GridPenguin: A District Heating Network Simulator

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HOW TO ENABLE INTERREGIONAL HEAT EXCHANGE? - REVIEW AND ANALYSIS OF BEST PRACTICE EXAMPLES

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Abstract: With the net zero emissions target, the combined share of renewable sources in global DH networks should rise from 8% to 35% within the current decade. Here, long heat transmission networks (HTNs) that are connecting multiple industrial waste heat and other sustainable sources, one or more district heating networks and other major consumers, industrial process heat sinks, and/or heat storages, could play a significant role in future energy systems. HTNs will enable the interregional exchange of heat between different consumers and suppliers which would not be completely possible on a strictly local level. With the integration of seasonal storages and the diversification of the heat supply, the supply risks will be minimized, as dependencies on a single source are reduced. The focus of this paper is to give an overview on best practice examples of heat transmission networks. Therefore, interviews were conducted with relevant stakeholders. The findings of these interviews together with an analysis of the best practice examples are summarized and were clustered by strengths, weaknesses, opportunities and threats (SWOT).

Keywords: heat transmission networks; waste heat; district heating, SWOT analysis; expert interviews; best-practice analysis

1 INTRODUCTION

With space heating and hot water making up around 70% of energy consumption in residential sector in IEA member countries, district heating (DH) is a main factor in the decarbonization of the heating sector. [1]. On the other hand, the industrial sector is worldwide one of the main consumers of energy. In an industrialized country the industrial sector accounts for approximately one third of end energy consumption, of which two third are made up by the energy-intensive industry [2], [3]. One of the key synergies between the DH and the industry sector is the utilization of industrial waste heat in DH networks as well as the supply of (low temperature) process heat to industries via DH networks [4]. However, one of the challenges is, that DH networks not necessarily extend near the location of the waste heat source. Especially large-scale industries are often located outside the city and DH networks are usually concentrated in dense urban areas [5].

Heat transmission networks (HTN) connect multiple industrial waste heat and other sustainable sources, one or more DH networks, industrial process heat sinks, and storages. These interregional networks connect urban consumption centers and waste heat-intensive industrial sites and, in doing so, traverse areas with further heat sources and sinks. In [6] some findings on HTN have been elaborated. In general, the high systemic complexity of HTNs bears great risks and with today's energy mix, a broad use of HTNs is not considered realistic. However, rising energy prices make the use of HTNs more economically attractive. In addition, due to the high number of parties involved, the operation has to be clearly structured and network-specific codes and market rules have to be created. HTNs can offer heat cheaply in summer due to a high feed-in potential and low demand. Thus, temperature can also be increased as losses become less relevant. New heat sinks, such as a [absorption driven] district cooling, industrial process heat, smaller networks or seasonal storage can be supplied in this way.

The focus of this paper is to give an overview on international best practice examples of heat transmission networks and the input from key-stakeholders. The findings of the analysis are summarized and clustered by strengths, weaknesses, opportunities and threats (SWOT).

2 OVERVIEW OF BEST PRACTISES

The collection of best practice examples was done via a literature review and compiled to the best knowledge of the authors but does not claim to be complete. Here, a distinction is made between HTNs and unidirectional transport pipelines (HTP) that transport heat from a single supplier into a single DH network. Although such pipelines do not meet the definition of a HTNs, they were nevertheless included in the collection because conclusions can be drawn about cost and economic efficiency.

As a result, a total of 38 systems were identified, 10 of which were classified as HTNs as defined above. The identified HTP systems are listed in Table 1 with basic information (where available). Section 2.1 presents selected HTN systems with more detailed information (where available) and adds information from interviews with key stakeholders from Denmark and the Netherlands.

