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Deliverable report

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Deliverable name	Techno-socio-economic assessment of storages and renewables in grids
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sweet swiss energy research for the energy transition

Summary

This deliverable reports the identification of relevant infrastructure configurations of thermal networks. Relevant properties were identified, and their interactions are analysed and qualitatively assessed regarding direct CO_2 emissions, the possibility of integrating renewables and/or efficiently using renewable resources and socio-economic motivation patterns towards grid transformation. This resulted in 47 thermal network configurations. Additionally, the methodology to combine these results with the previous activities in Task 3.1 is presented to finally carry out a holistic evaluation of the thermal networks in Switzerland, investigating the interaction of different demand and supply characteristics.

1 Introduction

Thermal networks are a key component of the energy transition. However, in 2019, around 17% of the heat provided by Swiss thermal networks was produced with gas [1], mostly because of coverage of the peak load by fossil fuels [1]. To reach the goals indicated in the Energy Strategy 2050 the energy sources of the thermal networks must become fossil-free, and the limited renewable resources should be used as efficiently as possible, which inter alia requires the application of thermal energy storages. The challenge is to identify which characteristics of thermal networks reflect a good fit with these goals or favour the achievement of these goals. This requires an in-depth analysis of relevant properties of different supply infrastructures. This forms the supplementary piece to the analysis of Swiss districts that are supplied by thermal networks and were presented in the deliverable report 3.1.1. Bringing together relevant network configurations and archetypal districts will make it possible to identify specific reference cases and measure their interaction between infrastructure and demand using quantitative evaluation criteria as illustrated in Figure 1. By assessing various connections between demand and supply characteristics, knowledge can be gained about which measures on both sides can be taken to achieve resource-efficient decarbonization. This is intended to provide a platform for academia and decision-makers to carry out scientific, regulatory and individual efforts in a targeted manner.

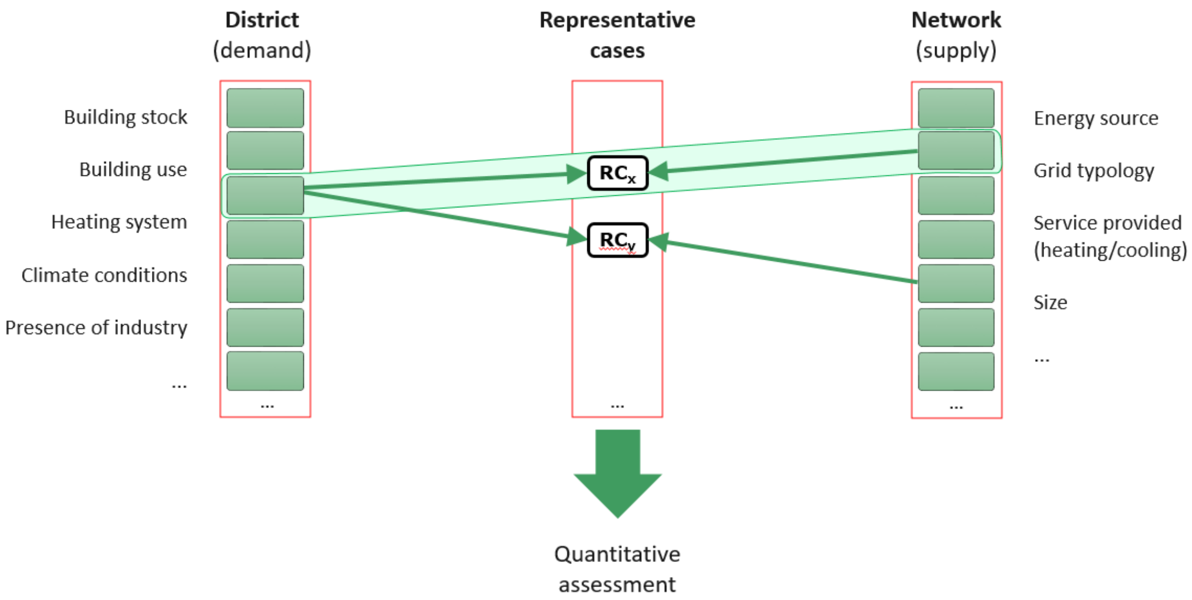

Figure 1: Interrelation of district and network characteristics. A specific demand archetype can possibly be served by multiple network configurations. Case studies that are representative for relevant interconnections between the two sides serve as reference cases (RC) to be quantitatively assessed.

Therefore, this deliverable presents a techno-socio-economic assessment of thermal network properties and their interactions resulting in a variety of network configurations where the integration of renewables and storages form the centrepiece. In addition, the evaluation criteria for the quantitative assessment of these configurations in connection with real demand characteristics are defined.

2 Deliverable content

The process inside the dashed box in Figure 2 describes the steps of the work reported here. Firstly, an extensive literature review was carried out to identify parameters used in the field to describe thermal networks. Secondly, the identified parameters were *qualitatively* assessed, and the most relevant ones according to the following three criteria were selected:

(1) Direct CO_2 emissions

(2) Possibility of integrating renewables and/or efficiently using renewable resources

(3) Socio-economic motivation patterns towards grid transformation

Thirdly, the selected parameters were divided into two groups. On the one hand, descriptive parameters characterize and distinguishing relevant network configurations, and on the other hand parameters to evaluate networks regarding the three criteria above. Fourthly, the values that parameters in the descriptive group could take were specified in categories. Fifthly, meaningful combinations of the categories for the selected parameters were established resulting in thermal network configurations. Finally, a *quantitative* assessment of those configurations in the context of certain demand characteristics can be carried out through the parameters in the second group.

