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Summary Version

(for Chapter 6 of the Final Report
of Annex TS1)

Subtask A:
Methods and Planning Tools

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1 Introduction

As part of the German contribution in *IEA DHC ANNEX TS1: Low Temperature District Heating for Future Energy Systems*, the Institute of Energy Economics and Rational Energy Use (IER) of the University of Stuttgart (Germany) coordinates Subtask A: Methods and Planning Tools. The full subtask A report is published in (Blesl, Stehle 2017).

Subtask A identifies and adapts a methodology for assessing and analyzing procedures to optimize local energy systems with focus on DH. Furthermore, a simplified planning tool for DH is developed and advanced tools for design and performance analysis of local energy systems, which are based on DH, are further developed.

For the evaluation of existing local and DHC models, a classification form was created together with Annex TS1 participants to conduct a survey on planning tools for DH. The used classification categories are summarized in Table 1.

Table 1: Classification categories for the evaluation of planning tools for district heating

Analytical Approach
Energy System Model
Thermodynamic Model

Target Audience
Municipal Authorities
Professional Planners
Internal Use, R & D

Level of Detail
Geographical Scope
Time Horizon

Model Type
Simulation Model
Optimization Model

Demand Categories
Households
Commercial
Industry
Transportation

Final Energy Consumption
Electricity
Heat
Transport

Variables
Costs
Energy
Exergy
Temperature

Input from Annex participants (in total twelve planning tools) could be gathered and evaluated to formulate requirements for the development of a simplified DH planning tool and to further develop an existing advanced tool (TIMES Local). Based on this, a new simplified planning for DH has been outlined and developed: Easy District Analysis (EDA). EDA is a simplified DH planning tool for urban planners for the energetic, ecological and economic analysis as well as the evaluation of urban districts.

In the following the results of the survey on local and DHC models are described and evaluated. The developed Easy District Analysis (EDA) tool is then presented and applied to a case study of an urban district consisting of 140 multi-family houses.

2 Description of Planning Tools for District Heating

Based on the survey results on local and DHC models, twelve planning tools for DH are briefly described in the following. As a first step, the analyzed planning tools are divided according to their analytical approach: energy system models, thermodynamic models and others (see Table 2).

Table 2: Overview of planning tools from the survey on local and DHC models

Energy System Models		
EnergyPLAN	KOPTI	LowEx-CAT
SIMUL_E.NET[1]	TIMES Local	
Thermodynamic Models		
HeatNET	LowEx-CAT	NET Local
SIMUL_E.NET	spHeat	Termis
Others		
District ECA[2]	EME Forecast	Exergy Pass Online[3]

Energy system models describe energy flows from primary energy over transformation, transport and distribution to final energy and useful energy. They are therefore suitable for an integral approach on low temperature DH. However, heat distribution and different temperature levels are often not modelled in energy system models in detail. *Thermodynamic models* are therefore also included in the survey on local and DHC models in order to consider heat grids along with their hydraulic and thermodynamic characteristics as well as different supply temperature levels of renewable energies (e.g. solar thermal, geothermal, heat pumps) to feed into the heat grid.

Models that neither described an energy system nor thermodynamic characteristics were classified as *others*.

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[1] Although SIMUL_E.NET focuses on bi-lateral energy trades on the DHC network, it also considers supply technologies and is therefore also listed under energy system models.

[2] District ECA is described as an energy system model in the classification form. However, being a district energy concept adviser, District ECA is listed separately in the category others.

[3] Exergy Pass Online is also described as a static thermodynamic model in the classification form. However, being a tool for the exergy analysis of the resource consumption of buildings, Exergy Pass Online is listed separately in the category others.

2.1 Energy System Models

In the following five energy system models are briefly presented (including two models that also contain thermodynamic aspects): EnergyPLAN, KOPTI, TIMES Local, LowEx-CAT and SIMUL_E.Net.

EnergyPLAN

EnergyPLAN, developed at Aalborg University in 2000, is a simulation and optimization model to run a regional to national future energy system in which the sectors power, heat and transport are linked via e.g. power to heat or e-mobility. To integrate intermittent renewable energy, the model is run in an hourly resolution with a time horizon of one year. The energy system (installed capacities, energy demand) needs to be set up by the user. The usage of technologies is optimized with the goal of minimum costs or minimum fuel use. An example for model application is a heating and cooling strategy for Europe in 2014 (Connolly 2014).

KOPTI

KOPTI (Kokonais OPTImointimalli , *engl. overall optimization model*) is an optimization model that was developed at VTT Technical Research Centre of Finland in 2003. It optimizes the run of a local energy system with the focus on the DHC system (e.g. CHP, storages) including the power system under the goal of minimum costs of electricity, heat and cooling. Market heat and electricity prices are considered in order to sell utilization options to the market (Koreneff 2014 b). KOPTI has been applied to ‘estimate the value of distributed generation for the different power system actors’ (Koreneff 2014 b).

TIMES Local

TIMES Local, based on the TIMES[4] model generator, is an optimization model, that was developed at the Institute of Energy Economics and Rational Energy Use (IER) at the University of Stuttgart in 2010. The focus lies on the heating market to optimize a local energy system with the target of minimizing the total system costs under defined constraints (e.g. CO_2-reduction). TIMES Local enables the energetic, ecological and economic analysis of the heat and power supply of a city taking into account the settlement and building structure of urban districts and its heat supply structure and alternatives. After the initial used technologies, the development of energy demand, energy prices, etc. are set, the model decides which technologies are used to achieve a cost minimum solution. The model’s time horizon can be set up to several decades on an

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[4] TIMES was developed within a working group of ETSAP; International Energy Agency in the 1990s.

hourly basis[5]. An example for model application is the German research project ‘EnEff: Stadt Ludwigsburg-Grünbühl/Sonnenberg’ in 2013 (Blesl 2014 a). Further details on TIMES Local are presented in the subtask A report (Blesl, Stehle 2017).

LowEx-CAT

LowEx-CAT, **Low Ex**ergy – **C**luster **A**nalysis **T**ool, is a TRNSYS-based simulation model that is under development by the Fraunhofer Institute for Building Physics (IBP) (now in Fraunhofer IWES). The focus of the model is the integration of low temperature technologies (e.g. solar collectors, heat pumps) to supply districts by DH grids (considering grid temperature, design and optimization of the grid distribution). The time horizon ranges from season to less than five years on an hourly basis. After the design of the district energy system is set up, the operation of an energy system is optimized by minimizing the degradation of exergy (exergy efficiency). This enables the analysis of the energy and exergy impact of different energy strategies (Kallert, Schneider 2014). The model is applied to several generic case studies (e.g. Kallert 2017). Further descriptions of LowEx-CAT can be found in the subtask A report (Blesl, Stehle 2017).

SIMUL_E.NET

SIMUL_E.NET, under development by the Korea Institute of Energy Research (KIER), is a simulation model based on Simulink for new concepts of DHC grids. It focuses on bi-literal heat trade between consumers and supplier or between prosumers on a small grid with several buildings connected. To realize these bi-lateral heat trades different variants of Energy Management System (EMS) algorithms are analyzed (Im 2014). Aside the grid and demand of buildings, supply and storage technologies are considered. Moreover, different pipe configurations or temperature levels can be taken into account to improve the efficiency of the grid. The model’s time horizon is one year with an hourly resolution. References for model use do not exist so far.

2.2 Thermodynamic Models

In the following four heat grid models are described briefly: HeatNET, NET Local, spHeat and Termis.

HeatNET

HeatNET, developed by the VTT Technical Research Centre of Finland since 2005, is a district heating network simulation model with a dynamic temperature calculation. Time step and length of a simulation can be defined by the user, the most common simulation being a period of one year with a time step of one hour. As input the user enters network

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[5] with 576 time slices: 24 (hours) x 12 (months) x 2 (workday and weekend)

related data (e.g. structure, pipe size, feed temperatures, capacities) and defines the heat demand for heating and domestic hot water, as well as a set of consumer specific information such as e.g. heat exchanger parameters. The simulation of a district cooling network can also be performed by HeatNET. The model determines ‘flows, heat losses and temperatures and pressures around the network’(Rämä 2014). The model was applied for ‘network calculation[s] in Finnish DH-systems, e.g. Hyvinkää building exhibition area case’ (Rämä 2014).

NET Local

NET Local is a static temperature simulation model for DHC grids that has been developed at the IER at Stuttgart University since 2012. It analyzes the influence of heat demand on different temperature levels of representative buildings or consumers on the grid temperature and possible supply types. This involves the evaluation of return line supply. Moreover, the temperature change along the district heating grid with a regional resolution is taken into consideration. The impact of different technology options, such as solar heat integration, can also be considered. The calculation is carried out for one single demand point with the output of the DHC grid temperature for feed line and return line in different supply regions. Model results are used to verify optimization results of TIMES Local. Examples of model application are ‘Ludwigsburg Grünbühl’ and ‘Stuttgart West’ (Blesl 2014 b).

spHeat

spHeat is a quasi-dynamic heat grid model that was developed at the University of Applied Science (HFT) Stuttgart in 2012. It performs a ‘hydraulic and thermal simulation of networks with multiple loop topologies’ focusing ‘on the impact of the spatial/geographic load distribution on the performance of the network’ (Hassine 2014). The time horizon ranges from single design point to one year on an hourly basis. The model’s outputs are pressure and temperature profiles along the grid. Aside structural improvement potentials spHeat can ‘analyse different solar thermal energy supply strategies’ (Hassine 2014). spHeat was used for case studies such as ‘Scharnhauser Park Ostfildern’ and ‘Sonnenberg Ludwigsburg’, both in Germany. More details on spHeat can be found in the subtask A report (Blesl, Stehle 2017).