Table 1: Overview of selected best practice examples of HTP

Location	Country	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm	Sources
Dürnrohr - St. Pölten	AT	31	50	200	450 / 400	[7], [8]
Hallein-Salzburg	AT	19	7,5	80	200	[8], [9]
Sappi – Graz	AT	11	40	170	400	[10],[11],[12],[13]
Mellach – Graz	AT	19	300	600	650 / 550	[8], [14]
Donawitz - Trofaiach	AT	8,2		32	250	[15]
Arnoldstein - Villach	AT	16	19	100		[16]
Chur-Trimmis	CH	9,2	18	31		[17], [18]
Melnik-Prag	CZ	32	340		1200	[19], [20]
Lippendorf - Leipzig	DE	15	300	900	800	[21], [22]
Mannheim - Speyer	DE	21,2	48			[21]
Aachen	DE	20	85			[21]
Boxberg - Weißwasser	DE	16	40		400	[23]
Zolling-Airport Munich	DE	28	150		500 -350	[24]
Viborg	DK	12	58			[21]
Kozani	EL	16,5	137		500	[21]
Helsinki	FI	20	490		1.000	[21]
Turku	FI	25	340		800	[21]
Akranes	IS	62	60		400	[21]
Nesjavellir - Riykjavik	IS	27	290		800	[21]
Rozenburg - Rotterdam	NL	16,8	160		700	[25]
Tilburg	NL	25	170		500	[21]
Diemen - Almere	NL	8,5	260		700	[21]
Almere	NL	10	170		500	[21]
Oslo	NO	13	275		600	[21]
Oradea	RO	86,3	546			[21]
Linkoping - Mjolby	SE	28	25			[21]
Lindesberg	SE	17	26			[21]
Gothenburg - Kungälv	SE	22	19			[21]

2.1 Selected examples of long heat transmission networks (HTN)

2.1.1 Austria

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
Pöls - Judenburg Heat pipe Aichfeld	Bioenergie Aichfeld GmbH	Multiple DHN and directly connected large consumers	18	30	100	300 / 250
In the region of Judenburg, Fohnsdorf and Zeltweg, there are several DH networks which have been connected to a common DH pipeline supplied by waste heat from the pulp manufacturer since 2012, as investments in new technologies have created a significant amount of surplus heat. In addition to the large industrial waste heat supplier and several DH networks, biomass heating plants and large customers are also connected to the transmission line. [26], [8], [27]						

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
Innsbruck-Wattens	TIGAS, Hall AG, IKB	Many distributed suppliers and small-scale sinks	20		147,5	

Since 2012, the DH network in Innsbruck has been connected to the network in Wattens via a DH transmission network. The transmission network enables better utilization of existing supplier infrastructure as well as the integration of previously unused industrial waste heat (paper mill and foundry) along the route and has the advantage that a possible failure of one system can be compensated very easily. The supply structure is in general highly distributed. There is a partial separation between transmission system operator and distribution system operator. Along the route, in addition to large industrial waste heat sources, several biomass plants, a sewage treatment plant and natural gas boilers are connected. [28], [29]

2.1.2 Germany

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
Niederrhein	joint company (Dinslaken +Duisburg municipal utilities)	high share of renewable sources; primary energy factor <1%	40	550	786	400

The Niederrhein DH transmission network was built between 1980 and 1983 and enabled industrial waste heat to be used on a large scale. The network connects the municipalities of Voerde, Dinslaken, Duisburg and Moers and feeds into distribution networks of local DH networks. In addition to renewable and fossil heating plants and CHP units, industrial waste heat from steel production and the chemical industry is also fed into the DH network. [24], [30]

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
Ruhr	STEAG GmbH	first interregional DH network and first network supplied by CHP in Germany	42	430	1600	800 - 300

The Ruhr DH network was commissioned in 1978 and connects the distribution networks of Bottrop, Essen, Gelsenkirchen and Herten. The transmission network and the connected distribution networks are operated by STEAG Fernwärme. Much of the heat fed into the rail system comes from the Herne coal-fired power plant. This is to be taken off the grid in the fall of 2022 and replaced by a new combined-cycle gas turbine power plant, which is expected to result in annual CO2 savings of around 70,000 tons. In the future, further heat sources are to be developed in the area of industrial waste heat. [24], [31], [32]

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
Saar	Fernwärme-Verbund Saar GmbH	central energy control center, thermal storage for peak loads	35	686	943	600 / 500

The Saar DH line was designed in 1973, to secure the energy supply via local infrastructure. The first part of the Saar DH line was put into operation by Fernwärme-Verbund Saar GmbH at the end of 1979. Today, it connects the towns of Dillingen, Saarlouis, Völklingen and Saarbrücken. The largest supplier is a CHP and a gas engine. In addition, waste heat from industry is used. A heat storage with a volume of 22,800 m³ is installed to cover peak loads. In addition to supplying its own distribution networks, the company also supplies the networks of local municipal utilities and directly supplies large consumers. [24], [33], [34], [35]