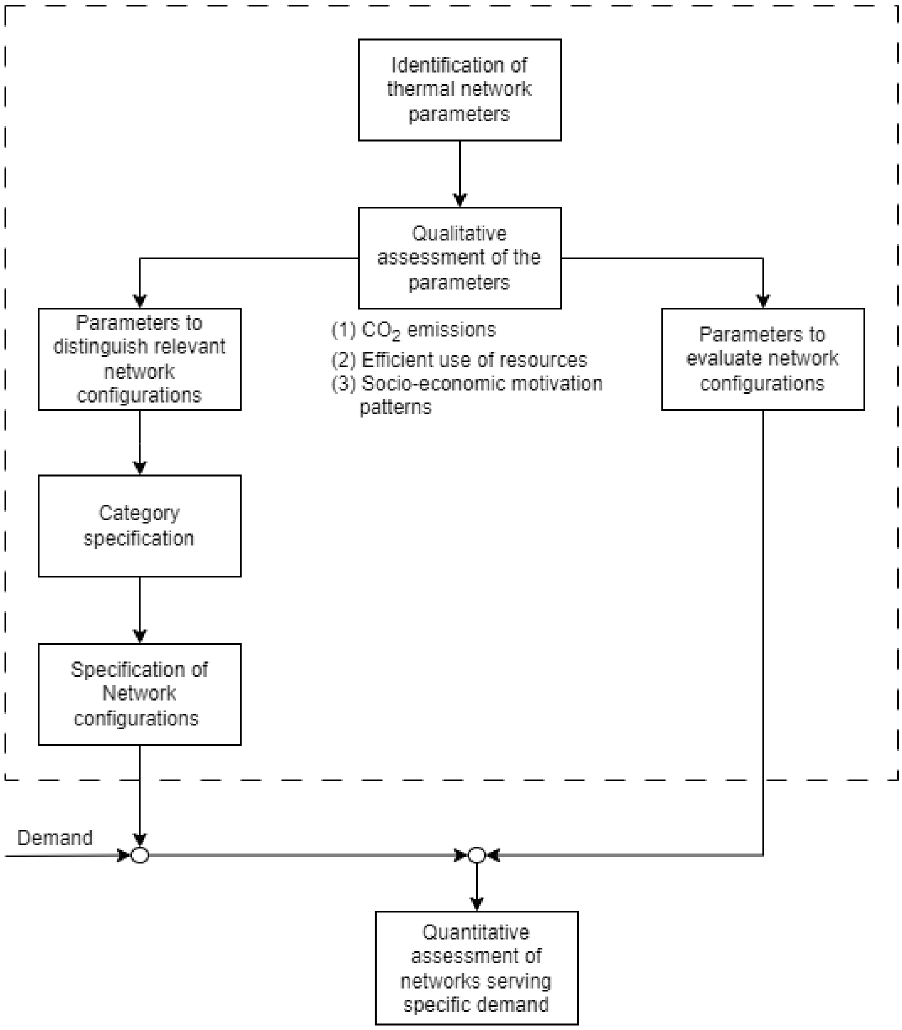

Figure 2: Flow chart describing the methodology corresponding to the socio-techno-economic assessment. The dashed box encloses the workflow presented in this document.

2.1 Parameter identification

A literature review was conducted to identify parameters used in the field to describe thermal networks. Selected contents were reviewed and parameters describing the thermal grids were annotated. The identified set of parameters was extended by the findings of the projects (1) Innosuisse QUBE (Quartierbezogene gemeinschaftliche erneuerbare Energielösungen), and (2) the SNF SOTES (Sociotechnological Breakthrough of Thermal Energy Storage). The next step was to divide the parameters into groups to have an overview of the areas covered by the parameters and to identify more easily relationships among them. They were divided into the groups technical, legal, economic, social, and ecological. The technical parameters were subdivided into demand characteristics, supply, architecture, and thermal storage. The 68 identified parameters and the groups they belong to can be seen in Table 1.

Technical	
Demand	
Number of connected buildings	
Total heated or cooled building floor area (ERA)	m2
Heating energy demand	MWh/a
Cooling energy demand	MWh/a
Spatial energy density Heating	MWh/(ha a)
Spatial energy density Cooling	MWh/(ha a)
Linear power density Heating	MW/km
Linear energy density Heating	MWh/(km a)
Linear power density Cooling	MW/km
Linear energy density Cooling	MWh/(km a)
Temperature Level Space Heating	°C
Temperature Level Space Cooling	°C
Full Load Hours Heating	h/a
Full Load Hours Cooling	h/a
Exergy-Demand	MWh
Ratio heating/cooling energy demand	MWh/MWh
Degree of urbanisation	
Building type	
Building age	
Building density	
Architecture	
Number of carrier pipes	
Network topology	
Energy direction	
Fluid flow direction	
Centralized/Decentralized	
Thermal Storage	
Storage capacity	MWh
Storage type	
Energy specific storage capacity	MWh/MWh
Power specific storage capacity	MWh/MW = h
Legal	
Legal form	
Grid ownership	
Operator	
Ecological	
Energy specific CO_2 Emissions	kg_{CO2}/MWh