Termis

Termis is a heat grid model that was developed by Schneider Electric Danmark A/S in 1988. It is able to perform both simulation and optimization of heat grids both in planning and operation stage. However, heat generation technologies such as CHP are not considered. The time horizon ranges from single design point to one year with a time resolution from 10 to 60 minutes or one year with twelve typical discrete loads. Termis does also use real-time data (SCADA) to optimize grid parameters. The model output is among other things the ‘process state of the network and network components’ (i.e. power, pressure, flow, temperature) (Outgaard 2014). Termis is not only used by e.g. Danish consulting companies for design analysis or real time operation and optimization, but also for projects in France, Spain, USA, Poland, Serbia, China, etc.

2.3 Others

Aside from energy system and thermodynamic models, other analytical approaches were considered in the following three models: Firstly, District ECA is described as a district energy concept tool for the assessment of the energy potential and efficiency. Secondly, a heuristic times series model to forecast heat and electricity loads is regarded: EME Forecast. Finally, a tool for the exergy analysis of the resource consumption of buildings: Exergy Pass Online.

District ECA

District Energy **C**oncept **A**dviser is a static and myopic simulation model that was developed by the Fraunhofer Institute for Building Physics (IBP) as part of EnEff:Stadt in 2012 (Fraunhofer IBP 2014, ANNEX 51 2014). It is used by urban planners during the first stage of district concepts. After the specification of the buildings and the energy supply, the final energy consumption and CO_2 emissions are calculated. This allows comparing different energy concepts such as local district heating or the use of gas condensing boilers. The regarded time horizon is one year with the same time resolution. Moreover, District ECA enables comparisons in energy use of a district with the national average and provides examples for energy efficient districts. Examples for model applications can be found in the German programme ‘EnEff: Stadt’, e.g. Stuttgart-Burgholzhof, Munich-Lilienstraße, Karlsruhe-Rintheim (Fraunhofer IBP 2014).

EME Forecast

Developed by VTT in 2002, EME Forecast is a heuristic time series model to forecast electricity and heat loads on an hourly basis. The time horizon can be adapted from single design point to ten years. It is used by VTT and a Finnish power supplier. The approach is to assume that a behavior of a variable in future (e.g. DH load) can be derived from historic data. Therefore, the model needs both history and forecast values of a variable that the DH load is dependent of (such as the outside temperature) and history values of the DH load itself. The forecasted hourly DH load is received by performing a heuristic time series approach combined with a dynamic regression analysis (Koreneff 2014 a). A reference for model use are the end-user load forecasts by Koreneff in 2010.

Exergy Pass Online

Exergy Pass Online, developed by Richtvert | Energy Systems Consultancy from 2012-2015, is a tool for the exergy-based assessment of the resource consumption of buildings. The model enables the comparison of buildings a ‘to find the optimal combination of heating, cooling, insulation standard and electrical appliances’ in order to reduce resource consumption and GHG emissions (Jentsch 2015). After specification of the building’s energy demand and selection of the supply technologies, the model’s output is a predefined result report (exergy pass) on resource consumption (exergy), energy, GHG emissions and costs. In contrast to energy passes, the exergy pass takes energy quality[6] into consideration and uses exergy as an assessment parameter for the evaluation of energy systems in the building sector. The exergy pass[7] will be used in the EU project SUSMILK (Jentsch 2015).

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[6] Energy quality can be described as the usefulness of energy. Its unit is the maximum share of energy that can be converted into electricity (Exergieausweis 2015).

[7] Only German version available.

3 Evaluation of Planning Tools for District Heating

Based on the descriptions of local and DHC models in the last section, an evaluation of them is carried out to identify integral and innovative approaches for low temperature heat supply at local level. This chapter concludes with the requirements for the development of a simplified tool for DH, which is presented in next chapter.

3.1 Methodology

To evaluate the survey results on local and DHC models, the gathered input is filtered and classified in seven categories (and some in subcategories):

- analytical approach,
- target audience,
- level of detail (geographical scope, time horizon),
- model type (simulation, optimization),
- demand sectors,
- final energy consumption and
- solution variables.

Each of these categories includes distinguishing features which apply (green box), partly apply (yellow box) or do not apply (grey box) to the analyzed model (see Table 3 and Table 4).

The category analytical approach distinguishes between *energy system model*, *thermodynamic model* and *other*. Target audience includes *municipal authorities*, *professional planners* and *research & development / internal use*. The level of detail is split into the subcategories geographical scope (from *DHC supplied area* to *region*) and time horizon (*single design point*, *<= 1 year*, *> 1 year*). The model type is classified in *simulation*, *investment/design optimization* and *operation optimization*. Whereas demand sectors were divided into *households*, *commercial*, *industry* and *transportation*, final energy consumption was allocated to *electricity*, *heat* and *transport*. As solution variables *costs*, *energy*, *exergy* and *temperature* were used.

3.2 Evaluation and Comparison of Planning Tools for District Heating

The classification results of the twelve analyzed planning tools are summarized in Table 3 and Table 4. Each tool is assessed in the above-named seven categories (e.g. analytical approach), whereby green boxes in Table 3 and Table 4 mean ‘true’, yellow boxes ‘partly true’ and grey boxes ‘false’. For example, District ECA is suitable for the target audience of municipal authorities. In contrast, boxes in grey mean that a model is not suitable, e.g. TIMES Local does not address to municipal authorities.

The classification results, as shown in Table 3 and Table 4 can also be used for a more accurate application of the planning tools for DH.

In the following each category is evaluated with regard to the analyzed planning tools.

Analytical Approach

The analytical approach differentiates between *energy system models*, *thermodynamic models* and *other* models. Energy system models cover the energy supply chain from primary energy to useful energy, whereas thermodynamic models focus on heat networks. Models that did not fit in this classification were classified as others. As energy system models were classified: EnergyPLAN, KOPTI, TIMES Local, LowEx-CAT and SIMUL_E.NET. The latter two can also be described as thermodynamic models. Thermodynamic only models are HeatNET, NET Local, spHeat and Termis. Classified as other were District ECA, EME Forecast and Exergy Pass Online.

Target Audience

The target audience can be divided into *municipal authorities*, *professional planners* and *internal use, R & D.* The following models address among others municipal authorities and can thus be described as rather user-friendly tools: EnergyPLAN, Termis, District ECA, EME Forecast, Exergy Pass Online. Anyway, most tools require at least trained users, especially tools used by researchers or professional planners.

Level of Detail: Geographical Scope

The geographical scope ranges from *DHC supplied area*, *street*, *district*, *city* to a whole *region*. Some tools are flexible in the geographic scope (e.g. TIMES Local, Termis, EME Forecast). Basically, most tools can cover a city level or parts of it (aside from EnergyPLAN that only models region and bigger). A DHC supplied area can be taken into account by most of the tools: the energy system models KOPTI and TIMES Local and the thermodynamic models HeatNET, NET Local, spHeat, Termis, as well as District ECA, EME Forecast and Exergy Pass Online.

Level of Detail: Time Horizon

For the time horizon a distinction is made between *single design point* (no time horizon), *≤ 1 year*, *> 1 year*. A time horizon of up to one year can be modelled by any of the analyzed planning tools (except for NET Local). Longer time horizons are covered in TIMES Local (few decades), LowEx-CAT (less than five years), Termis (more than ten years) and EME Forecast (up to ten years). A few tools model all three categories of time horizon: Termis and EME Forecast. Both NET Local and Exergy Pass Online consider a single design point.

Model Type

The models were classified in *simulation* and *optimization,* whereas optimization is further divided into *investment/design optimization* and *operation optimization*. Simulation is part of any of the selected planning tools[8]. However, optimization is only performed by some of the considered tools. Investment/design optimization is both modelled in the energy system model TIMES Local and in the heat grid model Termis. Operation optimization is performed by EnergyPLAN, KOPTI, LowEx-CAT and Termis. To some degree TIMES Local also optimizes the operation of an energy system, as the operational planning is optimized within investment/design optimization.

Demand Categories

The demand categories comprise *households, commercial, industry* and *transportation*. The analyzed planning tools focus mainly on two demand categories: Households and commercial. Industry is only taken into account by EnergyPLAN, Termis and District ECA (with some limitations KOPTI and HeatNET that do cover the DHC sector, not further specifying if industry is included). Transportation plays a minor role, as it is only included in one of twelve planning tools (EnergyPLAN).

Final Energy Consumption

Final energy consumption is divided into *electricity*, *heat* and *transport*. As planning tools for district heating are assessed, any of the investigated tools focuses on respectively includes the heat sector. Electricity is considered to some degree in any of the selected energy system models (e.g. although LowEx-CAT considers electricity using back-up heaters for DHW preparation, electricity generation is not taken into account). The transport sector is of minor importance for district heating and thus only considered in one tool (EnergyPLAN).

