a 3% interest rate.

K. Practical steps to incorporate the macroeconomic impact in the context of the EED

The practical steps to implement the Input-Output Methodology in the context of the EED are described below:

Step 1: Assessing first order effects

The analyst has to choose at least a reference plant for each technology and collect techno-economic data referred to it. The analyst have to apply the Input-Output approach (see Annex K) to assess the impact on the GDP derived from:

1. The <u>installation of the plant</u>. This impact can be expressed in terms of impact per MW of new capacity installed (EUR/MW) of that technology:

$$\Delta GDP_{Inst,y} = \frac{\Delta GDP_{Inv,y}}{PC_y}$$

Where,

$\Delta GDP_{Inst,y}$ is the impact on the GDP per MW installed derived from the investment costs on technology y (EUR/MW)

$GDP_{Inv,y}$ is the impact on the GDP derived from the investment cost on technology y (EUR)

PC_y is the capacity of the reference plant of technology y (MW)

2. The <u>operation of the plant.</u> This impact can be expressed in terms of impact per unit of energy produced with that technology (EUR/MWh).

$$\Delta GDP_{Oper,y} = \frac{\Delta GDP_{O\&M,y}}{E_y}$$

Where,

$\Delta GDP_{Oper,y}$ is the impact on the GDP per MWh produced derived from the operation and maintenance (O&M) costs of the technology y (EUR/MWh)

$GDP_{O\&M,y}$ is the impact on the GDP derived from the annual O&M cost on technology y (EUR)

E_y is the annual production of the reference plant of technology y (MWh)

Step 2: Assessing second order effects

The impact on the economy derived from the savings in the energy bill could be estimated as the impact of an increase in final demand equivalent to the amount of fuel savings, as explained in Annex K. This impact has to be expressed in terms of impact on GDP per unit of saving (valued in monetary terms):

$$\Delta GDP_{Sav} = \frac{\Delta GDP_{Final\ demand}}{Savings\ _{\nabla E}}$$

Where

ΔGDP $_{Savings}$ is the rate of impact on the GDP due to savings in the energy bill

ΔGDP $_{Final\ demand}$ is the impact on the GDP derived from the savings on the energy bill [EUR]

Savings $_{\nabla E}$ is the savings on the energy bill [EUR]

Step 3: Converting the impact on GDP into an impact on NDP

Once the impact on GDP of each technology is known, next step consist of discount the consumption of fixed capital[99] in order to obtain the information about the impact on the NDP.

Step 4: Assessing the macroeconomic impact of each scenario

The macroeconomic impact of each scenario will be estimated by using the information from the scenario definition. The macroeconomic impact will be sum of the three components described below:

Step 4.1: The impact of the installation of new capacity

The impact of the installation has to be assessed by taking into account the information, from the scenario definition, regarding the additional new capacity of each technology installed each year:

$$\left[SOC_{Inst,y,t}\right]_{Scen.} = \Delta NDP_{Inst,y} \cdot \left[\Delta IC_{y,t}\right]_{Scen.}$$

Where,

[SOC$_{Instal,\ y,t}$]$_{Scen.}$ is the macroeconomic impact derived from the installation of new capacity of technology y, in the year t, within a specific scenario [EUR]

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[99] The information regarding the Consumption of Fixed Capital (CFC) can be found in the National Accounts. Estimating the percentage of the CFC with respect to the GDP ($\delta = \frac{CFC}{GDP} * 100$) allows transforming the impact on GDP (ΔGDP) derived from the heating and cooling options into an impact on NDP derived from the heating and cooling options by discounting it: $\Delta NDP = \Delta GDP * (1 - \delta)$.

ΔNDP$_{\text{Inst,y}}$ is the impact on the NDP per MW installed derived from the investment costs on technology y [EUR/MW]

[ΔIC$_{\text{y, t}}$]$_{\text{Scen.}}$ is the increase on installed capacity of technology y, in the year t, within a specific scenario [MW].

When the construction time of the plant is longer than one year, this parameter has to be taken into consideration in order to distribute the macroeconomic impact over the construction time.

Step 4.2: The impact of the operation of existing capacity

The impact of the operation of existing capacity has to be assessed by taking into account the information, from the scenario definition, regarding the amount of energy produced each year by each technology:

$$\left[SOC_{O\&M,y,t}\right]_{Scen.} = \Delta NDP_{O\&M,y} \cdot \left[E_{y,t}\right]_{Scen.}$$

Where,

[SOC$_{\text{O\&M,y,t}}$]$_{\text{Scen.}}$ is the macroeconomic impact derived from the production of energy from existing capacity with the technology y, in the year t, within a specific scenario [EUR]

ΔNDP$_{\text{O\&M,y}}$ is the impact on the NDP from O&M expenditures per MWh produced by technology y [EUR/MWh]

[E$_{\text{y, t}}$]$_{\text{Scen.}}$ is the total energy produced with technology y, in the year t, within a specific scenario [MWh]

Step 4.3: The impact of the savings on the energy bill

The impact of the savings on the energy bill has to be assessed by taking into account the savings on the energy bill in each scenario:

$$\left[SOC_{Sav,t}\right]_{Altern.} = \Delta NDP_{Sav} \cdot \left[Savings_{t}\right]_{Altern.}$$