2.1.3 Denmark

<table>
<tr><th>Location</th><th>Operator</th><th>Special Feature</th><th>Length in km</th><th>Thermal Capacity in MW_{th}</th><th>Heat Supply in GWh/a</th><th>Diameter in mm</th></tr>
<tr><td>Triangle Region Denmark</td><td>TVIS</td><td>innovative pricing model; process heat customers supplied by the grid</td><td>123</td><td></td><td>1658</td><td>660 - 220</td></tr>
<tr><td colspan="7">The operator of the transmission network in the Triangle region, TVIS, which is a non-profit organisation, was founded in 1983, as a cooperation of the four municipalities connected to the network, Fredericia, Kolding, Middelfart and Vejle. The first stage of expansion of the network was completed in 1987. The reason for building the network was the desire to provide an environmentally friendly and price-stable heat supply for the municipalities. With the transmission network, waste heat from a large refinery, a biomass power plant, which provides the main share of heat and a waste incineration plant could be used. The heat price consists of a fixed and a variable part to adjust to the seasonality of the heat demand as well as a component related to the return temperature. The network already includes a process heat customer, which is supplied. In the future, the waste heat of an electrolyzer will be included in the grid. [36], [37], [38].</td></tr>
<tr><td>Copenhagen</td><td>CTR, VEKS, Vestforbr-ænding</td><td>Load management; 3 transmission networks connected</td><td>189</td><td></td><td>8000</td><td></td></tr>
<tr><td colspan="7">The DH network in the Copenhagen region was established after the introduction of the Heat Supply Act in the 1980s. The municipalities in the region established two companies to ensure the transport of heat from the large central CHPs to the individual distribution networks: CTR and VEKS. The network was continuously expanded and the burning of coal was gradually replaced by increased use of gas and biomass. The transmission networks are interconnected, allowing optimized exchange of heat. Heat is sold to all supplied municipalities at a uniform pool price. This consists of a variable and a fixed component to account for seasonal fluctuations. In order to guarantee the cost-optimal use of the generation plants in the entire Copenhagen interconnected grid, the companies CTR, VEKS and HOFOR have together started a cooperation on load management, which enables a day-ahead and intra-day market for the heat suppliers, analogous to the electricity markets [39], [40], [41], [42], [43]</td></tr>
<tr><td>DH Fyn</td><td>Fjernvarme Fyn</td><td>Several small-scale industrial heat sources included; waste heat of a data center can be integrated via heat pump</td><td>120</td><td>950</td><td>3600</td><td></td></tr>
<tr><td colspan="7">The DH network on Funen around the city of Odense. In an effort to replace coal completely, olive pellets, originating from olive oil production in Spain are imported. Additionally, a focus is placed on industrial waste heat. The waste heat of a data center built in 2020 can be fed into the grid via heat pumps. The heat pump station was built by Fjernvarme Fyn and offers the possibility to integrate further waste into the grid. [44], [45], [46], [47]</td></tr>
</table>

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
DH Aarhus	Affald-Varme Aarhus	High investments and efforts for decarbonization; high share of biomass CHP (>70%); fossil share <1%			3100	
DH in Aarhus has also emerged from the energy crisis of 1973. In 1985 a new transmission line connected the heat supply of Aarhus. A main advantage is the higher security of supply. Over the past 10 years, investments of more than $270 million have been made to decarbonize Aarhus' DH system. This has involved installing an 80 MW electrically heated boiler, converting a 540 MW coal CHP to wood pellets, building a new 80 MW biomass CHP, and constructing 24 MW heat pumps that use seawater as a heat source. [48]						

For a more detailed analyses of the HTNs in Denmark, interviews have been performed with one operator of a HTN, and a representative of the DH association from Denmark, that can be summarized as follows:

Financing and business cases for long transmission networks: The large DH systems in Denmark emerged from the energy crisis of the 1970s, when the heating market was heavily dominated by expensive imported oil. Policymakers then promoted the use of industrial waste heat to supply heat to residential buildings. At the time of the planning of the transmission network in the 80's, the participating municipalities could only raise about 0.2% of their own funds for financing. A company was formed in which each municipality was liable for the entire debt. In this way, some international financiers could be attracted. In order to guarantee repayment within 20 years, the heat price was adjusted annually. Decisive factors for the establishment of DH transmission networks were the familiarity of the technology, the lack of private-sector interests, the agglomeration of urban and rural heat suppliers that do not produce at maximum capacity, the low-cost laying of pipes over agricultural land, and the possibility of price advantages in connecting networks and optimized use of combined production capacities. Financing and business model are based, among other things, on a tax increase on other fuels (electricity, gas...) in order to make more attractive the injection of CHP, waste incineration and industrial waste heat, on the lack of profit motive of operators and the interconnection of individual networks to increase cost-optimized heat production.