Variables

The analyzed solution variables are *costs*, *energy*, *exergy* and *temperature*. If they are sorted by their frequency, the following ranking results: energy (almost in all of the tools), costs (half of the tools), temperature (five) and exergy (only in two). This ranking indicates the relevance of the particular variable for local and DHC modelers. If grid

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[8] Even though TIMES Local is primarily an optimization tool, it can also perform simulations if there are no degrees of freedom (such as investment decisions).

models are not considered, it shows that different temperature levels (e.g. low temperature DH) are rarely modelled yet in system analytical approaches (apart from LowEx-CAT).

Overall evaluation

The evaluation of the analyzed local and DHC planning tools has shown some promising approaches for low temperature DH. For example, LowEx-CAT combines an energy system approach with a heat network approach to display exergy efficiency. However, technology detail is limited to five technologies.

To conclude, there was no planning tool found to be appropriate for the objective of a simplified, integrated tool for low temperature DH to enable analyses and comparisons of different heat supply options in terms of energy, ecology and costs. Based on the evaluation results, a simplified planning tool for DH is developed and presented in chapter 4.

Further evaluation results of existing local and DHC models can be found in (Blesl, Stehle 2017).

Table 3: Evaluation of twelve planning tools on the basis of the classification categories (green = true, yellow = partly true, grey = false) (part 1).

Classification Categories			**Energy PLAN**	**KOPTI**	**TIMES Local**	**LowEx-CAT**	**SIMUL_ E.NET**	**Heat NET**	**NET Local**	**spHeat**	**Termis**	**District ECA**	**EME Forecast**	**Exergy Pass Online**
Analytical Approach		Energy System Model	🟩	🟩	🟩	🟩	🟩							
		Thermodynamic Model				🟩	🟩	🟩	🟩	🟩	🟩			
		Other										🟩	🟩	🟩
Target Audience		Municipal Authorities	🟩								🟩	🟩	🟩	🟩
		Professional Planners	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩
		Internal Use, R & D	🟩		🟩	🟩	🟩	🟩	🟩	🟩				
Level of Detail	Geographical Scope	Region	🟩	🟩	🟩		🟩	🟩			🟩		🟩	
		City		🟩	🟩			🟩			🟩		🟩	
		District		🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩
		Street			🟩		🟩				🟩		🟩	🟩
		DHC Supplied Area		🟩	🟩	🟨		🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Time Horizon	Single Design Point		🟩					🟩	🟩	🟩		🟩	🟩
		<= 1 Year	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	
		> 1 Year			🟩	🟩					🟩		🟩	

Table 4: Evaluation of twelve planning tools on the basis of the classification categories (green = true, yellow = partly true, grey = false) (part 2).

Classification Categories			**Energy PLAN**	**KOPTI**	**TIMES Local**	**LowEx-CAT**	**SIMUL_ E.NET**	**Heat NET**	**NET Local**	**spHeat**	**Termis**	**District ECA**	**EME Forecast**	**Exergy Pass Online**
Model Type	Simulation Model		🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Optimization Model	Investment/ Design	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜
		Operation	🟩	🟩	🟨	🟩	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜
Demand Categories	Households		🟩	🟨 DHC, Electricity	🟩	🟩	🟩	🟨 DHC Sector	🟩	🟩	🟩	🟩	🟩	🟩
	Commercial		🟩	⬜	🟩	⬜	🟩	⬜	🟩	🟩	🟩	🟩	🟩	🟩
	Industry		🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	🟩	⬜	⬜
	Transportation		🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Final Energy Consumption	Electricity		🟩	🟩	🟨	🟨	🟩	⬜	⬜	⬜	⬜	🟩	🟩	🟩
	Heat		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Transport		🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Variables	Costs		🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	🟩	⬜	⬜	🟩
	Energy		🟩	🟩	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	🟩
	Exergy		⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩
	Temperature		⬜	⬜	⬜	🟩	⬜	🟩	🟩	🟩	🟩	⬜	⬜	⬜

3.3 Summarizing Evaluation of DH Planning Tools

For the identification of integral and innovative approaches to low temperature heat supply at municipal level, an overview of existing approaches is provided as part of this subtask.

Initially, a classification form for local and DHC models was developed and distributed to tool developers. After obtaining the completed classification forms from the Annex TS1 participants, the planning tools were assessed in seven categories: analytical approach (energy system model, thermodynamic model, other), target group of users (municipal authorities, professional planners, R&D), level of detail (geographical scope, time horizon), model type (simulation, optimization), demand categories (housholds, commerical, industry, transportation), final energy consumption (electricity, heat, transport) and used variables (costs, energy, exergy, temperature).

The planning tools were divided according to their analytical approach into energy system and thermodynamic models. Energy system models cover the whole energy supply chain from primary energy sources to useful energy. However, they usually do not consider the thermodynamics of district heating (e.g. interactions on thermodynamic level of processes with requirements of predefined temperature levels). Thermodynamic models are thus required. There are also planning tools that did not fit into the categories stated above. These were classified as ‘others’ (e.g. EME Forecast).

For the target group of municipal authorities planning tools, such as District ECA and Exergy Pass Online, come into consideration, as they are described as user-friendly and do not require trained users, unlike most other tools do.

Regarding the geographical scale, it is not only important at which level of detail a planning tool can be applied for, but also to know its range of scales. From the analyzed tools three tools can model all different scales from a whole region over city, district and street (neighborhood) to a DHC supplied area (e.g. TIMES Local, Termis, EME Forecast). Apart from streets, this also accounts for KOPTI and HeatNET.

Another aspect of detail are the modelled time horizon and the time resolution. Most of the considered tools cover a time horizon of one year and less with an hourly resolution. Longer time horizons are modeled in TIMES Local (few decades), LowEx-CAT (less than five years), Termis (more than ten years) and EME Forecast (up to ten years).

Simulation is part of any of the selected planning tools. However, optimization is only performed by five tools: EnergyPLAN, KOPTI, LowEx-CAT (all three operation optimization of an energy system); TIMES Local (investment/design optimization of an energy system); and Termis (operation and investment/design optimization of a heat grid).

As for the demand categories the focus lies on households and commercial buildings. Only some tools include the industry sector (EnergyPLAN, Termis and District ECA) and only one does the transportation sector (EnergyPLAN).

For an integrated approach of DH energy systems including CHP, the heat and power sector need to be considered. However, as planning tools for DH focus on the heat sector, the power sector plays a minor role or is not modeled at all. Transportation is usually not considered.

Even though costs are the essential variable to assess investments (e.g. into new or existing grids), an economic approach is only applied by about half of the selected planning tools for DH: EnergyPLAN, KOPTI, TIMES Local, SIMUL_E.NET, Exergy Pass Online, (meanwhile LowEx-CAT) and Termis as the only grid model.

The integration of renewable energy sources into the energy system is another important aspect of low temperature DH. Both EnergyPLAN and LowEx-CAT focus on this aspect. However, EnergyPLAN does not consider heat grids or urban districts - in contrast to LowEx-CAT.

For the evaluation of low temperature DH, the variable temperature is needed. Apart from the heat grid models only LowEx-CAT is able to include the temperature in simulations. LowEx-CAT, classified as both an energy system and thermodynamic model, seems to be a suitable tool for the evaluation of low temperature DH. However, the level of detail is limited to five technologies and costs were not taken into account (at the time of the evaluation, but are meanwhile considered).

The building stock as well as the development of urban districts is not considered by most of the selected planning tools. A promising approach is followed by District ECA, as it includes buildings along with their characteristics and energy demand as well as the supply at a district level. However, performing future scenarios is not possible, as well as modeling heat grids or entire energy systems.

To conclude, the evaluation has shown some promising approaches for low temperature DH. However, there was none found to be appropriate for the objective of a simplified, holistic tool for low-ex DH.

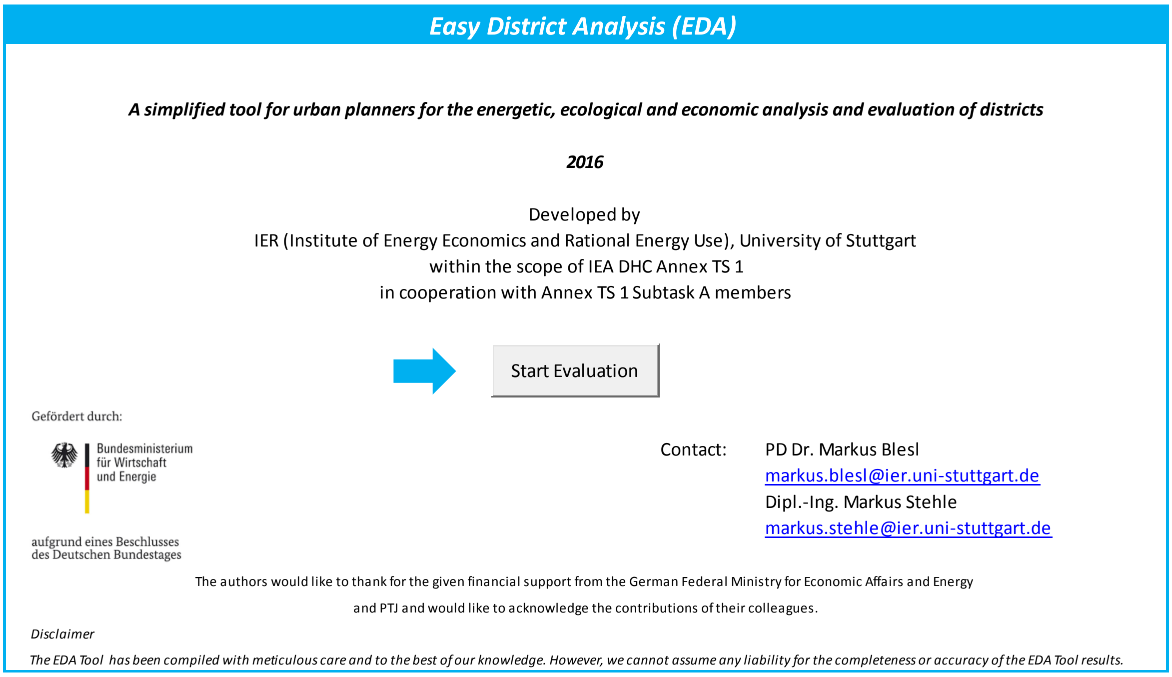
By evaluating the selected planning tools for DH schemes, requirements can be derived for the development of a simplified planning tool.