Technical	
Supply	
Total installed power Heating	MW
Total installed power Cooling	MW
Grid length	km
Main energy source	
Peak load supply	
Energy output from main energy source	MWh
Energy output from peak load energy source(s)	MWh
Share of pump energy on total energy sold	%
Temperature Level Hot Carrier	°C
Temperature Level Cold Carrier	°C
Network temperature type	
Seasonal COP of Heat Pumps/Chiller units	
Overall conversion efficiency rate of thermal power plants	%
Energy services provided	
Energy efficiency	%
Exergy efficiency	%
Installed power of main energy source	MW
Installed power of peak load energy source(s)	MW
Ratio main/peak load energy output	MWh/MWh
Ratio of installed power main/ peak load energy source(s)	MW/MW
Transfer heat loss	%
Heat carrier fluid	
Pressure	bar
Pipe diameter	m
Pipe insulation	
Pipe material	
Generation	
Economic	
Investment cost	CHF/MW
Investment to operational cost	CHF/CHF
Connection fee	CHF
Standing Costs	CHF/a
Unit Cost	CHF/a
Levelized cost of energy	CHF/MWh
Social	
Building ownership	
Dominant user profile	

Table 1: Identification of parameters describing thermal grids divided by groups.

2.2 Qualitative assessment

The most relevant parameters were selected according to the three criteria:

(1) Direct CO_2 emissions
(2) Possibility of integrating of renewables and/or efficiently using the renewable resources
(3) Socio-economic motivation patterns towards grid transformation

The number of selected parameters was kept as small as possible to have a reasonable number of combinations.

As the demand parameters refer to the district that the network is serving and not the network itself (being the latter the focus of this deliverable) they were excluded from the selection. However, some of these parameters describe relevant district characteristics that will be relevant for the quantitative assessment of pairings of specific network configurations and demand structures.

2.2.1 Direct CO_2 emissions

The first selection is rather straightforward, as direct CO_2 emissions are caused by the choice of the energy sources used to cover the main and/or peak energy demand. They both determine the specific CO_2 emissions of the network. The latter is hence an evaluation parameter. Therefore, the following parameters were chosen to represent the direct networks emissions:

- *Main energy source*
- *Peak load supply*
- *Energy specific CO_2 emissions (evaluation parameter)*

The first two parameters are also relevant to criterion (2) concerning the efficient use of renewable energy: a meaningful use of a renewable source depends on the demand, geospatial location, or availability of alternative sources. For example, the low temperature demand of residential settings does not need to reach the high temperatures supplied by biomass. If there is no alternative low-exergy source available, the exergetic efficiency could at least be maximized by applying combined heat and power (CHP) production. However, to assess this meaningfulness of the use of sources, it individually needs to be brought into the context of the corresponding district and cannot be assessed based on pure supply characteristics.

2.2.2 Integration and efficient use of renewable energy

There are various parameters that impact the integration of renewables or that give an indication on the effectiveness of resource utilization. The following list shows all the chosen parameters and the justification why they were chosen:

- *Thermal power* (considering both total installed power heating and total installed power cooling): This parameter is commonly used to describe thermal networks and indicates the network's size in terms of demand. It is a relevant parameter, on one hand, since the impact of decarbonizing a single network is higher the higher the demand is, and, on the other hand, the meaningfulness of utilizing certain renewable sources is depending on the network's demand. For example, the energy of surface waters or deep geothermal sources require a reasonably high demand to be connected to the source to fully exploit their potential.

- *Energy and fluid flow direction*: these two parameters distinguish three network architectures.
  - Directed, unidirectional: classical architecture, with a warm and cold pipe corresponding to the flow and return pipe and central pumps.
  - Directed, bidirectional: there is a warm and cold pipe that change their temperature depending on the operating mode or there are more than two pipes.
  - Undirected, bidirectional: there are two or more pipes and decentralized pumps, such that the fluid and the energy can flow in both directions.

  The two last architectures allow the integration of decentralized sources such as waste heat and storages and therefore impact the network's performance regarding criterion (2).

- *Seasonal storage*: This parameter was derived from the parameter 'power specific storage capacity', which is a quantitative property to distinguish short- and long-term storages. However, the purpose of both types is different. Short-term storages are used to shave peaks and run energy conversion units at more constant load, which is thus a way to provide peak load supply.

In contrast, long-term storages increase the utilization of specific sources. For efficient use of resources, it is therefore particularly relevant to distinguish networks that do or don't have seasonal thermal energy storages (STES) in place depending on the source and demand. In case that there is a seasonal fluctuation in demand, STES can store renewable heat or excess waste heat generated in summer and use it later in winter when there is the highest demand and lowest availability of heat. Therefore, STES plays a key role in efficiently using these resources.