Where,

[SOC$_{\text{Sav,t}}$]$_{\text{Altern.}}$ is the macroeconomic impact derived from the savings in the energy bill, in the year t, within the alternative scenario [EUR]

ΔNDP$_{\text{Sav}}$ is the is the rate of impact on the GDP due to savings in the energy bill

[Savings $_{t}$]$_{\text{Altern.}}$ is the savings in the energy bill, in the year t, within the alternative scenario [EUR]

The macroeconomic impact of heating and cooling options has to be assessed in both scenarios, in order to estimate the change of the impact between the baseline and the alternative scenario. The

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macroeconomic benefit of each scenario in one year will be the sum of these three components, considering all the technologies used in that scenario each year:

$$[SOC_{Total,t}]_{Scen.} = \left[\sum_{y=1}^{n} SOC_{Inst,y,t}\right]_{Scen.} + \left[\sum_{y=1}^{n} SOC_{O\&M,y,t}\right]_{Scen.} + [SOC_{Sav,t}]_{Scen.}$$

The macroeconomic impact of savings takes place only in the alternative scenario so its value in the baseline scenario will be zero.

L.   Summaries of national practices in performing energy planning, energy system analysis, heat maps

Germany

In the framework of its energy transition strategy Germany has set the target to reach 80% share of renewable energies by 2050, with intermediate targets of 35% to 40% share by 2025 and 55 to 60 % by 2035. As regards energy efficiency, gross energy consumption is to be reduced by 50% by 2050 compared to 2008 levels. Heat demand in buildings should be reduced to 20% on 2050 compared to 2008, while overall greenhouse gas emissions should be cut by 80% by 2050, compared to 2005. Germany is currently analysing least cost options to the decarbonisation and energy efficiency of its buildings. The on-going elaboration of the strategy is building on existing policies that support the introduction of renewable energy, cogeneration and district heating in building refurbishment projects. As part of the national energy efficiency and renewable energy strategies, Germany has set a target of 25 % share of cogeneration in electricity production.

Germany prepared a comprehensive assessment to support the decisions taken by the German authorities in regards to heat planning and cogeneration plants. The study is split in 4 sections.

A Cost-benefit analysis is conducted first. Its purpose is to compare and to determine the most cost-effective options. The net present value is estimated on both economic and financial terms. There was a split between household, commercial and industrial sector. The cost-benefit analysis is carried out without reference to quantities — unlike the subsequent potential analysis, and only compares the cost of different technological options. In the residential sector CHP was an uneconomical option due to the very high investment costs. Thermal insulation options despite the high capital costs had a better result but gas boilers were clearly the most economic option. For the commercial sector a CHP plant was only superior in economic terms in the hospital subsector. From a financial point of view, in the same sector, the CHP is as attractive as a gas boiler investment. The subsector with the lower NPV was the office buildings. In any case, the heat demand was a very crucial parameter: the larger it is, the more likely it is that the cost benefit analysis favours the cogeneration option instead of a gas boiler.

The results of the cost-benefit analysis are used in the second part of the study which refers to the cogeneration potential, by estimating the amount of investments that can be realized for the whole Germany. For the household and tertiary sectors, the CHP potential was determined based on the detailed analysis of 41 representative model towns. The forecast of the heat demand takes into account both renovations and new constructions. The potential of cogeneration is based on a full cost comparison with a gas boiler for 8 typical applications. The projection of heat production

potential by centralized district heating and cogeneration is 128 TWh/a in financial terms and 207 TWh/a in economic terms with the assumption that the connection rate of the consumers to a nearby network is 90%. The heat demand that is going to be covered by district heating is not considered in the potential of individual CHP. This potential is estimated to 21 TWh/a in financial terms and 3 TWh/a in economic terms.

The potential analysis for installing cogeneration in industry is estimated by means of an analysis of the heat demand of individual industries considering CHP temperature range up to 300 ° C and its technical developments in their production. The break down of industrial heat demand per temperature was adopted by an external study[100]. A scenario with the following characteristics was considered:

- CHP applications stagnates in the three sectors of industry, (chemicals, quarrying/mining and paper)
- A significantly increase in CHP applications for other manufacturing sectors (Food, capital goods, consumer goods and commodities industries).

The heat generating potential of the first industrial sectors in the baseline scenario will have an 11% (0.6% per year) increase by 2030 (without promoting cogeneration) and decreases in 2050 by about 8%. In contrast, the sectors with increasing CHP generating potential as a whole considers an increase of 5.7% per year by 2030 and after that 3.6% per year by 2050. Overall, through this course in 2050, the heat potential that could be generated by CHP plants, is 20% more than the base case.