A simplified tool should be simplified in terms of user-friendliness, but not mandatory in the complexity of calculation. Due to the intermittent availability of solar energy, the analysis and evaluation of solar integration into heating grids along with thermal storage requires a high temporal resolution to cover the use of DH technologies. Aside the technical consideration, also economic conditions need to be covered by a simplified tool in high temporal resolution. For example, revenues for cogeneration from electricity feed vary due to hourly changing electricity prices. Thus, for economic optimization algorithms have to be developed to find the optimal use of technologies depending on economic conditions. Aside the comparison of technical and economic operation of DH systems, different temperature levels of standard and low temperature DH need to be analyzed with regard to the impact on carbon emissions and costs.

All in all, the simplified tool should enable the analysis and evaluation of different DH supply variants (e.g. solar integration), temperatures (standard DH vs. low temperature), operation modes (technical vs. economic operation) on the use of technologies and the related impact on carbon emissions and costs. Such a simplified planning tool is presented in the next section.

4 Easy District Analysis (EDA) – A Simplified Tool

The EDA tool (Easy District Analysis) is an excel-based simulation tool that has been developed by the IER (Institute of Energy Economics and Rational Use of Energy) at the University of Stuttgart (Germany) in cooperation with Annex TS 1 Subtask A members. It enables the easy analysis of districts in terms of energy consumption, CO_2 emissions and costs of different DH supply options.



Easy District Analysis (EDA)

A simplified tool for urban planners for the energetic, ecological and economic analysis and evaluation of districts

2016

Developed by
IER (Institute of Energy Economics and Rational Energy Use), University of Stuttgart
within the scope of IEA DHC Annex TS 1
in cooperation with Annex TS 1 Subtask A members

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Disclaimer

The EDA Tool has been compiled with meticulous care and to the best of our knowledge. However, we cannot assume any liability for the completeness or accuracy of the EDA Tool results.

Figure 1: Start tab of the Excel VBA –based tool Easy District Analysis (EDA)

The development of the simplified tool EDA involved several steps. Starting with an evaluation of existing planning tools for district heating to derive requirements for a simplified tool (see last chapter), the methodical approach for the EDA-Tool was developed, implemented into Excel VBA, and applied to a case study.

4.1 Description and Methodical Approach

Easy District Analysis (EDA) is a simplified tool for urban planners and utilities for the energetic, ecological and economic analysis as well as the evaluation of districts with regard to low temperature heating to enable comparisons with other heat supply options.

EDA is a simplified tool rather in terms of the required amount of input data than in terms of the complexity of calculation. This means with little information on a district energy system that is being analyzed, an annual load profile is generated in hourly resolution (taking simultaneity of demand into account) to enable the integration of intermittent renewable energy (e.g. solar thermal) into the district heating system and to consider storage options. As a simplified tool EDA addresses mainly to urban planners, it is intended to be used in the pre-planning phase of a district energy system.

The approach of EDA for the analysis and evaluation of energy supply options for districts is sketched in Figure 2. Basically, the tool covers the urban energy system from supply side (energy carriers, technologies) over distribution (heat grid) to demand side (annual demand). As input the user selects supply technologies (e.g. CHP plus peak boiler) and energy carriers (e.g. natural gas), grid parameters (e.g. supply and return temperature) as well as the considered district (e.g. 100 multi-family houses). EDA calculates then a load profile (space heat, domestic hot water), optimizes the use of technologies in technical or economic terms and enables the evaluation and comparison of different district heat supply options in terms of primary energy, final energy, CO_2 emissions and costs.

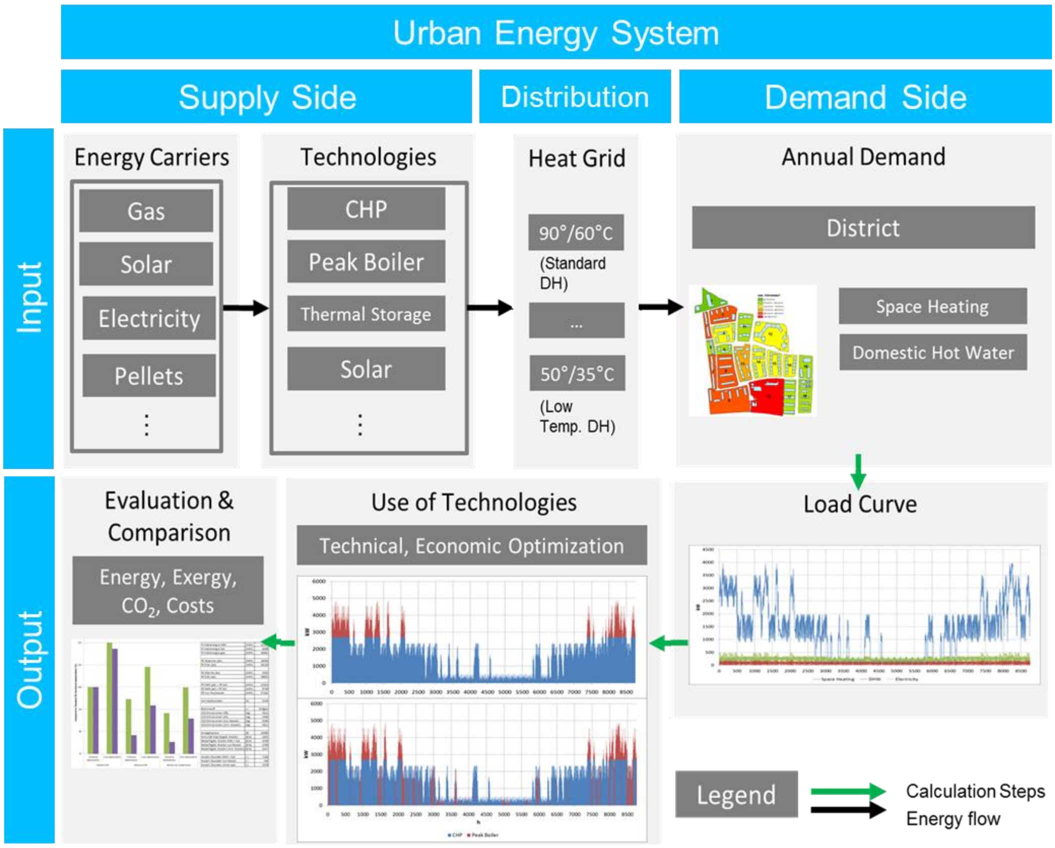


Figure 2: Approach for a simplified tool to evaluate energy supply options for districts: Easy District Analysis (EDA)

The structure of the EDA tool can be divided into input that follows the DH supply chain (supply, distribution, demand) and into output as the tool results (load curve, use of technologies, evaluation & comparison) (see Figure 2).

Supply Four different DH supply options can be compared. The basic option is a DH system of cogeneration with boiler. These technologies can be compared for technical and economic operation. Furthermore, this basic DH system can be complemented by DH storage to decouple heat demand temporally from the supply side and to enable the use of cogeneration depending on electricity prices. To decarbonize DH supply, solar integration with thermal storage can be taken into account, whereby solar thermal energy is supplied by a ground-mounted solar collector field. The supply tasks of technologies in EDA include both space heat and domestic hot water (DHW).