Cost structure for customers of long transmission networks: All distribution systems connected to the transmission network purchase heat from it at the same price. Since some systems operate with hourly prices, different load profiles of the distribution networks lead to different prices. In addition, there is a financial incentive to redirect the return temperature in the distribution network by making better use of the heat flow.

Industrial waste heat integration: While the supply of industrial waste heat is common in Denmark, the supply of process heat through a DH network is rare. Due to the lack of heavy industry in Denmark, the potential is rather low. Coupling of heating and cooling networks that can be used as heat sinks in summer is also not common. In order to protect the interests of the industry as well as the non-profit network operator regarding waste heat integration, the project was divided into 3 phases. In phase 1, the network operator pays the industry the substitution price of the network (price of the most expensive supplier). In phase 2, all profit goes to the network operator. In phase 3, the profits are divided according to the investments made by the partners. Decisive for success were mutual trust, open communication or calculation, and the division of the project into 3 phases.

Heating market: Varmelast was launched to curb the monopoly position of the large heat producers in Copenhagen. Varmelast enables load control of the heat network by means of the heat market, in which waste incineration plants participate in addition to the large CHPs. The producers submit their bids, the determined schedules are prepared every morning and adjusted four times a day.

Risk assessment, decarbonization and challenges: As the size of the network increases, the dependence on individual feeders decreases and thus the security of supply increases. Due to the diversified producer structure, the heat from the transmission network is independent of the price structure of a fuel (gas, electricity...). This provides price stability. With a well-developed DH system, decarbonization of a few sources is easier than retrofitting many individual systems. The investment decisions in a new transmission network, due to the decentralization of suppliers, is a major challenge in view of the upheavals in the energy system. The shift from large, central suppliers to smaller, decentralized suppliers also poses a great challenge for the control of the system.

2.1.4 Netherlands

Location	Operator	Special Feature	Length in km	Thermal Capacity in MW_{th}	Heat Supply in GWh/a	Diameter in mm
Rotterdem - Den Haag (planned)	Gasunie	Industrial waste heat from port of Rotterdam; geothermal potential will be integrated	23	250		700
To replace natural gas as the most important energy source for providing heat in buildings in the Netherlands, a plan has been developed for an extensive sustainable heating system in South Holland. As part of this heating system, the WarmtelinQ project will connect the DH network of The Hague with the network of Rotterdam starting in 2023. For this purpose, an underground pipeline will be built, connecting to an existing transport pipeline from the port of Rotterdam to the center of Rotterdam. The pipeline is being built and operated as an open network by the state network operator Gasunie. This means that the pipeline will be made available to all parties wishing to use it on the same terms. The supply of heat to end users is the responsibility of the energy suppliers. Waste heat from the port of Rotterdam is to be used primarily as heat sources. In the future, local geothermal potentials are also to be tapped as heat sources. [49]						

The Netherlands are one of the few countries, where a new HTN is planned to be build, so an interview has been done with a consultancy who did a detailed study on the prospective HTN. The interview can be summarized as follows:

Regional heat plan for South Holland: The Port of Rotterdam, the City of The Hague and surrounding are working on a large, interconnected heating network. Since the planning of a comprehensive heat network is complex, taking into account heat and temperature requirements, demand structure, route for pipelines, optimal merit order, hydraulics, etc., a comprehensive model was developed to represent this system as a digital twin.

Scenario analysis of the large, interconnected heat network (backbone): At the moment, the heat demand is currently mostly met from fossil sources. Possible heat sources include: Waste heat (Rotterdam port, hydrogen production, low temperature waste heat) and geothermal energy. The possible heat sinks include: Local heating networks (some need to be newly built). It was clear in the analysis, that the economic viability of the backbone depends on the number of heat customers. The analysis also considered of different scenarios, such as a "Maximum scenario": Heating demand covered by renewable heat from backbone, a "Isolated solution": All distribution networks individually tap suitable heat sources as well as an "optimal approach" lies in between (stranded assets have to be avoided).