For the estimation of waste heat available, no analysis was conducted in this study but assumptions from different sources were adapted[101] (AGEB 2008, FH-ISI, ENOVA Spillvarme 2009). According to those it was assumed that a fixed percentage of waste heat above 140 °C is available compared to their total energy use. Heat of this quality is also considered to be suitable for electricity generation with ORC technologies. Metal manufacturing and processing were assumed to have a big amount of waste heat available (~ 30 – 40%) while other sectors much lower (~3 –8%). According to the above, 87 TWh of waste heat were identified. It is claimed, that there was no

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[100] Prognos, BHKW Consult, Fraunhofer IFAM, IREES (2014): Potenzial- und Kosten-Nutzen-Analyse zu den Einsatzmöglichkeiten von Kraft-Wärme-Kopplung (Umsetzung der EU-Energieeffizienzrichtlinie) sowie Evaluierung des KWKG im Jahr 2014. Zwischenbericht für den BMWi. Berlin, Raststadt, Bremen, Karlsruhe IREES 2014; verändert nach Wagner 2002 & FfE 2002

[101] AGEB (2012): Energiebilanz der Bundesrepublik Deutschland 2012, Arbeitsgemeinschaft Energiebilanzen. http://www.ag-energiebilanzen.de/DE/daten-und-fakten/bilanzen-1990-2012/bilanzen-1990-2012.html

available data to assess the economic potential of using this waste heat either for electricity generation (using ORC) or direct utilization of heat was higher.

The 3rd part focuses on the potential for CHP electricity generation, according to the results of potential from the CHP on heat demand. Currently 15% of the heat market is covered by CHP plants. For this study emphasis is given in flexibility: the technical concepts that allow it, or have already been implemented and in which applications the flexibility of CHP is already being used today. The extent to which cogeneration potential can be integrated in the future electricity system along with the role that CHP may take in future power system is also analysed, taking into consideration the security of supply. The long-term positive effects on the CO_2 emissions from the CHP operation are also evaluated.

The CHP especially in areas with high energy density is a favorable option to provide the heat supply and resource-efficient low-CO2 electricity. In the long term, however, the renewable energy share should be increased in the district heat supply in order to exploit the heat-side potential. Power-to-heat concepts can also favour the integration of intermittent high RES shares in the electricity market.

In the final section a mid-term evaluation is conducted for the development of cogeneration and the effects of the Combined Heat and Power Act (KWKG). Based on that, short-term prospects which are crucial for the further development of cogeneration until 2020 are presented.

The proportion of electricity produced in CHP plants in the total electricity production in Germany is also presented along with the development of CHP, networks and storage investment funded. An important aspect of the evaluation is also the development of the CHP plant operation economy. This is differentiated by asset class and type of use and taking into account the revenue from electricity and heat production and possible subsidies to CHP. Based on this analysis, the development of the share and cost of CHP is estimated by 2020.

Finally, recommendations are given for further development of CHP for specific applications as well as other measures that are not directly related with CHP.

Denmark

Denmark has prepared a Comprehensive assessment on the potential to expand high-efficiency cogeneration and efficient district heating and cooling. The assessment is based on three separate technical studies on district heating, district cooling and scenario analyses.

The scenario analyses were made to illustrate the future Danish energy system within the framework of the Energy Agreement from 2012. These scenarios are designed to meet the energy policy objectives of Denmark to have a fossil free energy system in 2035. The expected role of

district heating and combined heat and power is evaluated. The technical possibilities and bottle necks were identified.

The Balmorel model was used together with a heat atlas for analysing the district heating supply. The Balmorel model uses a combined top-down/bottom-up process of the energy system. The model optimises the operation of electricity and district heating systems. It includes both investment and operation costs and socio-economic aspects. The analysis also contains the electric inter-connections with neighbouring countries.

The models calculated the district heating and electricity prices and these were then used to calculate the heat supply rates in all urban areas for district heating and individual heating. The technical potential was assigned to those areas that did not contain district heating today and with sufficient heat demand. The economic district heating potentials were established by comparing the cost of district heating to the costs of individual heating in various optimization processes.

Due to lesser experience with evaluating cooling demand and due to that available data were limited, indirect methods for establishing the cooling demand were developed. The method was primarily based on available data on electricity consumption for cooling from a study of 2008, which were supplemented with information from specific projects. This allowed making an inventory of 82 different industries that were split into comfort-, process- and IT-cooling.

The evaluation of the economic potential for technologies of the Comprehensive assessment started from the technical potential. The unprofitable potential from a society point of view was subtracted from the technical potential. All projects with a capacity lower than 1 MW were disregarded since they were seen as too small for a district cooling project. For cooling the economic gain was compared to individual cooling, which allowed calculating a maximum length of transmission district cooling pipes for a certain project. If the calculated length were longer than the distance between the heat consumers and producers, it was classified as a potential district cooling project.

Mapping of heating and cooling

- The heat atlas contains information about heat demands and the number of heat installations per types and village areas. The atlas contains seven types of heat installations and 4000 villages.
- Heat demand maps have a resolution of 1 km^2. The heat supply points were based on data from the energy production count of the Danish Energy Agency in 2013. Each point was attached to a specific address.
- The district heating network was based on data from the Danish Energy Agency GIS database 2014. It includes both transmission and distribution networks.

- A nation-wide map of local cooling demand that is suitable for district cooling were made based on knowledge of each industry's expected consumption of electricity for cooling.