- *Network Temperature*: The lower the network temperature, the broader the range of energy sources that can be integrated in the network. Therefore, the network temperature indicates the potential of exploiting high shares of renewable low temperature sources and waste heat.

- *Energy services provided*: This parameter considers whether there is only a single use of a source or whether there is combined use. This is relevant to assess the effectiveness of using the source, namely whether a high temperature source is used for combined heat and power (CHP) production or the heat from cooling services is used for heating purposes.

- *Exergy efficiency (evaluation parameter)*: This parameter relates the exergy input from the source use to the exergy demand of a district. This is a quantitative parameter to evaluate the efficiency of resource use. Therefore, this parameter acts as evaluation criterion when comparing network configurations in the context of their respective districts.

2.2.3 Motivation patterns

Based on the research in the QUBE- and SNF-SOTES-Project it found that the public is more willing to accept the inconvenience of space requirements and construction work of infrastructure projects if the people have the possibility to have a say on the projects and if the projects are of clear public interest while private profit interest is not the main motivation. This circumstance can heavily influence the viability of different technologies, e.g. space intensive storages. Therefore, the parameter *grid ownership* was chosen to reflect this effect by measuring the percentage of shares that are hold by the local public, be it public institutions or cooperations. Moreover, the economic feasibility is also a relevant parameter regarding the social acceptance of a thermal network. This parameter is mainly characterized by *the levelized cost of energy* (LCOE), which combines other economic parameters such as investment and operation costs. Hence, the LCOE was also chosen for the assessment. Both parameters, grid ownership and LCOE, are considered evaluation parameters because they help in assessing the viability of the defined configurations.

Table 2 summarises the qualitative assessment process, indicating to which group the selected parameters belong to.

Group	Parameter
Distinguish network configurations	Main energy source
	Peak load supply
	Thermal power
	Fluid flow direction
	Energy flow direction
	Seasonal thermal energy storage
	Network Temperature Type
	Energy services provided
Evaluate network configurations	Energy specific CO_2 emissions
	Exergy efficiency
	Grid ownership
	Levelized cost of energy

Table 2: Qualitative assessment of thermal network parameters

2.2.4 Parameter exclusion

The previous paragraphs highlighted why each parameter was selected but it is as well important to give information on why the other parameters were not. There are four different reasons why a parameter was dismissed.

Firstly, the information of the following parameters is directly contained in one of the selected parameters or is a consequence of them:

• Total installed power heating • Total installed power cooling • Installed power main energy source • Installed power peak load energy source(s) • Ratio of installed power main/ peak load energy source(s)	covered by *thermal power*
• Temperature level hot carrier • Temperature level cold carrier • Generation	covered by *network temperature type*
• Number of carrier pipes • Centralized/Decentralized	consequence of *energy / fluid flow direction*
• Storage capacity • Energy specific storage capacity • Power specific storage capacity	aim to distinguish between short- and long-term storage. This is covered by the parameters *seasonal thermal energy storage* and *peak load supply*
• Investment cost • Investment to operational cost • Connection fee • Standing costs • Unit costs	Covered by *levelized cost of energy*
• Overall conversion efficiency rate of thermal power plants • Seasonal Coefficient of Performance for Heat Pumps/Chiller units • Transfer heat loss • Energy efficiency	Covered by *exergy efficiency*

Secondly, the values of the following parameters cannot be determined without knowing specific demand characteristics:

• Energy output from main energy source • Energy output from peak load energy source(s) • Ratio main/peak load energy output	Require the knowledge about the energy demand and it's time-dependent variation.
• Building ownership • Dominant user profile	Require the information on the district with location and buildings

Thirdly, the following parameters contain too specific detail information to be applied to distinguish networks:

- Pressure
- Pipe diameter
- Pipe insulation
- Pipe material
- Share of pump energy on total energy sold
- Storage type
- Network topology
- Grid length
- Operator
- Legal form

Fourthly, the thermal networks configurations considered have typically water as heat carrier fluid. It would have been interesting to consider alternative fluids like CO_2 and thermochemical fluids as well for future networks. These technologies have the potential to eliminate transfer heat losses or to reduce the cost due to narrower pipes. However, the low TRL of these technologies makes it impractical to incorporate them in the proposed methodology, because their technical limitations and specifications are not fully defined and understood yet.

2.3 Category specification

In the next step, quantitative or qualitative categories were defined for the selected parameters distinguishing relevant network configurations. A thermal network configuration is specified by the combination of categories of the parameters and not all combinations are reasonable. To have a reasonably small number of combinations, the number of categories of the parameters was kept as minimal as possible but with the capability to highlight the relevant differences between thermal networks according to the three criteria listed in the previous section. The following sections explain how and why the categories of the chosen parameters were set. An overview of the 8 parameters and their categories can be seen in Table 3.