WarmtelinQ: The connection between the port of Rotterdam to The Hague should be implemented with the WarmtelinQ project. For optimal planning, a digital twin is used to simulate the system in minute resolution. The digital twin will continue to be used in operation after the pipeline is completed to ensure optimal load control (heat merit order) and hydraulic integrity. Different risks has been identifies for the project, such as the short term utilization rate of the pipeline and its future development , the connection rates of new customers as well as the coverage of peak load capacities to be provided locally as a priority.

3 EVALUATION

3.1 Quantitative comparison

The identifies HTPs and HTN are analyzed in terms of key parameters. As it can be concluded from Table 2 below, HTNs are generally longer compared to HTPs. The average heat delivery of HTNs varies by a factor of about 8 compared to HTPs.

Table 2: Overview of the average properties of THNs and HTPs

Parameter	Average	HTN	HTP
Distance in km	32.3	62.2	22.7
Capacity in MW_{th}	221.8	482.7	163.8
Heat delivery in GWh_{th}/a	1422.1	2302.3	264.1
Specific investment cost in €/m	725.3	816.6	699.2
Linear power density in MW/km	8.8	10.7	8.4
Linear heat density in MWh/m·a	21.6	24.8	16.4

According to Figure 3-1, the relation between the supplied heat in HTNs (red squares) and the network length can be approximated by a rising power function with an exponent of about 1.75. HTPs (blue dots) do not follow a specific trend; Parameters of HTPs with lengths below 20 km vary to a larger extent. This graph shows that the specific amount of heat in GWh transported per kilometer is decreasing with increasing network length. This could lead to the conclusion that with less heat transported, less profit is generated by the DH network. This does not fit together with the "economy of scale" approach, where a system will become more profitable with increasing size. Further research has to be conducted to answer this trend.

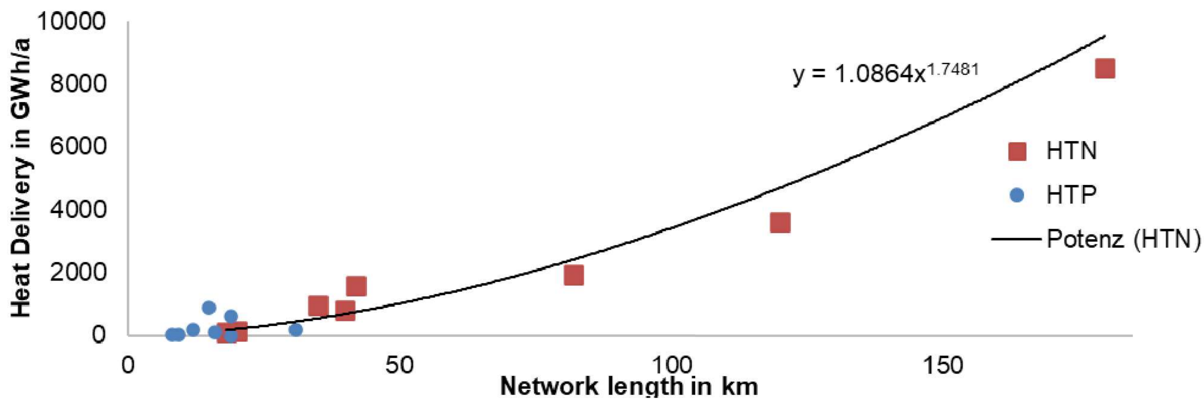

Figure 3-1: Comparison of supplied heat and network length for HTN and HTP

3.2 SWOT Analysis

Based on the findings from the literature review and interviews, an analysis of the strengths, weaknesses, opportunities, and threats (SWOT analysis) on HTNs was conducted, see Table 3.

Table 3: SWOT Analysis on long heat transfer networks1

Strengths	**Weaknesses**
• Enables optimal integration and utilization of regionally available heat sources that are not located directly nearby DH areas • Possibility of providing heating to customers outside metropolitan areas • Less dependence on individual suppliers due to the large number of connected suppliers; diversification of the heat supplier technologies used • Interconnection of individual networks enables cost-optimized heat supply, i.e. only the production plants with the lowest heat generation costs are operated • Resilient and price-stable heat supply for the connected communities possible • Promoting cooperation between municipalities and the optimal use of existing resources	• High infrastructure investment costs • High complexity, resulting in higher effort for planning and operation • High inertia for changes in system parameters (e.g. temperature changes) • a reduction of system temperatures in the HTN is only possible with corresponding changes in the distribution networks • Provision of peak load should be done at local level of distribution networks to keep peak load capacity in transmission network low, thus reducing variable heat costs • High need for coordination between different stakeholders: Heat suppliers, transport network operators and distribution network operators
Opportunities	**Threats**
• Affordable land for the integration of (seasonal) heat storage more likely available along the pathway of the HTN than in urban DH networks • Political commitment and correspondingly conducive legal and regulatory framework (e.g., tax reductions, subsidies for connection	• Utilization rate of the transmission pipeline and its future development are key parameters and may vary, depending on retrofitting rates, the will of local decision makers and other factors • Challenging investment decisions for new infrastructure in view of the general