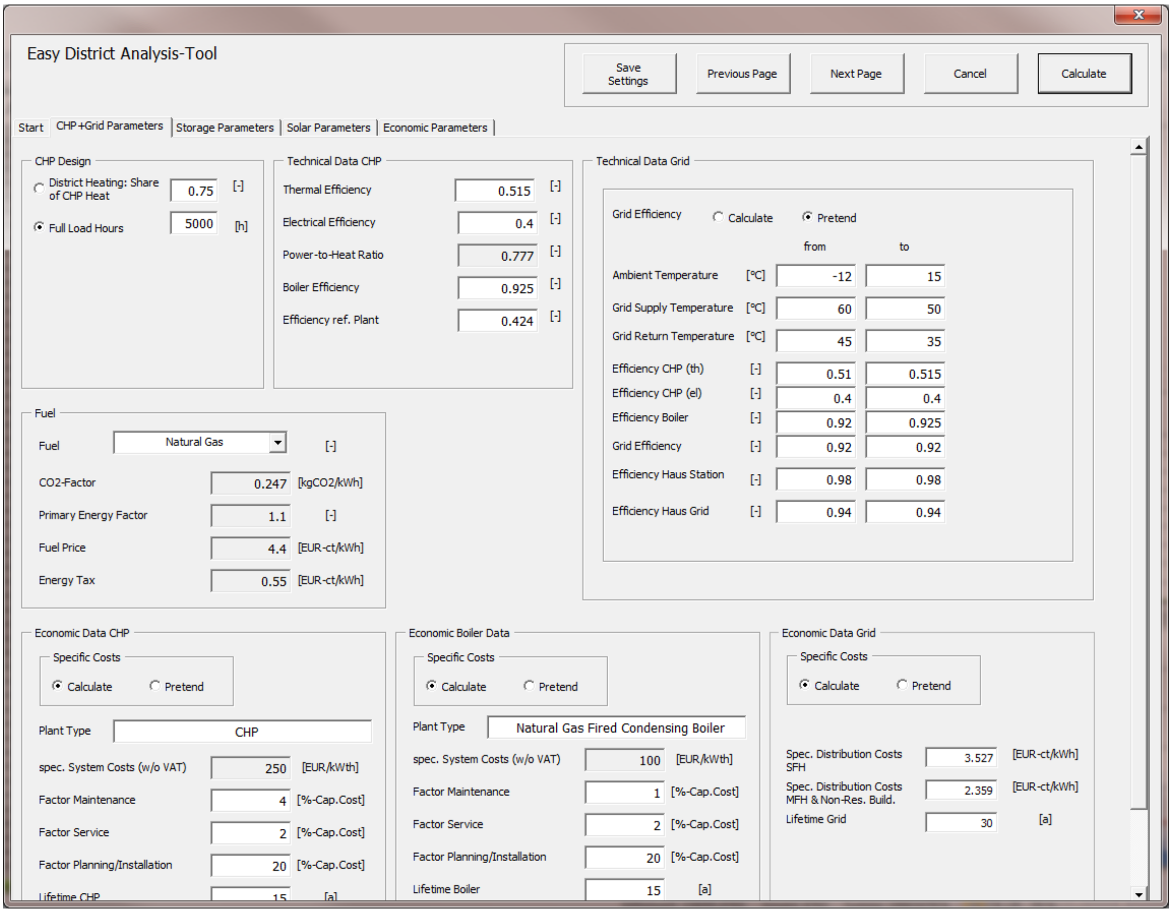
For all technologies technical (e.g. efficiency), economic (e.g. fuel price, specific costs per kW) and ecological (e.g. CO_2 emissions) parameters can be set. The design of the CHP plant is calculated on preset full load hours or on the share of CHP heat on DH supply, and on the load profile of the present district.

Distribution For the distribution of the supplied heat, different temperature levels for the supply and return line can be chosen, e.g. from standard DH (90°C/60°C) to low temperature DH (50°C/35°C), to analyze the impacts on resource consumption and CO_2 emissions. The efficiency of supply technologies is dependent on the chosen supply and return temperature.

Demand Space heat and domestic hot water (DHW) are taken into account for the analysis of district heating supply. The calculation of space heat demand is based on the number and net floor area of different building types (single-family, multi-family houses, non-residential buildings) and associated specific space heat demands per m^2 which can be differentiated according to construction years. DHW demand is estimated by number of inhabitants or number of residential units and specific DHW demands per person/unit. There is no diffentiation for different temperature level requirements of DHW and space heat. Technologies on the consumer side (e.g. thermal storage inside buildings) are not part of EDA. However, different technologies of heat transfer on the demand side, such as low temperature radiators, can be considered by different efficiencies of the heat distribution inside the buildings.

After the inputs are set, the EDA tool provides mainly three outputs: annual load curve in hourly resolution, the optimized use of technologies, and the evaluation and comparison of different district heat supply variants.

Load Curve Based on the annual demand data, a load curve in hourly resolution is generated. As demand of multiple consumers shows a certain degree of simultaneity, a shift algorithm based on a Gaussian distribution was developed to consider equalizing effects on the load profile (see more on load profiles in chapter 4.2).



CHP Design
○ District Heating: Share of CHP Heat 0.75 [-]
● Full Load Hours 5000 [h]

Technical Data CHP
Thermal Efficiency 0.515 [-]
Electrical Efficiency 0.4 [-]
Power-to-Heat Ratio 0.777 [-]
Boiler Efficiency 0.925 [-]
Efficiency ref. Plant 0.424 [-]

Fuel
Fuel Natural Gas [-]
CO2-Factor 0.247 [kgCO2/kWh]
Primary Energy Factor 1.1 [-]
Fuel Price 4.4 [EUR-ct/kWh]
Energy Tax 0.55 [EUR-ct/kWh]

Technical Data Grid
Grid Efficiency ○ Calculate ● Pretend

		from	to
Ambient Temperature	[°C]	-12	15
Grid Supply Temperature	[°C]	60	50
Grid Return Temperature	[°C]	45	35
Efficiency CHP (th)	[-]	0.51	0.515
Efficiency CHP (el)	[-]	0.4	0.4
Efficiency Boiler	[-]	0.92	0.925
Grid Efficiency	[-]	0.92	0.92
Efficiency Haus Station	[-]	0.98	0.98
Efficiency Haus Grid	[-]	0.94	0.94

Economic Data CHP
Specific Costs ● Calculate ○ Pretend
Plant Type CHP
spec. System Costs (w/o VAT) 250 [EUR/kWth]
Factor Maintenance 4 [%-Cap.Cost]
Factor Service 2 [%-Cap.Cost]
Factor Planning/Installation 20 [%-Cap.Cost]
Lifetime CHP 15 [a]

Economic Boiler Data
Specific Costs ● Calculate ○ Pretend
Plant Type Natural Gas Fired Condensing Boiler
spec. System Costs (w/o VAT) 100 [EUR/kWth]
Factor Maintenance 1 [%-Cap.Cost]
Factor Service 2 [%-Cap.Cost]
Factor Planning/Installation 20 [%-Cap.Cost]
Lifetime Boiler 15 [a]

Economic Data Grid
Specific Costs ● Calculate ○ Pretend
Spec. Distribution Costs SFH 3.527 [EUR-ct/kWh]
Spec. Distribution Costs MFH & Non-Res. Build. 2.359 [EUR-ct/kWh]
Lifetime Grid 30 [a]

Figure 3: Input parameters for CHP plant, boiler and the grid can be set in the EDA-Tool

Use of Technologies Based on the generated load profile and set input parameters (e.g. full load hours), the design of the cogeneration plant with boiler is calculated. The design of other technologies, such as a ground-mounted solar collector field and respectively or district heating storage, can be preset or based on design criteria (e.g. solar fraction or m³, kWh). The DH storage can be used as short-term storage (e.g. daily storage of CHP heat to profit from high electricity prices at the EPEX SPOT[9]) or long-term storage (e.g. seasonal storage of solar energy) depending on the design of the storage.

The use of these technology capacities can be optimized technically and economically. Technical optimization means minimizing primary energy consumption by maximizing the use of efficient technologies such as CHP. Economic optimization means to run a heat supply system in a cost minimal mode by considering the revenues from CHP electricity, which depend on changing electricity prices.

Evaluation & Comparison Different DH supply technologies (e.g. CHP with peak boiler) and operation modes (technical operation, economic operation) for a given demand can be evaluated and compared in terms of the use of technologies and related primary energy

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[9] European Power Exchange for power spot trading

consumption, carbon emissions and costs. As technology parameters can be set by the user both an existing and new DH system can be evaluated.

The EDA tool enables the analysis of four different supply options:

(1) Technical operation of cogeneration with boiler (TechOp)

(2) Economic operation of cogeneration with boiler (EconOp)

(3) Economic operation complemented by DH storage (EconOp+Storage)

(4) Economic operation with solar integration and DH storage (EconOp+Storage+Solar)

Technical operation (1) and economic operation (2-4) differ in the goal of optimizing the use of technologies: Whereas technical operation involves minimizing primary energy consumption by maximizing the use of efficient technologies (e.g. cogeneration), economic operation means to operate the technologies at marginal costs (which depend on e.g. the revenues from CHP electricity feed). As a result technical operation leads to minimal carbon emissions and economic operation to minimal operation costs.

In case of economic operation (4) of solar DH with storage, solar energy is given priority over cogeneration, although marginal costs of cogeneration might sometimes be lower (e.g. during high electricty prices).

Aside the evaluation and comparison of different DH supply options and operation modes in terms of primary energy consumption, carbon emissions or heat production costs, the effect of solar integration on the use of DH technologies (e.g. cogeneration, boiler) can also be assessed.

4.2 Load Profile Generator

The methodical approach for the generation of load profiles differs for residential and non-residential buildings. In the following the generation of load profile for residential buildings is described (for the description of load profiles for non-residential buildings see subtask A report (Blesl, Stehle 2017)).

Residential Buildings

The EDA tool distinguishes between two types of residential buildings: single-family and multi-family houses. As energy demand of buildings fluctuates depending on the season of a year (summer, winter, transition), weather (sunny, cloudy) and consumer pattern (workdays, Sundays) ten different typical days are defined as shown in Table 5.