Sweden

Sweden prepared the Comprehensive assessment (CA) on the potential use of high-efficiency cogeneration and district heating and cooling. The analysis is partially based on earlier technical and economic studies on district heating and combined heat and power[102,103,104,105,106].

In the Comprehensive assessment, the potential for new CHP, district heating and cooling were estimated using a Cost-Benefit Analysis (CBA). Net Present value calculations were performed that included socio-economic and environmental costs. The tool used for the CBA was MARKAL-NORDIC. It is a cost optimisation model that finds the most cost efficient composition of technologies to reach energy policy targets. Such studies use input data with regard to projected investment cots, assumptions on energy prices, and the expected evolution of the heat demand. MARKAL-NORDIC comprises the energy system of Sweden, Norway, Finland and Denmark. The heating and cooling demand are divided into more than 80 sectors. The geographical locations of demand and supply were not included in the analysis.

The potential for district heating was based on a report by Fjärrsyn from 2011. The data were collected from national studies and statistics. In addition, these estimations have been enriched by performing interviews and collecting information from district heating companies and by making estimations of energy efficiency effects (e.g. improved insulation of buildings) and increased use of heat pumps. The report concluded that although the number of new connections to the district heating network will increase the total heat supplied by district heating will be reduced.

The potential for district cooling[107,108] was based on assumptions for three categories of cooling equipment, i.e. compressor cooling machines using electricity, absorption cooling machines using district heating, and free cooling using nearly no primary energy. The expected future shares

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[102] Öhrlings PricewaterhouseCoopers, 2005, Fjärrvärme och kraftvärme i framtiden (SOU 2005:33)

[103] Svensk Fjärrvärme, 2009, Fjärrvärmen 2015, branchprognos

[104] Svensk Fjärrvärme, Svensk Energi, Skogsindustrierna, Svbio, 2011, Sveriges utbyggnad av kraftvärme till 2020

[105] Profu, 2011, Fjärrvärmen i framtiden

[106] Fjärrsyn, 2009, Fjärrvärmen i Framtiden – behovet, 2009:21

[107] Svensk Fjärrvärme, 2009, Fjärrvärmen 2015, branchprognos

[108] Fjärrsyn, 2013, "Potentialen för kraftvärme, fjärrvärme och fjärrkyla rapport 2013:15", http://www.svenskfjarrvarme.se/Global/FJ%C3%84RRSYN/Rapporter%20och%20resultatblad/Rapporter%20omv%C3%A4rld/2013/2013_15%20Potentialen%20f%C3%B6r%20kraftv%C3%A4rme/Potentialen%20f%C3%B6r%20kraftv%C3%A4rme.pdf

between these categories were grounded on assumptions related to the present composition of technologies in large district cooling systems in Sweden.

The potential for high-efficiency cogeneration for district heating was estimated based on information from calculations using MARKAL and Martes [109]. The Martes analysis is founded on calculations for 15 real district heating systems. These results were then extrapolated to the national dimension. The potential for industrial cogeneration was evaluated using MARKAL calculations and questionnaires.

The assessment for industrial co-generation was based on five different studies[110,111]. One study was based on a questionnaire in which the forest industry was asked to describe their production capacities, fuel mixes, and investments plans until 2020. [112] The focus was on the forest industry due to that it supplies 93% of the industrial cogeneration in Sweden today. Three studies were based on MARKAL calculations that were used to project the economic potential for industrial co-generation.[113,114] The conclusion from the five studies was that the potential of industrial co-generation was estimated to be 8.6 TWh in 2020 and 8.8 TWh in 2030.

Five national maps[115] were created to meet the requirements of the EED.

- Maps displaying plot ratio based on data from the real property register of Lantmäteriet were created. The geographical resolution of these maps was 1 km^2. The heat demand density is displayed in four classes, i.e.<0.03 (<15 TJ/km^2), 0.03-0.1 (15-50 TJ/km^2), 0.1-0.3 (50-150 TJ/km^2), and >0.3 (>150 TJ/km^2).
- Industry data were collected from the European Pollutant Release and Transfer Register (E-PRTR v4.2). The industries were displayed in 9 separate sectors.
- Power and heat centrals were displayed in a map based on data from the property register of Lantmäteriet. They were divided into condensing power plants, combined heat and power plants, and heating stations.

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[109] Öhrlings PricewaterhouseCoopers, 2005, Fjärrvärme och kraftvärme i framtiden (SOU 2005:33)

[110] Öhrlings PricewaterhouseCoopers, 2005, Fjärrvärme och kraftvärme i framtiden (SOU 2005:33)

[111] Profu, 2012, Underlag till Energimyndighetens Långsiktsprognos

[112] Svensk Fjärrvärme, Svensk Energi, Skogsindustrierna, Svbio, 2011, Sveriges utbyggnad av kraftvärme till 2020

[113] Profu, 2010, Data/information on national potential for the application of high-efficiency cogeneration following Article 6 and Annex IV of the cogeneration Directive 2004/8/EC, 15-15-15 scenario

[114] Profu, 2010, Analys av biobränsleanvändning inom fjärrvärmesektorn och industriellt mottryck, kopplat till MARKALberäkningar, uppdrag för Energimyndigheten

- A map on all Bio-CHP and Waste incineration CHP plants with data of companies from their register of Swedbio. The register also contains planned constructions.
- Electricity grid data from the Swedish national grid operator for power lines of 400 and 220 kV including switchgears and substations were mapped. The map also includes AC and DC transmission connections to neighbouring countries. Planned constructions are also included.