[1] This SWOT analysis is not including factors related to DH in general, or to individual supply options, like waste heat; it is focussing specifically on factors related to HTNs

costs, connection obligations, etc.) promote the development and economic viability of infrastructure • Many participants could enable the establishment of a heat market analogous to the electricity market for the cost-optimal use of existing heat sources • Unstable energy prices favor the large-scale utilization of alternative heat sources; and HTN are sometimes the only possibility to use them efficiently in urban areas.	transition trends in the energy system (tendency for shifting from large centralized to small, decentralized and individual systems)

4 SUMMARY AND CONCLUSIONS

Within this paper, an assessment of international best practice examples regarding heat transmission networks (HTN) has been done. Based on literature research and interviews a SWOT – analysis was conducted.

Interest in HTNs is increasing nowadays, due to rising energy prices and several working examples. Larger networks, including seasonal storages and backup boilers can reduce supply risks and lead to price stability, due to a diversification of the heat supply portfolio.

Outlook: To further push the realization of HTNs in Austria, within the “HeatHighway” project different case studies are investigated. One of them is the Tyrolean “Inn valley”, where the potential is investigated of extending the existing HTN Innsbruck – Wattens towards the east. Literature research is conducted to identify potential heat sinks and sources today and in the future [50]. With the involvement of local stakeholders, the concept of the HTN east of Wattens will be evaluated. This will lead to a basic route and the concept will be evaluated with a techno-economic feasibility analysis.

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6 REFERENCES

[1] ‘District heating needs flexibility to navigate the energy transition – Analysis’, *IEA*. https://www.iea.org/commentaries/district-heating-needs-flexibility-to-navigate-the-energy-transition (accessed Aug. 24, 2022).
[2] ‘Energie in Österreich 2021 - Zahlen, Daten, Fakten’, p. 68.
[3] ‘eia_193_de.pdf’. Accessed: Aug. 24, 2022. [Online]. Available: https://nachhaltigwirtschaften.at/resources/nw_pdf/eia/eia_193_de.pdf
[4] ‘Industrielle Abwärmenutzung. Kurzstudie’, p. 44.
[5] Ralf-Roman Schmidt, Roman Geyer, and Pauline Lucas, ‘DISCUSSION PAPER The barriers to waste heat recovery and how to overcome them?’ Jun. 2020. [Online]. Available:

https://ec.europa.eu/futurium/en/system/files/ged/20200625_discussion_paper_v2_final.pdf
[6] S. Moser and S. Puschnigg, 'Supra-Regional District Heating Networks: A Missing Infrastructure for a Sustainable Energy System', *Energies*, vol. 14, no. 12, Art. no. 12, Jan. 2021, doi: 10.3390/en14123380.
[7] 'Da kommt die Wärme her', *Fernwärme St. Pölten*. https://www.fernwaerme-stp.at/fernwaerme/da-kommt-die-waerme-her/ (accessed Aug. 29, 2022).
[8] Moritz, Gerhard; Lechner, Herbert; Günter, Pauritsch; Lang, Bernhard; Jamek, Andrea; Zach, Franz, 'MACHBARKEITSSTUDIE zur Fernwärmetransportleitung St. Veit / Glan – Klagenfurt', 2013.
[9] 'Wärmeschiene Hallein - Salzburg mit Energiepreis ausgezeichnet', *OTS.at*. https://www.ots.at/presseaussendung/OTS_20050512_OTS0152/waermeschiene-hallein-salzburg-mit-energiepreis-ausgezeichnet (accessed Aug. 29, 2022).
[10] 'Fernwärme aus Gratkorn für Graz: Kooperationsprojekt gestartet', *MeinBezirk.at*, Nov. 10, 2017. https://www.meinbezirk.at/graz/c-lokales/fernwaerme-aus-gratkorn-fuer-graz-kooperationsprojekt-gestartet_a2312852 (accessed Aug. 29, 2022).
[11] '2019-Werk-Gratkorn-Umwelterklärung-(EMAS).pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://cdn-s3.sappi.com/s3fs-public/2019-Werk-Gratkorn-Umwelterkl%C3%A4rung-(EMAS).pdf
[12] admin, 'Bioenergiegruppe Startseite', *Bioenergie Gruppe*. https://www.bioenergiegruppe.at/ (accessed Aug. 29, 2022).
[13] 'Fernwärme in Graz'. https://www.energie-graz.at/egg/news/beitrag/knistern-tut`s-heute-nur-mehr-im-kachelofen (accessed Aug. 30, 2022).
[14] 'Kraftwerk Mellach wird wieder Fernwärme nach Graz liefern', *Inside Graz*, Mar. 16, 2021. https://www.inside-graz.at/umwelt/kraftwerk-mellach-fernwaerme-nach-graz-liefern.html (accessed Aug. 29, 2022).
[15] Philipp, 'Industrielle Abwärme für Trofaiach – Fachverband Gas Wärme', *Fernwärme*, Nov. 25, 2013. https://www.fernwaerme.at/industrielle-abwaerme-fur-trofaiach (accessed Aug. 29, 2022).
[16] 'Fernwärmelei-tung von Arnold-stein nach Villach', Sep. 06, 2018. https://www.5min.at/201809165441/fernwaermeleitung-von-arnoldstein-nach-villach/ (accessed Aug. 29, 2022).
[17] 'Derungs und Tremp - «Heisses Wasser statt warme Luft».pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://fernwaerme-chur.ch/wp-content/uploads/2021/06/jahresbericht-fernwarme-chur-2020.pdf
[18] 'jahresbericht-fernwaerme-chur-2019.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://fernwaerme-chur.ch/wp-content/uploads/2020/05/jahresbericht-fernwaerme-chur-2019.pdf
[19] D. Andrews *et al.*, *Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion*. 2012. doi: 10.2790/47209.
[20] S. Moser and S. Puschnigg, 'Supra-Regional District Heating Networks: A Missing Infrastructure for a Sustainable Energy System', *Energies*, vol. 14, no. 12, Art. no. 12, Jan. 2021, doi: 10.3390/en14123380.
[21] K. C. Kavvadias and S. Quoilin, 'Exploiting waste heat potential by long distance heat transmission: Design considerations and techno-economic assessment', *Applied Energy*, vol. 216, pp. 452–465, Apr. 2018, doi: 10.1016/j.apenergy.2018.02.080.
[22] 'Lippendorfer Fernwärme für Leipzig bis 2023'. https://www.stefanschroeter.com/653-lippendorfer-fernwaerme-fuer-leipzig-bis-2023.html#.Ywy_TNPP02x (accessed Aug. 29, 2022).
[23] 'Stadtwerke Weißwasser - Fernwärme für Weißwasser'. https://www.stadtwerke-weisswasser.de/privatkunden/unternehmen/25jahre/serie-historie-sww/fernwaerme-fuer-weisswasser (accessed Aug. 29, 2022).
[24] 'EnEff: Wärme Kostengünstiger Fernwärmetransport für den effektiven Ausbau der KWK. Prof. Dr.-Ing. Stefan Holler Statusseminar, 7. - PDF Free Download'. https://docplayer.org/41354452-Eneff-waerme-kostenguenstiger-