Table 5: Classification of typical days (according to VDI 4655)

Season	Workday [W] (based on calendar)		Sunday [S] (based on calendar)	
	Fine [H] (Average cloud amount <5/8)	Cloudy [B] (Average cloud amount ≥5/8)	Fine [H] (Average cloud amount <5/8)	Cloudy [B] (Average cloud amount ≥5/8)
Summer [S] ($T_{average}$>15°C)	SWX		SSX	
Transition [Ü] ($T_{average}$=5°C…15°C)	ÜWH	ÜWB	ÜSH	ÜSB
Winter [W] ($T_{average}$<5°C)	WWH	WWB	WSH	WSB

Typical days represent typical load profiles of space heat, domestic hot water and electricity demand of single-family and multi-family houses, whereby 15 climate zones in Germany are differentiated. The energy demand (space heat, domestic hot water, electricity) of a typical day is basically calculated with the annual demand and with an energy demand factor for the typical day, which is given by the VDI guideline 4655 (VDI 4655 2008) for the different buildings types and climate zones in Germany. For domestic hot water and electricity demand the number of persons (for single-family houses) or the number of flats (for multi-family houses) is also taken into account (see formulas (4-1) - (4-3)):

$$Q_{Heat,Typical\ Day} = Q_{Heat,a} * F_{Heat,Typical\ Day} \tag{4-1}$$

$$Q_{DHW,Typical\ Day} = Q_{DHW,a}(\frac{1}{365} + N_{Pers\ /\ Flat} * F_{DHW,Typical\ Day}) \tag{4-2}$$

$$W_{Electr,Typical\ Day} = W_{Electr,a}(\frac{1}{365} + N_{Pers\ /\ Flat} * F_{Electricity,Typical\ Day}) \tag{4-3}$$

with

Q_{Heat}: Space heating demand [kWh]

Q_{TWW}: Domestic hot water demand [kWh]

W_{Electr}: Electricity demand [kWh]

$F_{Typical\ Day}$: Energy demand factor of a typical day [-]

N_{Pers}: Number of persons (single-family house)

N_{Flat}: Number of flats (multi-family house)

To arrange these typical days chronologically within a year, weather data on cloud coverage and ambient temperature are used from test reference years (TRY) provided by the German Weather Service (DWD). An hourly resolution is obtained when the demand of a typical day is multiplied by a normalized hourly value, which is given by the VDI guideline 4655 depending on climate region and building type.

By means of this information an annual load profile is generated in an hourly resolution for one building. As demand of multiple consumers does not happen in simultaneity, load profiles cannot be simply added up. Simultaneity factors that consider the simultaneity of demand for space heat, domestic hot water and electricity are therefore considered.

$$gf = \frac{\sum P(t_{max})}{\sum P_C} \qquad with\ gf = [0 \ldots 1] \tag{4-4}$$

with

gf:	Simultaneity Factor
$P(t_{max})$:	Maximum requested performance within a year
P_C:	Performance, if all consumers would demand the maximum performance simultaneously

As simultaneity factors relate on the maximum requested performance [kW] within a year (see formula (4-4)), they provide no detail on the hourly distribution of demand [kWh] of multiple consumers. Therefore, a shift algorithm was developed to consider equalizing effects on the load profile (see formula (4-5)). Based on a Gaussian probability distribution, the demand of one hour is shifted to other hours (from minus twelve to plus twelve) assuming that a shift of few hours is more likely than a shift of several hours. The variance of the Gaussian distribution was derived from the simultaneity factor, depending on the number and kind of consumers. The shift algorithm can be seen in formula (4-5), whereby gf_h is a weighting factor for the load shift from minus twelve to plus twelve hours (see formula (4-5)).

$$Load_{h,shift} = \sum_{h=-12}^{h=-1} Load_h * gf_{h+24} + \sum_{h=0}^{h=12} Load_h * gf_h \tag{4-5}$$

The weighting factor gf_h can be described as follows:

$$gf_h = \frac{N_{SFH,MFH,NRB}}{\sqrt{2\pi * \sigma^2}} * e^{-\frac{h^2}{2\sigma^2}} \tag{4-6}$$

with

$N_{SFH,MFH,NRB}$:	Number of single-family houses, multi-family houses, non-residential buildings
h:	Shift in hours
σ^2:	Variance

As a result an annual load profile for different kinds of demands and buildings is generated in hourly resolution taking simultaneity of demand of multiple consumers into account.

4.3 Optimization of the Use of Heat Supply Technologies

The optimization of the operation of different DH technologies can be performed by the EDA tool in two ways: technical and economic optimization.

Technical operation means to maximize the use of efficient technologies (such as cogeneration) in order to minimize primary energy consumption, although this might involve higher operation costs.

Economic optimization leads to cost-minimal operation of DH technologies, although this might involve higher primary energy consumption and greenhouse gas emissions. The hourly cost-effective mode of operation depends on fuel costs (that are assumed to remain unchanged within a year), varying efficiencies (dependent on supply temperature levels) and varying revenues from power production. For example, in Germany according to the combined heat and power law 2016 (KWKG 2016) electricity fed into the grid produced by CHP plants greater than 100 kW_{el} need to be traded directly (e.g. on the power exchange EPEX SPOT[10]). Therefore, operation costs of cogeneration depend on the varying electricity prices. Moreover, cogeneration electricity receives financial support, unless the electricity prices are negative. For negative electricity prices (e.g. during periods of high renewable power generation), the operation of a CHP unit can become less economic than the single operation of a boiler (see Figure 4). This might be more often the case in the future, as negative electricity prices at the European Power Exchange (EPEX) are expected to become more frequent.

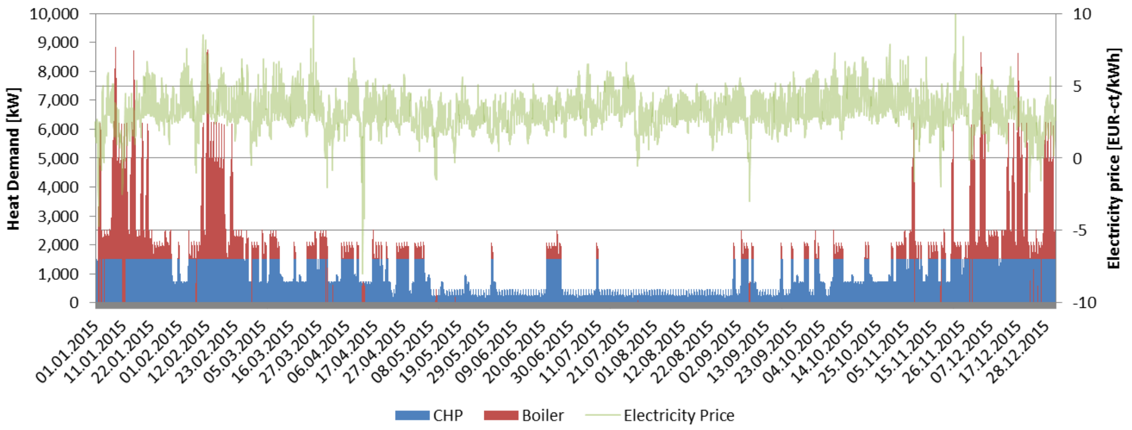

Figure 4: Economic operation – use of technologies depending on the occurence of negative electricity prices (green line, right axis)

A flow chart in Figure 5 describes the decisions that the EDA tool has to undergo in order to identify the cost minimum operation of a DH system (CHP and boiler). Three decisions are made along the program sequence: Electricity price negative or not (green), heat load

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[10] European Power Exchange for power spot trading

higher than thermal output of the CHP unit or not (blue) and costs of CHP and peak boiler greater than costs of boiler only or not (orange).

For negative electricity prices the operation costs of the CHP plant are higher than the boiler operation costs. Thus, the boiler only supplies heat to the grid. If the electricity price is not negative, the next branch asks if the heat load of the grid is greater than the maximum thermal output of the CHP unit. If not, the CHP unit is not operated under full load, which influences the cost calculation. This involves e.g. revenues from CHP bonus, grid usage costs, energy tax and fuel price. If the operation costs of a “CHP+Boiler” system are greater than the “Boiler only” system, the heat supply is then only operated by the boiler.