Lithuania

Heat planning in Lithuania is a common practice at municipal level for over a decade, although no comprehensive national heat planning has been in place up until now. The heat planning process is regulated by dedicated laws and regulations, among which the most important are The Law on Heat Sector (IX-1565 on 20-05-2003) and The Rules for Preparation of Heat Sector Special Plans (4-13/D1-28 on 16-01-2004). The most important objectives of these laws are the increase of energy efficiency, legitimisation of competitiveness in heat sector, assurance of reliable energy supply, protection of consumer rights, increase in utilisation of renewable and local energy sources and decreased environmental pollution.

According to the requirements of the law, all the municipalities should have heat plans prepared for their territories. Already existing plans should be renewed after changes in the municipality's heat sector or national energy policy occur, but at least every 5 years. There are 60 municipalities in Lithuania, among them 7 are so-called city municipalities, containing the largest cities of Lithuania.

Special plans are meant to contain long term modernization and development directions of each municipality's heat sector. Thus they should emphasise the transfer of national energy targets into the lower, municipal level. Special plans should harmonize interests of different stakeholders supplying the consumers with heat and energy sources. The most important stakeholders are heat consumers, municipalities (as representatives of heat consumers or controllers of district heating infrastructure), district heating companies, and suppliers of energy sources (mostly natural gas and biomass).

The process of heat planning is started, organized, supervised and finalised by the municipality. For preparing the plan an external contractor is selected after a public procurement process. The preparation of a heat plan can be financed by municipality, as well as by local and foreign support funds and programmes and by using other financing sources.

The heat plan consists of the following parts:

a) Solutions of the plan, containing explanatory notes and map of municipality or its part, containing a set of rules for heat supply. One of the most important outcomes of heat plan are the rules how consumers should be supplied with heat and what fuel type and energy source can be used for heat generation in different parts of municipality (territorial zones). These rules are presented in the form

of maps. Maps are to be prepared on the basis of georeferenced data base, however, in case proper data is lacking, as a base the newest topographical maps with the scale 1:10000 or 1:5000 can be used. There is no requirement for a map to be interactive and municipalities usually make it available to the public on their web sites only as scanned copies of the maps. Electronic copies of explanatory notes are usually also available through municipality's web sites.

b) Documents on planning procedures. These contain different rulings of municipality on heat plan being prepared as well as documents related with public consultations, report on evaluation of heat plan outcomes from environmental and economic points of view and so on.

The preparation of a heat plan is performed in steps:

- Calculation and analysis of current demand of heat for the heating of the buildings and preparation of sanitary hot water. The emphasis in the heat plan is mostly on consumers in high density urban areas where district heating usually already exists. Heat consumption in rural areas or low density urban areas is usually not evaluated at all. Energy demand for space cooling is usually also not evaluated.
- Evaluation of heat sector of municipality (i.e. existing heat generation equipment, systems of local heating and district heating, etc.) and infrastructure of natural gas and electricity supply.
- Evaluation of current air pollution level.
- Forecast of heat demand evolution as well as forecast of infrastructure development and changes in air pollution levels. Other forecasts, necessary for completion of the heat plan are also made, such as forecast of prices of energy sources (biofuel, natural gas, electricity) and other technical and economic indicators.
- Strategic planning of municipality's territory: division of municipality's territory into zones and setting of heat supply rules for each zone.

Limits of the zones are set by the compilers of heat plan. It is preferred that each zone would contain one type of heat consumers, such as multi-storey buildings, individual living houses, service buildings, etc. Consumers in each zone should have the same possibility to use particular energy supply option, such as district heating, natural gas or electricity, i.e. there should be a branch of district heating network or other energy supply system leading to particular zone, etc.

The main energy supply option for each zone is selected based on a number of criteria. The decision is based on the evaluation of different scenarios, such as supply of heat to all the consumers of the zone through district heating network, supply of heat to all the consumers from individual natural gas or biomass boilers and so on. The preferred method of heat supply chosen is the one which has lowest long term costs.

If district heating network already exists, then it is analysed if its decentralization would mean lower costs of energy to consumers in the long period. If it is the opposite, then district heating is the preferred option. District heating network could be analysed in parts in order to assess how decentralization of that part affects costs of energy supply to that part's consumers as well as what would be the impact on other consumers of district heating system. Another important factor to consider preference of energy supply in particular zone is the effect of decentralization on air pollution level. If decentralization (through replacement of large centralized heat generators with a lot of small local energy generation installations) would significantly increase air pollution, then it cannot be considered as a preferred option.

Heat plans usually also contain additional parts, dealing with development plans of municipality's heat sector. The content of these parts depend on the conditions of particular municipality and different energy related laws and national strategies. These may contain, for instance analysis of possible development and renovation of district heating networks and their energy generation installations, calculations of feasibility of use of different renewable energy sources and different technologies, such as heat pumps, etc.

