

# Integration of renewable energies into district heating networks: A bibliometric analysis

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## Abstract

In Europe, buildings are responsible for circa. 40% of total energy consumption and 36% of total greenhouse gas emissions. The use of energy in buildings is therefore important to improve their performance, with the aim of saving energy and reducing environmental impact. In recent years, the gradual introduction of clean energy systems in buildings has been increasingly encouraged or even required by public authorities. District heating networks integrating totally or partially of renewable energies have proved to be an important technology to address efficiency in building-related energy production and distribution. This article presents a bibliometric analysis of these types of district heating networks over the last 33 years and provide a methodological framework for bibliographic research in the investigation of district heating network. In this way, Researchers could use them as a guide to identify appropriate journals and sources to consult in this area of research.

**Keywords:** Renewable energy, District heating network, Building, Analysis, Bibliometric analysis

## I. INTRODUCTION

The European Directive 2012/27/EU encourages the use of a clean energy share into district heating and cooling networks [1]. The RepowerEU was also recently introduced in order to increase energy savings and to reach EU energy autonomy. Solar energy can make a relevant contribution to this objective, as it can be deployed quickly and be effective when integrated into district heating networks (DHNs). Indeed, the temperature dynamics of energy

decentralized sources makes an important effect on network performance [2]. In the sustainable context, the utilization of DHN for the distribution of heat to consumers has proven to be an energy useful way for satisfying thermal demand of different places. DHNs supply heat from a both centralized and decentralized production units to buildings, by means of a network system of underground pipes carrying hot water, see Figure 1.

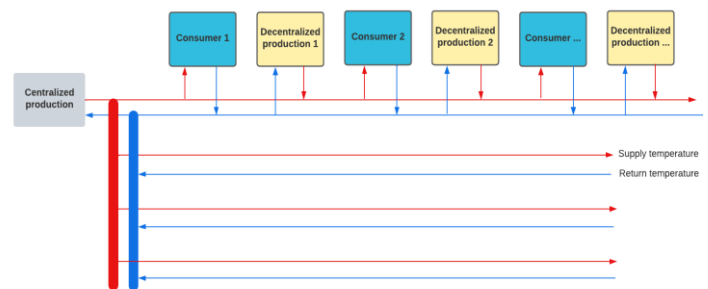


Figure 1. Layout of DHNs with both centralized and decentralized units. Red and blue colors refer to hot and cold pipes, respectively.

DHNs are forecasted to provide around 50% of the heat demands of the EU in 2050, against the current rate of 10% [3]. Integrating renewable energy in the existing or new DHN is a potentially effective means to achieve this aim. Despite many desirable advantages of renewables sources, it is often a challenge to integrate it into DHNs, especially when the temperature dynamics of fluctuating clean sources has to be considered.

Analysis of the literature suggests that most research uses different optimization methods such as system efficiency, cost, and environmental impact in order to determine the relevant design or operating processes of DHNs. Sarbu et al. [4] highlighted that the advantage of using this network resides in its environmental impact, and the fundamental advantage of renewable energy systems is that it can be utilized with fuels to build a cogeneration system more efficiency. Olsthoorn et al. [5] indicated that there are several parameters upon which a district heating system can be optimized, including improvement of energy efficiency, costs analysis,

optimization and reduction of environmental effects. Sorknæs et al. [6] investigated the economic and energy influences of going from 3<sup>rd</sup> generation district heating to 4<sup>th</sup> ones in Denmark. They found that this transformation leads to the decreases primary energy consumption of the energy system by 4.5% and the costs of the system by 2.7%. Balaman et al. [7] developed a new model for sustainable design of renewable energy supply chains. That model, based on cost and service level, manages DHNs design with thermal energy storages in support. Bartolozzi et al. [8] evaluated the environmental impact of renewable sources using life cycle analysis method. A neighborhood of 1000 inhabitants equipped by a district network in Italy was investigated. Results indicate that the DHNs integrated with renewable energy system reduced the carbon footprint and others environmental impacts. Blanco et al. [9] proposed a planning method based on stochastic programming. They analyzed how district heating system can provide regulating power and thus improve the planification of the renewable energy resources. The analysis of the literature shows that in the field of DHNs with integration of renewable energies, research works are very vast with many disparate and varied studies often of descriptive type. These findings suggest that researchers in this field should be guided by a research methodology, and a framework that ease the orientation towards the most appropriate journals and sources. To achieve this aim, this work uses the Scopus database, VOSviewer software and bibliometrix R-tool, to determine the country's, co-citation network, co-occurrence network, sources network, most relevant affiliations and the journals that publish most papers in this topic.