2.3.1 Main Energy Source

Out of the high diversity of possible energy sources, the categories of main energy sources were kept minimal by grouping the sources where possible. For instance, wood logs, chips, pellets, and biogas were summarized under the term *biomass* because their important common features include the strongly limited potential, the possibility to produce very high temperatures, and the easy storability. Other high temperature sources such as *Municipal Waste Incineration (MWI), deep-geothermal* and *high temperature waste heat* are categories on their own since they differ by the geospatial applicability and the temporal availability. A MWI plant can basically be built everywhere, while deep-geothermal plants are geospatially restricted due to specific geological requirements. Other high temperature waste heat from industry differs from the first two sources due to the higher fluctuation in heat supply and the usually private ownership of the source. Nuclear waste heat would have similar characteristics as the waste heat from MWI plants, but as this only accounts for two networks and Switzerland has decided to phase out nuclear energy in the medium term, this energy source is not considered. Low temperature sources on the other hand are divided into three categories. The differentiation between high and low temperature sources is explained in section 2.3.6. Firstly, surface water, groundwater, shallow-geothermal, tunnels and wastewater treatment plants were grouped into the category of *location-bound low temperature sources*, as their availability is geospatially restricted but continuously available. *Air* as a source on the other hand is available everywhere. Thirdly, *low temperature waste heat*, which is potentially not continuously available, is covered by the category of multiple decentralized energy sources. *Solar heat* as main energy source is an own category as well, since for a year-round supply seasonal thermal energy storage is essential. Finally, the different *fossil* sources were also grouped together as they have similar characteristics and have to be replaced anyways.

2.3.2 Peak Load Supply

The categories of peak load supply distinguish between *fossil* and *non-fossil* sources. The latter considers inter alia biomass and short-term storages. Although there is a diversity in how to provide fossil-free peak load, it was decided not to distinguish between different sources and technologies, since energy-wise the peak load supply typically only accounts for around 15 % of the total resource use of a network. Therefore, an exergetically non-ideal peak load supply is not as drastic as a non-ideal base load supply. Of high importance is primarily the substitution of fossil peak-load supply and the choice of source/technology for this is secondary.

2.3.3 Thermal Power

The thermal power is divided in the following three categories:

- < 1 MW
- 1-10 MW
- >10 MW

The categories were derived from the list of thermal networks of the Swiss Federal Office of Energy [2] for which the 'Power' values are available. The categories represent small, medium and large networks in terms of their demand. Figure 3 shows the distribution of the existing thermal networks in Switzerland on the three categories. The small and medium size represent both around 450 networks. The large networks are by their nature the smallest number and mainly cover networks fed by waste heat from municipal waste incineration (MWI) and big wood chips plants. However, in terms of energy consumption, assuming average full load hours of 2200 h/a, the large networks make out the biggest share with around 6.5 TWh, while the medium networks consume around 3 TWh and the small networks 0.4 TWh.

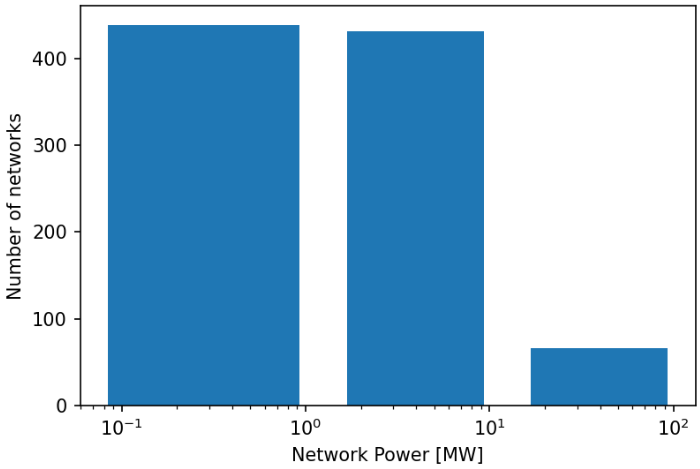

Figure 3: Histogram of number of networks in the three power categories

Therefore, this distinction is firstly important because it assesses the impact of decarbonising a single network, i.e. decarbonising a single large network has generally a higher impact on the resource use than a single small network. Secondly, the economic conditions and technology options vary with the size of the network. And thirdly, the full exploitation of certain energy sources such as surface water is only possible by building large networks.

2.3.4 Energy and fluid flow direction

The categories of these two parameters are:

- Energy flow: Directed/undirected
- Fluid flow: uni-/bidirectional

These categories lead to the three meaningful combinations mentioned in the previous section. The three combinations imply under what conditions decentralized renewable sources and storages can be integrated in the network.

2.3.5 Seasonal Thermal Energy Storage

For seasonal storages it is only considered whether there is STES or not. It is considered that storages with a power specific capacity of more than 500 h count as seasonal. This corresponds to three weeks at full load and is in line with the majority of applications listed in [3]. This parameter is highly relevant for energy sources that are not controllable. On the one hand this accounts for the (seasonally) continuously available high temperature sources MWI, deep-geothermal and high temperature waste heat. These sources can only be exploited to their full potential if there is either a continuous heat demand (high number of full load hours) or STES is applied. On the other hand, solar heat as main energy source can only be implemented in combination with STES. The regeneration of low temperature sources such as borehole fields or ice storages are not considered as STES.