Poland

Heat planning in Poland is a common practice at local (municipal) level. According to the Article 18.1 of the Law of Energy of Poland, planning and organizing of heat, electricity and gaseous fuel supply is a responsibility of municipality (gmina) in its territory. The process of preparation of a so-called *Draft framework of heat, electricity and gaseous fuel supply* is organized by the major of municipality. For preparing the draft framework an external contractor is selected after a public procurement process.

The draft framework should be aligned with the regional energy policies of province (wojewodztwo) and state energy policies. The main goal of state energy policy is to create conditions for the sustainable and balanced development of energy sector through ensuring the energy security of the country, increased competiveness and energy efficiency and decreased environmental impact. The provincial government evaluates the alignment of these policies prior to the final approval by the council of the municipality.

Information is derived from different sources, among other plans prepared by energy companies, which under the law they are obliged to provide to the mayor.

The draft framework for municipality's territory is prepared for a period of at least 15 years and it should be renewed at least every 3 years.

The draft framework should include the following information:

- Description of current state of heat, electricity and gaseous fuel supply systems as well as foreseen changes. The current situation analysis includes population growth tendencies, description of industrial activities in the municipality, analysis of building stock (year of build, area, typical energy consumption), etc. The current state and foreseen changes in district heating, electricity and natural gas supply systems are also analysed. Additionally information is presented about the state of renewable energy supply and consumption. Evaluation of current environmental pollution level is also performed.

- Description of solutions for rationalisation of heat, electricity and natural gas consumption. After evaluation of likely developments in the energy sector of a municipality, it is described what measures could be taken to overcome foreseen hurdles, such as renovation of buildings, use of waste heat, increase in renewable energy penetration, etc.

- Description of possibilities to utilize local and surplus resources of energy and fuels, including electricity and heat produced in renewable energy and cogeneration installations as well as how to utilize waste heat from industrial installations. Technical and economical potentials of main renewable energy sources, such as biomass, are usually calculated. However, thorough analysis of potentials of many renewable and waste energy sources is often lacking.

- Description of the measures which could be taken in a municipality to implement energy efficiency improvement measures in the buildings, especially public institutions. Potential of energy savings is usually presented. Draft framework might include work programme for implementation of the measures to achieve this potential.

- Since energy supply systems of particular municipality usually are parts of national or regional systems, the draft framework also discusses measures for collaboration with neighbouring municipalities, needed to maintain and rationalize shared energy supply systems.

In the case when energy supply companies do not align their plans to the decisions set in Draft framework, major of municipality prepares a second stage document, so-called *Draft plan of heat, electricity and gaseous fuel supply* for the territory of municipality or its part. Draft plan should adhere to the decisions set in Draft framework, approved by municipality's council.

Draft plan contains the following information:

- proposals for modernising and development of heat, electricity and gaseous fuel supply systems supported by their economic evaluations;

- proposals for utilisation of renewable energy sources and high efficiency cogeneration;

- proposals for implementation of energy efficiency improvement measures in the buildings;

- schedule for implementation of proposals;

- expected costs of implementation of proposals and the sources of their financing.

Implement the decisions of the Draft plan could be discussed during negotiations with energy supply companies. In case the negotiations do not lead to decisions being implemented, municipality's council may decree to which parts of Draft plan energy related activities, carried out on the territory of municipality should adhere.

There are no specific requirements for both Draft framework and Draft plant to contain comprehensive heat maps. Graphical information in heat maps usually only contains information about heat, electricity and gaseous fuel supply infrastructure, such as the extension of district heating network or the location of main electricity transformers.

UK

Energy planning

UK has an extensive experience in energy planning. Planning on energy efficiency is one its dimensions. UK Government published the Energy Efficiency Strategy in November 2012. The Strategy identifies the energy efficiency potential based on the Energy Efficiency Marginal Abatement Cost Curve. Measures are valued taking into consideration the social perspective and valuing environmental benefits. The Strategy identified the barriers for its implementation and the key benefits of energy efficiency.

In April 2014, the UK Government published the UK Energy Efficiency Action Plan that sets out how the implementation of the Energy Efficiency Directive will help to realising this potential. The Action Plan identified nineteen policy measures to contribute towards the target of 18% reduction in final energy consumption by 2020, relative to 207. Some of the most contributing policies include: Energy Efficiency Obligations, the Carbon Emissions Reduction Target (CERT) and Energy Company Obligation (ECO).

More specifically, in the field of heat planning, the UK Government published in 2012 'The Future of Heating: A strategic framework for low carbon heat in the UK'. It describes how the heat system will need to evolve and identifies the key changes required for ensuring there is affordable, secure and low carbon heating up to 2050.

In March 2013, 'The Future of Heating: Meeting the Challenge' identified specific actions to deliver low carbon heating across, focusing on four different aspects:

- Industrial heat: Installing Combined Heat and Power (CHP) schemes in large heat consuming industries is identified as one of the main options to reduce emissions from in industry.
- Networked heat (district heating): Developing heat networks can have a significant contribution. Networks can be supplied by industrial waste heat as well as new sources,

such as geothermal and heat pumps. The Government is supporting local authorities by establishing a Heat Networks Development Unit and providing funding to local authorities to assist with early-stage project development costs.