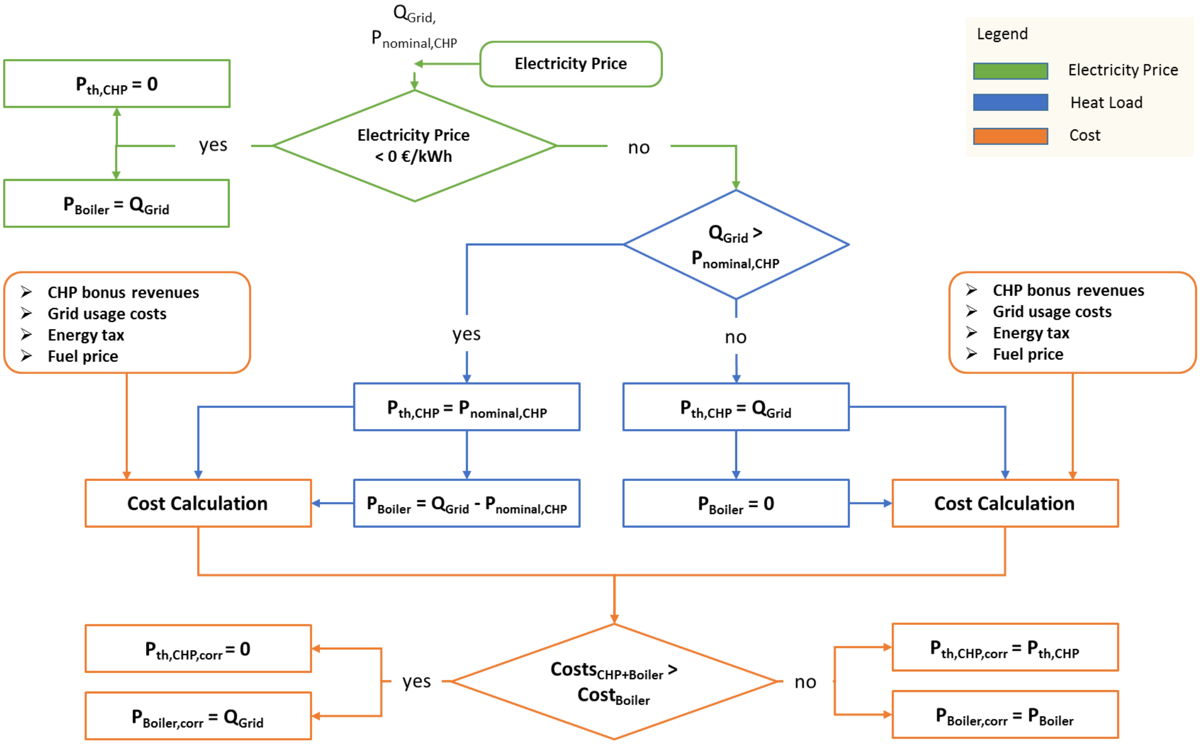

Figure 5: Flow chart in case of economic optimization

4.4 Application of EDA in a Case Study

In the present case study a district heating (DH) system of a cogeneration plant and a boiler is considered to supply about 140 multi-family houses (based on the data description of (Pietruschka et al 2016)). Two aspects are analyzed: grid temperatures (standard DH vs. low temperature DH) and the operation mode (technical vs. economic operation) of a DH system.

The aim is to find out what impact has a decrease of grid temperatures and the operation mode on carbon emissions, the use of technologies and costs of the DH system.

The motivation for low temperature DH is that a reduction of temperatures compared to standard DH involves higher efficiencies along the district energy system resulting in falling primary energy consumption and carbon emissions. Low temperature can be used, because high temperature levels are often not required for the supply of space heating and domestic hot water. For instance, radiators only need temperatures between 55°C and 90°C, panel heating between 35°C and 45°C and floor heating systems between 25°C and 35°C. Moreover, low temperature DH allows the easy integration of renewable energy and opens up new potentials of low energy supply (such as solar thermal and geothermal energy or waste energy).

For the present case study of an urban district of 140 multi-family houses two scenarios are analyzed in the following:

(1) It is distinguished between technical (TechOp) and economic operation (EconOp) of DH to analyze the impact of economic conditions on carbon emissions.
(2) The impact of solar integration on the use of DH technologies, carbon emissions and costs (EconOp+Storage+Solar) is analyzed compared to (TechOp).

Furthermore, for both scenarios a distinction is made between standard DH and low temperature DH. They are both operated with flexible supply temperatures that depend on the ambient temperature:

- Standard DH: supply from 90°C to 70°C / return from 60°C to 55°C
- Low temperature DH: supply from 60°C to 50°C / return from 45°C to 35°C

The operation optimization of the use of technologies is performed for German baseload electricity prices in 2015 and for the German CHP bonus (KWKG 2016). Although full-costs analysis takes temporal development of prices (e.g. the expiration of CHP bonus after 30,000 full load hours) into account, the operation optimization is limited to the economic conditions of the year 2015 (German CHP bonus, German electricity baseload prices, etc.).

A listing of all assumptions and inputs as well as further scenarios can be found in the subtask A report (Blesl, Stehle 2017).

TechOp vs. EconOp

A comparison of relative CO_2 emissions between standard DH (left) and low temperature DH (right) is shown in Figure 6. As reference serves the case of standard DH in technical operation mode. Carbon emissions are allocated according to the exergy method (left column) and to the power bonus method (right column).

Technical operation (TechOp) and economic operation (EconOp) play a different role in carbon emissions. Due to the economic situation (e.g. declining electricity baseload prices for electricity feed from cogeneration) the CO_2 reduction potential of DH is not exploited to the possible extent. However, the economic operation mode can perform better in carbon emissions if grid temperatures are decreased. Compared to technical operation of standard DH, low temperature DH in economic operation can even save up to 13 % of CO_2 emissions. Thus, low temperature DH can contribute to climate protection even under economic conditions. The comparison also shows for TechOp a possible carbon reduction potential of low temperature DH of up to 15 % for the present case study.

These values apply to operation optimization under consideration of the German CHP bonus. However, as the German CHP bonus is limited to 30,000 full load hours, it can be expected that carbon emissions of economic operation will then rise significantly.

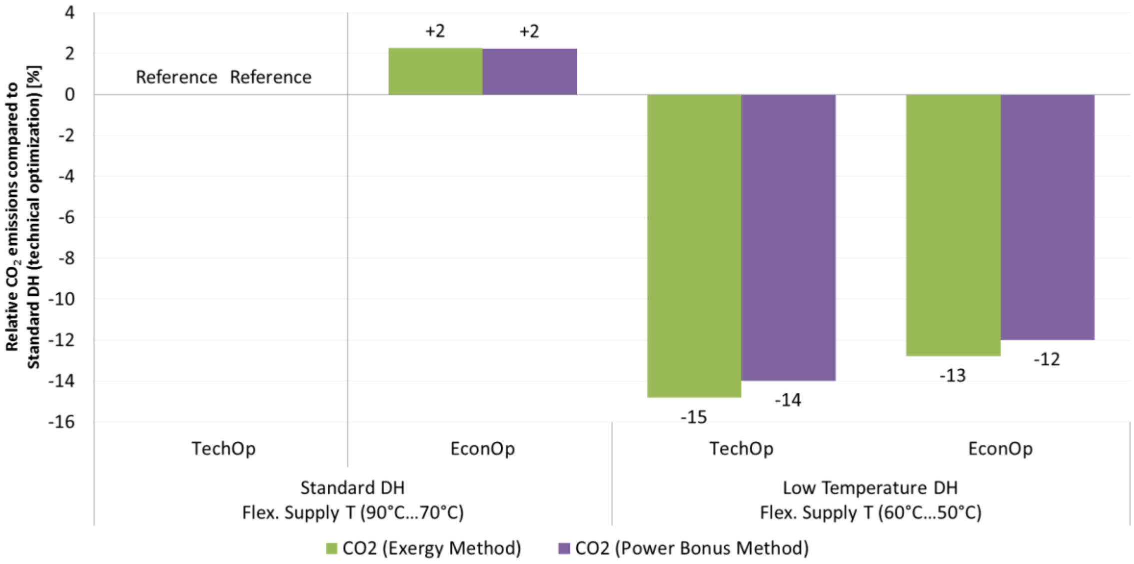

Figure 6: CO_2 emissions for standard DH (left) and low temperature DH (right) compared to standard DH for technical operation (consideration of CHP bonus) depending on the allocation method.

TechOp vs. EconOp+Storage+Solar

The independency of DH supply from the used energy source enables the use of climate-friendly technologies, such as solar thermal energy. The integration of solar thermal energy into the DH system causes feedback on the use of the DH supply technologies. Two DH systems are compared in the following: cogeneration plant with boiler in technical operation (TechOp) and cogeneration plant with boiler along with solar integration and thermal storage in economic operation (EconOp+Storage+Solar). The cogeneration plant is designed on 5,000 full load hours for the case of technical operation. The collector surface is set at 10,000 m² (corresponds to solar fraction of round 30 % in case of standard DH). For the design of the DH storage 3.5 m³ per m² solar collector are assumed resulting in a total capacity of 35,000 m³. Still the capacity might not be enough to store all of the provided solar energy (e.g. for standard DH: about 9 % of solar energy can not be used; low temperature DH: 26 %).

Figure 7 shows the impact of solar integration on the use of the cogeneration plant. In case of standard DH the share of cogeneration on DH supply drops from 66 % to 40 % respectively the full load hours decline from 5,000 to 3,000. For low temperature DH the declines are even higher: the full load hours are nearly halving from 5,000 to 2,600. However, the share of solar energy increases to 35 % for low temperature DH instead of 27 % for standard DH. To decouple demand and solar availability, most of solar energy is stored in the seasonal storage.