2.3.6 Network Temperature

The categories of network temperature type were obtained from the literature [4] (see Figure 4) and distinguishes High Temperature (HT) to Low Temperature (LT) networks. The temperature of HT networks is higher than 60°C and it can directly operate all space heating services and hot water. Among LT networks (having a temperature below 60°C) three cases are distinguished: (1) Between 30°C and 60°C, which is suitable for most heating applications in new builds but hot water must be further treated, (2) Between 20°C and 30°C, which requires the application of heat pumps for all heating and cooling purposes, and (3) Between 0°C and 20°C, which can be directly used for cooling and require heat pumps for all heating purposes. These four types were condensed into three categories, distinguishing HT networks above 60°C, LT networks below 20°C and networks with temperatures in between. For the HT and LT networks, heating or cooling services respectively can be obtained directly, while for network temperatures in between, heat pumps are always required.

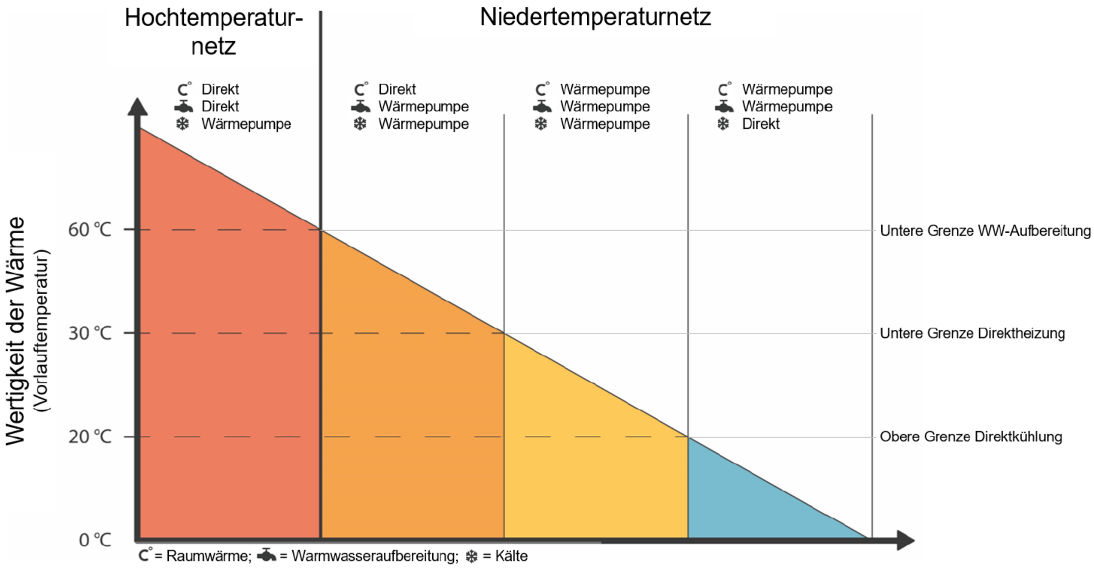

Figure 4: Classification of thermal networks according to their temperature [4]

As mentioned in the previous section, the temperature level implies whether cooling services can be provided and what renewable sources can be integrated in the network. Generally, the lower the temperature the broader the options, while network temperatures below 60°C in combination with high temperature sources tend to be unfavourable in terms of exergy efficiency.

Based on this, the ability to directly operate a high temperature network was chosen to distinguish high- from low-temperature sources. Hence, sources that provide temperatures above 60°C are considered as high temperature. This criterion also distinguishes shallow- from deep-geothermal sources.

2.3.7 Energy Services Provided

The four categories of energy services provided are:

- Heating only
- Cooling only
- Heating & Cooling
- Heating & Electricity

High-temperature sources that are of high exergetic value are used most efficiently if there is co-generation of electricity and/or high-temperature demand. Especially for networks that currently use biomass, this is by far not always the case. Therefore, the meaningfulness of using a certain energy source is depending on what energy services are provided but also which energy services are required. Co-generating electricity when using high temperature sources is mostly independent from the local electricity demand and could generally be more widely applied. However, if there is no high temperature demand, the usage of alternative low temperature sources should generally be prioritized.

Main energy source
Municipal Waste Incineration
Biomass
Deep-Geothermal
Air+Heat Pump
Solar
Location-Bound Low-Temperature + Heat Pump
High Temperature Waste Heat
Multiple decentralized sources
Fossil
Network Temperature Type
< 20 °C
20 - 60 °C
> 60 °C
Energy flow direction
Unidirectional
Bidirectional

Thermal power
< 1 MW
1-10 MW
> 10 MW
Peak load supply
Fossil
Non-fossil
Energy services provided
Heating
Cooling
Heating & Cooling
Heating & Electricity
Seasonal thermal energy storage
Yes
No
Fluid flow direction
Directed
Undirected

Table 3: Selected parameters distinguishing relevant network configurations, and their categories. Meaningful combinations of them define the configurations explained in the next section.

2.4 Thermal network configurations

After the parameter selection and categories specification, the next step was to define combinations of the parameter categories that differentiate networks in terms of their performance based on the three criteria defined in section 2.2. The procedure was to take an initial parameter to differentiate the networks based on its categories. For each category, different further parameters were selected in order to obtain further delimitations of network configurations. This resulted in 47 network configurations, which differ according to an individual selection of parameters. The categories of the remaining parameters do not provide any significant differentiation. They are listed in the final set of configurations as additional information. A first version of the resulting configurations was presented and discussed in a workshop with DeCarbCH members from different work packages. The final configurations are presented from Table 4 to Table 12.