- Heat in buildings: Apart of introducing energy efficiency measures to reduce space heating and cooling demand (as the Green Deal and smart metering), the Government considers the necessity of finding less carbon intensive ways to heat. The Strategic Framework suggested a combination of an increase in heat networks in urban areas and promoting the renewable heat in rural off-gas grid areas in the short to medium-term, whilst planning ahead for the changes to gas heating in the decades to come. The Government extended the Renewable Heat Premium Payment scheme and will explore the potential role of tighter standards on building emissions and heating systems.

- Grids and infrastructure. Decarbonising the heat sector will, over time, have an impact on energy infrastructure derived from the use of networks for new fuels (biomethane and the potential of hydrogen), the construction of new heat networks and heat storage infrastructures, and the expansion of the electricity grid derived from the a greater electrification of heat. The decisions on the different elements of infrastructure have to be taken by considering the whole system to balance the trade-offs and constraints.

<u>Heat maps</u>

UK has also a large experience with heat mapping. In 2012 the Department of Energy and Climate Change (DECC) published the National Heat Map of England, created by the Centre for Sustainable Energy. The map shows the heating demand of the entire country, including information relative of all the sectors: households, services (public and private) and industry. The information is provided at an address-level. It also identifies potential heat sources, as CHP and thermal power stations but also energy-from-waste plants, heat recovered from industrial sites, and biomass boilers. The Map provides information related to the water source heat potential, including: the potential for using heat pumps to extract thermal energy from coastal waters, estuaries, canals and rivers; and the total heat available from the rivers and canals intersecting a settlement.

The Map has been designed with the aim of supporting the planning and deployment of district heating networks. It is a tool that allows identifying priority locations where heat distribution is most likely to be convenient based on heat demand density demand but not for designing heat networks directly. The usefulness of the tool is proven as four of the twenty four cities awarded to receive funds by DECC to support the development of heat network projects had requested heat map data from CSE. The cities are Leeds, Manchester, Newcastle and Sheffield.

There are other public accessible maps and tools in UK, as:

- CHP Development Map, commissioned by DECC with UK coverage. It is complementary to the National Heat Map, providing CHP developers, e.g., a higher break down on layers or information about existing district heating networks.
- Leeds Energy Planning Tool, developed by the University of Leeds, which provides a district heating planning tool for England and Wales. The tool allows identifying potential appropriate locations for viable district heating. The tool offers the possibility of taking into account social factors (such as alleviating fuel poverty) in the decision.
- The CHP Site Assessment Tool, provided by DECC to allow developers to get an indicative viability assessment and compare different options for installing CHP on specific locations.
- The Fuel Poverty Map of England, published by DECC, which shows the percentage of households in fuel poverty.

Energy system modelling tools

DECC based their policies in the outcomes of different Energy System Models, such as:

- RESOM (Redpoint Energy System Optimisation Model) that was used to support the 'Future of Heating: Meeting the challenge'. RESOM was used to explore potential pathways to 2050 for decarbonising heat within the context of the whole energy system. The key solutions are those that minimise the total energy system costs to 2050. Using such a comprehensive approach allows finding the key technologies and energy vectors within all the sectors, avoiding partial solutions, to meet the UK climate change targets.

2050 Pathway Calculator that was used for the analysis to explore energy pathways in the long term to meet the 80% emissions reduction target. The 2050 Pathways Calculator allows exploring combination of solutions to meet the emissions target while matching energy supply and demand. The analysis considers the different options and trade-offs to find a solution in the long term.

Netherlands, heat maps

The creation of Dutch heat maps made part of a larger project aimed at creating an atlas related to sustainable energy projects in the Netherlands. These maps were meant to facilitate the transition to a sustainable energy system. They were developed in collaboration between the Dutch government and several other stakeholders, e.g. the CBS (Central Statistical Office), RIVM, TNO, Tennet, Havenbedrijf Rotterdam, and Provincie Zuid Holland. The heat map is regularly updated with reliable data. Individual data are upscaled or generalised in order to protect the privacy of stakeholders.

The heat demand is broken down in sectors, e.g. residential, industrial zones, agricultural, greenhouses. District heating networks are also available. The location of buildings, e.g. greenhouses, swimming pools, hospitals, offices, schools can be identified on the map.

This heat map also contains information about amount of heat that is consumed per household down to the level of neighbourhoods. Annual heat demand of greenhouses, and industries in the temperature ranges (<120˚C, 120-200˚C, and >200˚C) can be seen to the level of municipality.

Renewable potential is also available, for example, geothermal at 65-120˚C from aquifers between 1500-400 m depth, geothermal energy at 175C at 5500 m depth or 225˚C at 7500 m is available. Variable biogas streams are displayed, e.g. liquid manure, biowaste from agriculture.

There are also layers available for waste heat at less than 120˚C (TJ/year), and between 120-200˚C. These are provided with the exact geographical location.