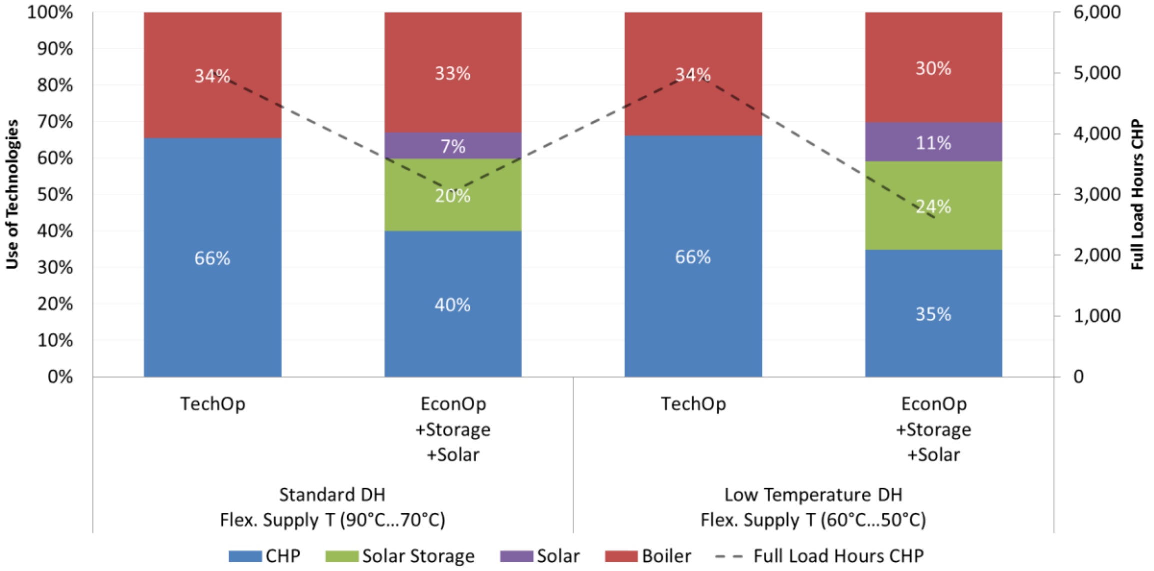

Figure 7: Use of technologies for DH supply in case of standard DH (left) and low temperature DH (right) and number of full load hours of the cogeneration plant (dashed line)

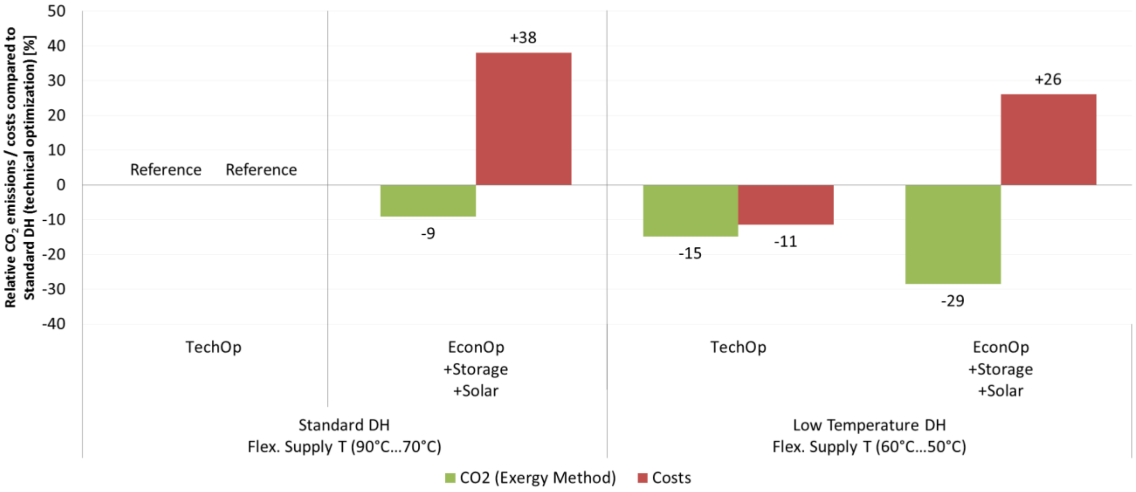

Figure 8: CO_2 emissions (green) and costs (red) for standard DH (left) and low temperature DH (right) compared to standard DH for technical operation

The effect of the shift in the use of technologies on carbon emissions and costs of DH needs to be analyzed. A lower usage of cogeneration results in fewer revenues from electricity feed. On the other hand, fuel costs are decreased as solar radiation is free of charge. As solar energy mostly replaces cogeneration, carbon savings are not as high as expected. In reality, CO_2 savings are higher as boilers are not only used for peak load, but also for low loads in summer.

The quantitative effects of solar integration into the DH system for the present case study are shown in Figure 8. In case of standard DH solar integration with storage involves higher costs (+ 38 %), but saves up to 9 % of carbon emissions compared to technical operation.

Compared to standard DH, decarbonization involves fewer costs (+ 26 % instead of + 38 %) with low temperature DH. The reduction of carbon emissions is standing out with round 30 % compared to round 10 % of solar integration for standard DH. Due to lower temperatures solar yield from the collector field is increased by 45 % from 370 kWh/m² (standard DH) to about 540 kWh/m² (low temperature DH). This is not only explained by lower collector heat losses, but also by an increasing period of solar thermal feed (+ 32 % hours of solar feed) as lower grid supply temperatures are easier achieved. Moreover, low temperature DH increases the solar fraction of DH supply. Due to higher efficiencies of solar collectors, storage capacities in m³ need to be designed larger per m² collector surface or vice versa, for a given storage capacity less collector surface is required. Thus, above presented cost benefits would be higher, if the design of the collector field would be adjusted to reduce solar excess heat (that can not be further stored).

In conclusion, the case study has shown that low temperature DH can be a key approach to decarbonize DH supply. The trend for rising carbon emissions of CHP DH supply (due to economic conditions) can be countered by low temperature DH even in economic operation, as less CO_2 emissions are released compared to standard DH in technical, CO_2-optimal operation (in case of CHP bonus). Furthermore, low temperature DH with solar integration does not only increase carbon savings (e.g. due to increased solar yield and solar fraction), but also decreases costs of solar DH compared to standard DH. However, solar DH still involves - despite free of charge solar energy - additional costs compared to TechOp for the present case study.

4.5 Conclusion and Outlook

The Easy District Analysis (EDA) tool was developed on the basis of requirements for a simplified DH planning tool that were derived from a survey on local and DHC models.

The target group of EDA are urban planners and utilities, and it is intended to be used in the pre-planning phase of a district energy system. The focus of the EDA tool lies on the evaluation of the impact of different grid temperatures (e.g. standard DH vs. low temperature DH) and of different operation modes (technical vs. economic operation) on the use of DH technologies, primary energy consumption, carbon emissions and heat production costs.

To enable the easy district analysis, a load curve of space heat and domestic hot water is generated. The design of the cogeneration plant and boiler is based on the load curve and preset full load hours. Solar collector surface can be designed on e.g. solar fraction. After the capacities of technologies are calculated, the use of different DH supply options can be compared in terms of technical and economic operation. Technical operation leads to minimum carbon emissions, whereas economic operation means the hourly cost-effective operation of DH technologies based on fuel costs and varying revenues from electricity feed. Economic conditions, such as the development of the electricity baseload price, hinder the realization of the carbon mitigation potential of CHP DH supply to its full extent.

A case study applied to a district with 140 multi-family houses has shown that low temperature DH can play a key role in the decarbonization of DH supply. On the one hand, the trend of rising carbon emissions in CHP DH supply due to economic conditions can be countered by low temperature DH (with CHP bonus). With higher efficiencies for low temperature DH, carbon emissions are up to 13 % fewer for economic operation compared to standard DH in technical operation (with CHP bonus). On the other hand, compared to standard DH, low temperature DH can boost solar DH in terms of yield and solar fraction significantly and thus, increase the carbon mitigation potential of solar-powered DH. Moreover, heat production costs are reduced considerably by low temperature DH compared to standard DH.

The future development of the EDA tool can cover several aspects. Although EDA performs a full-cost analysis over a chosen time horizon, operation optimization of the use of DH technologies is limited to the conditions of the base year so far (e.g. electricity prices, CHP bonus). Thus, the temporal development of economic parameters could be also included for the operation optimization (e.g. to evaluate the shift of the use of technologies, after the end of 30,000 full load hours with CHP bonus or to evaluate future falling electricity baseload prices). The EDA tool could also be extended by further renewable technologies (e.g. geothermal energy, industrial waste heat) and power-to-heat technologies (e.g. heating element, heat pump), in order to find out how these multiple energy sources can be combined to best use their potentials within the context of technical, economic and ecological aspects. Moreover, issues on self-consumption vs. feed of cogeneration electricity of a district could also be taken into account. Aside DH, district cooling (DC) could be implemented in the EDA tool to consider cooling demand.

To identify suitable districts for the realization of low temperature DH, the initial heating and building standard situation along with costs for change of energy carrier could be considered. Going beyond the simplified consideration of technologies in terms of annuities, competing DH and non-DH technologies could be compared from the actor's perspective. On the one hand, the investment decisions need to be disaggregated to different actors (instead of one aggregated homo oeconomicus actor). On the other hand, preferences of actors for attributes of technologies could be considered with a multi-attribute utility analysis approach. Based on technical and socio-economic criteria, districts could then be analyzed on their suitability to be changed to low temperature DH. Thus, a comprehensive comparison could be drawn between districts to identify qualified districts to start with the transformation to low temperature DH. Moreover, actor-specific measures could be identified to support the implementation of low temperature DH.

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