As the assessment of direct CO_2 emissions and the efficiency of resource use first of all requires the information on what sources are used in the grids, the main energy source is the initial parameter to distinguish the networks. The following section lists the further selection of parameters for each energy source. In each case (except of fossil served grids) the parameter *Peak Load Supply* was selected due to its direct impact on the carbon footprint and therefore its key role regarding the decarbonisation of the grids.

2.4.1 Municipal Waste Incineration

The following additional parameters were selected:

- Peak load supply
- Seasonal storage

The presence of STES is relevant as this high temperature source is continuously available and if not linked to a corresponding continuous demand the summer excess heat would be wasted. The categories of the remaining parameters are a consequence of the source since MWI plants have typically a power >10 MW, co-produce electricity and produce by their nature heat at high temperatures. This leads to four configurations shown in Table 4.

Main energy Source	**Municipal waste incineration (MWI)**			
Thermal Power [MW]	>10			
Peak load supply	fossil		non-fossil	
Network Temperature [°C]	>60			
Seasonal storage	no	yes	no	yes
Fluid flow direction	directed			
Energy flow direction	unidirectional			
Energy services provided	heating & electricity			

Table 4: 4 configurations of MWI networks.

2.4.2 Biomass

The following additional parameters were selected:

- Peak load supply
- Thermal Power
- Energy Services

Thermal power was chosen as an important parameter, since on one hand biomass fired thermal networks can be and are built in all possible sizes and the challenges to decarbonize the peak load supply or to switch production to a co-generation of electricity are different depending on the size. For example, the economic incentive of switching to co-generation of electricity and its efficiency is lower the smaller the network. Therefore, the energy services provided are an important indicator of the efficiency of using biomass. However, the meaningfulness of using biomass in general is also depending on the demand.

Main Energy Source	**Biomass**											
Thermal Power [MW]	<1				1-10				>10			
Peak load supply	fossil		non-fossil		fossil		non-fossil		fossil		non-fossil	
Network Temperature [°C]	>60											
Seasonal storage	no											
Fluid flow direction	directed											
Energy flow direction	unidirectional											
Energy services	h	h&e	h	h&e	h	h&e	h	h&e	h	h&e	h	h&e

Table 5: 12 configurations of biomass networks. “h” stands for heating and “h&e” for heating and electricity.

2.4.3 High Temperature Waste Heat

The following additional parameters were selected:

- Peak load supply
- Seasonal storage

For these energy sources, the same arguments apply like for MWI plants with the differences that the available thermal power would often be smaller than MWI plants, that it is generally more difficult to get the necessary long-term commitment of private companies and that depending on the processes there could be a higher fluctuation of availability.

Main energy Source	**High T Waste Heat**			
Thermal Power [MW]	< 10			
Peak load supply	fossil	non-fossil	fossil	non-fossil
Network Temperature [°C]	> 60			
Seasonal storage	no		yes	
Fluid flow direction	directed			
Energy flow direction	unidirectional			
Energy services	heating			

Table 6: 4 configurations of networks using high temperature waste heat as main energy source.

2.4.4 Deep-Geothermal

The following additional parameters were selected:

- Peak load supply
- Seasonal storage
- Energy services

In this case, the same conditions apply like for MWI plants since the source is continuously available. The difference is that the possibility to co-generate electricity is depending on the temperature of the geothermal water and therefore the depth of the well. The deeper the well, the higher the capital cost and therefore the more power needs to get extracted to be economically feasible. Therefore, co-generation of electricity is only considered for geothermal wells with high power. The excess heat from summer could be seasonally stored in aquifers at shallower depth.

Main energy Source	**Deep-Geothermal**							
Thermal Power [MW]	1-10				>10			
Peak load supply	fossil		non-fossil		fossil		non-fossil	
Network Temperature [°C]	>60							
Seasonal storage	No	Yes	No	Yes	No	Yes	No	Yes
Fluid flow direction	directed							
Energy flow direction	unidirectional							
Energy services	heating				Heating & electricity			

Table 7: 8 configurations of networks driven by deep-geothermal heat.

2.4.5 Fossil

The only additional parameter chosen is 'Thermal Power'. This is due to the different economic conditions and technological options that networks of different sizes deal with regarding the decarbonization of the network.

Main energy Source		**Fossil**	
Thermal Power	[MW]	<1	>1
Peak load supply	-	fossil	
Network Temperature	[°C]	>60	
Seasonal storage	-	no	
Fluid flow direction	-	directed	
Energy flow direction	-	unidirectional	
Energy services	-	Heating or heating & electricity	

Table 8: 2 configurations of fossil fuel driven networks.

2.4.6 Location-Bound Low-Temperature Sources

The following additional parameters were selected:

- Peak load supply
- Network Temperature
- Energy & fluid flow direction

The network temperature and the energy and fluid flow direction imply what energy services can be performed and what other renewable sources could be integrated. The differentiation between fossil and non-fossil peak load supply is only feasible for networks >20°C, because for networks below 20°C, high temperature fossil sources could only be integrated decentralized and therefore it cannot be clearly differentiated between fossil and non-fossil peak load supply. Thermal power was not chosen as a parameter, since it is very much depending on the specific low-temperature source what loads are feasible.