fernwaermetransport-fuer-den-effektiven-ausbau-der-kwk-prof-dr-ing-stefan-holler-statusseminar-7.html (accessed Aug. 29, 2022).
[25] 'Leiding over Noord - Visser & Smit Hanab'. https://www.vshanab.nl/nl/projecten/detail/leiding-over-noord (accessed Aug. 29, 2022).
[26] 'Energiebericht_Steiermark_2014_.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.technik.steiermark.at/cms/dokumente/12678764_146432123/21aa3edf/Energiebericht_Steiermark_2014_.pdf
[27] 'Q2 - Der Wäremvorteil aus Pöls - Fernwärmeversorgung'. http://www.xn--wrme-vorteil-gcb.at/de-fernwaermeversorgung-2.html (accessed Aug. 29, 2022).
[28] '11_hilber_vortrag.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://eventmaker.at/uploads/16600/downloads/11_hilber_vortrag.pdf
[29] 'tigas_gb20_web_3mb.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.tigas.at/uploads/tx_bh/tigas_gb20_web_3mb.pdf?mod=1643036164
[30] 'Fernwärmeversorgung Niederrhein GmbH - PDF Free Download'. https://docplayer.org/10239000-Fernwaermeversorgung-niederrhein-gmbh.html (accessed Aug. 29, 2022).
[31] 'Mit STEAG Fernwärme seit über 60 Jahren - PDF Free Download'. https://docplayer.org/213491126-Mit-steag-fernwaerme-seit-ueber-60-jahren.html (accessed Aug. 29, 2022).
[32] 'Historie', *Steag Fernwärme*. https://www.steag-fernwaerme.de/de/unternehmen/historie (accessed Aug. 30, 2022).
[33] 'FVS_Fernwaermeschiene.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.fvs.de/uploads/pics/FVS_Fernwaermeschiene.pdf
[34] 'FVS_Broschuere.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.fvs.de/uploads/pics/FVS_Broschuere.pdf
[35] 'Fernwärme - Verbund Saar GmbH', *Fernwärme - Verbund Saar GmbH*. https://www.fvs.de/de/ (accessed Aug. 30, 2022).
[36] 'TVIS | SAMMEN OM VARMEN'. https://www.tvis.net/gron-omstilling/ (accessed Aug. 29, 2022).
[37] 'TVIS' Årsberetning 2020 by TVISvarme - Issuu'. https://issuu.com/tonnekjaersvej11/docs/tvis_rsberetning2020 (accessed Aug. 29, 2022).
[38] 'SAV customers visit Fredericia district heating scheme'. https://www.sav-systems.com/news/sav-customers-visit-fredericia-district-heating-scheme/ (accessed Aug. 29, 2022).
[39] 'VEKS Aarsberetning 2020 UK.pdf'.
[40] 'Environmentally-friendly-District-heating-to-Greater-Copenhagen.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.ctr.dk/wp-content/uploads/2019/11/Environmentally-friendly-District-heating-to-Greater-Copenhagen.pdf
[41] 'District-heating-close-up.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.ctr.dk/wp-content/uploads/2019/11/District-heating-close-up.pdf
[42] S. Vestforbr, '50 Ledelsespåtegning 51 Den uafhængige revisors revisionspåtegning', p. 54, 2021.
[43] 'DISTRICT HEATING IN COPENHAGEN: ENERGY-EFFICIENT, LOW- CARBON, AND COST-EFFECTIVE - PDF Free Download'. https://docplayer.net/30952939-District-heating-in-copenhagen-energy-efficient-low-carbon-and-cost-effective.html (accessed Aug. 29, 2022).
[44] 'Hvad er din varme lavet af?' https://www.fjernvarmefyn.dk/viden/fjernvarme-er-miljoevenligt-nemt-og-billigt/hvad-er-din-varme-lavet-af/ (accessed Aug. 30, 2022).
[45] '2_Fjernvarme-Fyn-Heat-Recovery.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: http://grass-events.com/wp-content/uploads/2018/03/2_Fjernvarme-Fyn-Heat-Recovery.pdf

[46] 'Kim_WINTHER_-_FJERNVARME_FYN.pdf'. Accessed: Aug. 29, 2022. [Online]. Available: https://www.ehpcongress.org/archive-2019/wp-content/uploads/Kim_WINTHER_-_FJERNVARME_FYN.pdf
[47] '2_Fjernvarme-Fyn-Heat-Recovery.pdf'. Accessed: Aug. 30, 2022. [Online]. Available: http://grass-events.com/wp-content/uploads/2018/03/2_Fjernvarme-Fyn-Heat-Recovery.pdf
[48] M. B. M. Jensen, 'The Role of District Heating in District Energy', p. 27.
[49] 'Veelgestelde vragen', *WarmtelinQ*. https://www.warmtelinq.nl/veelgestelde-vragen (accessed Aug. 29, 2022).
[50] Nicolas Oliver Marx, Stefan Reuter, and Ralf-Roman Schmidt, 'Heat Highway: Decarbonizing the heating supply via regional district heating networks, Status-Quo for a case study in Tyrol';, presented at the 8th International Conference on Smart Energy Systems, Aalborg, Denmark, Sep. 2022.
[51] 'Heat Highway – Energieinstitut an der Johannes Kepler Universität Linz'. https://energieinstitut-linz.at/portfolio-item/heat_highway/ (accessed Aug. 30, 2022).