STRATEGO project

Heat Roadmap Europe 3 from STRATEGO WP2: "*Supporting the development of enhanced National heating and cooling plans*", published in June 2015 contains several deliverables that describe practices and methodologies applied related to the heat mapping[116]. More specifically:

- Background Report 5 – Mapping Heat & Cold Demands
- Background Report 6 – Mapping Potential for DHC
- Background Report 7 – Potential for Excess Heat
- Background Report 9 – Mapping Renewable Heat

Potentials of developing district heating and cooling (DHC) grids require a geographically explicit quantification of heating and cooling demands.

In BR5 the technical and economic potential of developing DHC grids is identified. Energy density is used as the criteria with the assumption that an area that is above the threshold will have no other limitation in developing a network. All villages larger than 1-2 km^2 and exceeding a population of 200 are examined. The heat maps produced are raster-based GIS with a resolution of 1 km. The analysis however is done at a resolution of 100 m by using the following publicly available datasets:

- population is mapped using the GEOSTAT 2011 1 km population grid by GISCO
- the urban tissue mapped qualitatively using CORINE 2006 land use grid with 100 m resolution by the European Environment Agency
- urban land use is the degree of soil sealing, mapped quantitatively by the European Environment Agency at a 100m resolution grid.

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[116] Mapping methodology is also describing in the following paper: Persson U, Möller B, Werner S. Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 2014 ;74:663-681.

Population is disaggregated distributed over built-up areas, by using the soil sealing as weighing factor. The following Corine land use classes are used as a mask (all other classes are masked out): 111 (Continuous urban fabric), 112 (Discontinuous urban fabric) and 121 (Industrial or commercial units). Finally some processing was used for boundary cleaning in order to remove smaller groups of 1-4 cell clusters, which may represent larger non-built-up areas or linear structures such as roads.

The above are used in combination with statistics about specific or absolute heating and cooling demand values on a per-capita (heat) or per-m2 (cooling) basis on a NUTS3-level.

In BR6 energy density was used as a single criterion to assess the feasibility of DHC systems. Energy densities on a national level was split in 4 classes:

- 0 – 30 : DH Almost impossible
- 30 – 100 TJ/km^2 : Potential for 4th generation DH
- 100 – 300 TJ/km^2 : DH currently possible
- above 300 TJ/km^2 : DH currently feasible

The percentage of demand that falls in each one of the classes, and consequently the district heating/cooling potential, was estimated. A threshold of 1km2 was use to interconnect neighbouring heat demand areas into bigger coherent areas.

Similar approach was used for district cooling with the following classes

- 0 – 30 TJ/km2 : Cooling demand, rural areas
- 30 – 100 TJ/km2 :DC Almost Impossible
- 100 – 300 TJ/km2 : Potential for advanced DC
- > 300 TJ/km2 : DC Currently Possible

The concept of effective width and linear heat density was used to estimate the capital costs and to correlate the specific investment cost per heat or cold annually sold as function of the heat and cold densities, both related to the corresponding land area. It was concluded that district cooling systems are more expensive to install for the same amount of energy delivered.

Finally a cost-supply curve was presented which establishes a relation between the cumulative heat demand and the marginal costs of building a district heat distribution system.

BR7 presents a methodology to identify the excess heat from industrial sites. This map layer consists of bottom-up facility data. The E-PRTR dataset was used as a proxy to estimate the primary energy consumed at a facility level. More specifically:

- Retrieve geographical coordinates and annual carbon dioxide emissions on facility level from the E-PRTR dataset

- Establish characteristic carbon dioxide emission factors, per Member State and per main activity sector, by use of IEA energy statistics on fuel use and standard carbon dioxide emission factors
- Calculate primary energy supply on facility level based on annual carbon dioxide emissions and characteristic carbon dioxide emission factors
- Apply default recovery efficiencies (per industrial sector) to calculated primary energy supplies to assess theoretically available annual excess heat volumes on facility level

BR9 includes mapping for agriculture and forestry biomass resources, geothermal heat resources and water bodies.

For Biomass from agriculture emphasis was given on residues and waste products. Straw production among the 28 member states was assessed using Eurostat agricultural statistics using an average of the years between 2009 to 2013. Then, agricultural areas were mapped by extracting the "Arable land" land use class from the CORINE2006 land cover database.

Forestry biomass distribution by density is done using the forest density map available at 1km resolution from the European Forest Institute. From this map NATURA2000 zones were excluded. A wood resource extraction ratio (m^3/(ha a) was calculated using the actual forest management statistics in combination with these assumptions. The extraction ratio was multiplied with the forest density map that excludes conservation areas, as well as a heat value of wood residues to derive an energy density map. In order to focus on local available resources while assessing the use of biomass for heating, only resources within a radius of 30km threshold were considered for each demand point.

For the geothermal heat resources data from the GeoDH project were used. Temperatures exceeding 60 °C and located no deeper than 3 km were selected as thresholds. Geoelec project is also suggested as a more advanced method for mapping geothermal resources.

Ambient heat as a source of heat to be used by means of large-scale heat pumps has been mapped using land-use mapping (Corine) of surface water bodies exceeding 1 hectare in size as well as rivers (EEA) and their network hierarchy. Proximity to surface water has been mapped in a focal statistics function, which summarizes the number of 1ha cells per km^2 within a radius of 5km.

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