<table>
<tr><th>Main Energy Source</th><th colspan="8">Location-bound low-temperature source (LB LT) + Heat Pump</th></tr>
<tr><td>Thermal Power [MW]</td><td colspan="8">Any</td></tr>
<tr><td>Peak load supply</td><td>fossil</td><td>non-fossil</td><td>fossil</td><td>non-fossil</td><td>fossil</td><td>non-fossil</td><td colspan="2">-</td></tr>
<tr><td>Network Temperature [°C]</td><td colspan="2">> 60</td><td colspan="4">20 - 60</td><td colspan="2"><20</td></tr>
<tr><td>Seasonal storage</td><td colspan="8">No</td></tr>
<tr><td>Fluid flow direction</td><td colspan="7">directed</td><td>undirected</td></tr>
<tr><td>Energy flow direction</td><td colspan="4">unidirectional</td><td colspan="4">bidirectional</td></tr>
<tr><td>Energy services</td><td colspan="4">heating</td><td colspan="4">heating & cooling</td></tr>
</table>

Table 9: 8 combinations of networks that use location-bound low temperature sources to heat and/or cool.

2.4.7 Air-source heat pump

The following additional parameters were selected due to the same reasons as mentioned above:

- Peak load supply
- Network Temperature

As there is no information on the thermal power of the 11 air-source driven thermal networks in Switzerland, there is no specific information on the thermal power given. It is assumed that the size of the networks will in most cases below 1 MW.

Main energy Source	Air-source Heat Pump		
Thermal Power [MW]	< 1		
Peak load supply	fossil	non-fossil	-
Network Temperature [°C]	20-60		<20
Seasonal storage	no		
Fluid flow direction	directed		
Energy flow direction	unidirectional		
Energy services	heating		cooling

Table 10: 3 combinations of network using air-source heat pumps to heat and/or cool.

2.4.8 Solar heat

The following additional parameters were selected:

- Thermal Power
- Network Temperature

The differentiation in size according to the thermal power is relevant due to different seasonal storage technologies are feasible for small networks than for bigger ones. The network temperature distinguishes between grids that are only serving heating demand or that can also integrate waste heat by cooling.

Main Energy Source	Solar heat			
Thermal Power [MW]	<1	>1	<1	>1
Peak load supply	non-fossil			
Network Temperature [°C]	20-60		>60	
Seasonal storage	yes			
Fluid flow direction	directed			
Energy flow direction	unidirectional			
Energy services	Heating & cooling		heating	

Table 11: 4 combinations of solar heat driven networks

2.4.9 Multiple decentralized sources

The only additional parameters selected is the peak load supply for heating purposes.

Main Energy Source	Multiple decentralized sources	
th. Power [MW]	<10	
Peak load supply	fossil	non-fossil
Network Temperature [°C]	<60	
Seasonal storage	no	
Fluid flow direction	undirected	
Energy flow direction	bidirectional	
Energy services	heating & cooling	

Table 12: 2 combinations of networks using multiple sources

2.5 Quantitative assessment

The final part will be the quantitative assessment of the configurations in interaction with different demand characteristics based on the four evaluation parameters:

- Energy specific CO_2 emissions in [kg/MWh]
- Exergy efficiency in [%]
- Grid ownership in [%] publicly held shares
- Levelized cost of energy in [Rp/kWh]

Networks can be evaluated and compared using these parameters. However, this cannot be done solely based on the information known from the above configurations, but must be done in the specific application, in particular taking into account the demand characteristics of the corresponding district. Multiple networks can be assessed using each individual evaluation parameter - a combined assessment is not possible as the parameters do not relate to a common neutral scale. Therefore, the results of this deliverable will be combined with the results of the previous deliverable D3.1.1, which analysed the demand side and identified and characterised archetype districts. Extending this analysis to include the presented supply configurations will result in a new set of archetypes that consider both demand and supply. The resulting representative districts can then be assessed based on the above evaluation parameters. In this way, concrete examples can be used to show which network configurations are well suited to cover certain demand structures regarding the three criteria mentioned or which measures can be taken to improve this interaction on both the supply and the demand side.

3 Conclusion & Outlook

An assessment of techno-socio-economical thermal network parameters and their interaction, including renewables and storages, resulted in 47 configurations which are defined depending on their main energy source. These configurations will help in identifying decarbonisation paths for thermal grids. Characterising a network based on these configurations and comparing it with other configurations enables the identification of options that are to be checked to decarbonize not only the network itself but also to achieve that it is in line with overall decarbonisation targets. The assessment of two configurations against each other can only be made regarding the respective demand of the district that is served.

In the previous activities reported in the deliverable report 3.1.1 in DeCarbCH, a GIS-based analysis of Swiss districts served by thermal networks was presented. Linking the presented network configurations with the characteristics of the identified districts will therefore be the next goal within DeCarbCH Task 3.1 to derive thermal network archetypes that consider both, supply and demand, which are to be used in the methodology and tools developed in WP01.

Furthermore, the overview on the network configurations enables a platform to systematically show in the other tasks of WP03, what technology options exist to implement a configuration or to move from one to another configuration respectively, and what the impact on the control of the networks and the local energy planning is.

4 References

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