## II. METHODOLOGY

A bibliometric analysis method was applied to explore the development of research investigating DHNs with integrated renewable energy supply (see Figure 2). Bibliometric analyses were performed using VOSviewer software and bibliometrix R-tool. This methodology combines data collection (from database) to data mapping and visualization based on R language. The R-package used can be then linked to software tools for science mapping (VOSviewer) to label the graphical illustration of large bibliometric maps. Different networks were generated to evaluate: the collaborations between different countries, Co-occurrence words, Sources, Co-citations and relevant institutions in this research field.

A total of 1447 documents were included in our study, main information about collected data were presents in Table 1 and Table 2. A comprehensive search was performed online using the Scopus database on February 20, 2023. During our research, we used the Scopus database option "search within: article title, abstract, keywords" based on the combination of the following words: "Renewable energy " and "District heating".

**Table 1. Main information about data.**

Timespan	From 1981 to 2023
Sources (Journal, Books, etc.)	423
Documents	1477
Annual Growth Rate (%)	8.07
Average citations per document	20.81
References	50367
Keywords	6487
Authors	3460

International co-authorships (%)	20.85
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**Table 2. Document types.**

Article	907
Conference paper	387
Review	88
Book chapter	53
Conference review	17
Editorial	12
Short survey	7
Book	3
Note	2
Data paper	1

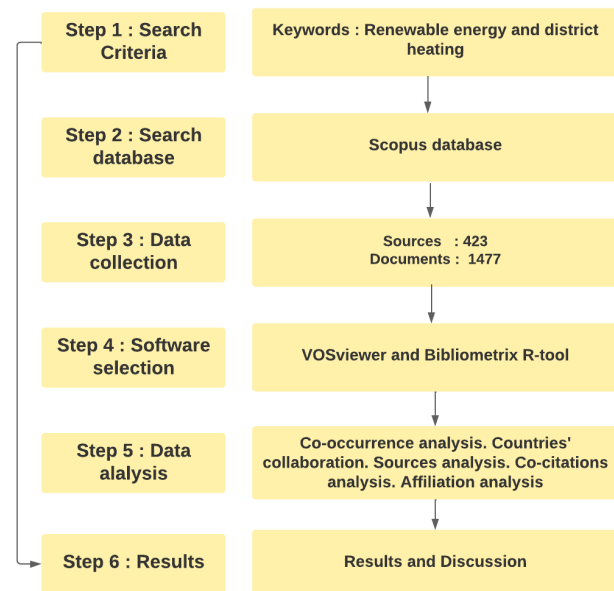


Figure 2. Flowchart of the bibliometric analysis.

## III. RESULTS

### A. Published articles on scopus database

Figure 3 represents a bibliometric research, that was lead using the bibliometrix tool (graphic R language), along with Scopus database. Analysis is based on 1477 articles published from 1981 to 2023, With very few articles between 1981 and 2004 and then an annual growth of 8.3% from then until today.

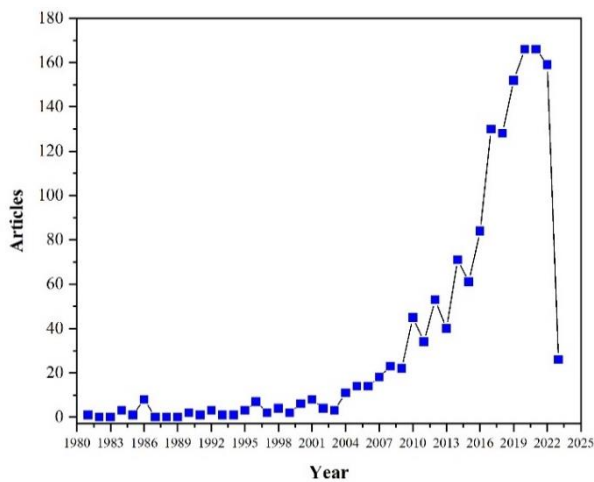


Figure 3. Published articles on Scopus database over time.

### B. Co-occurrence analysis

Co-occurrence analysis represents the most common keywords used by researchers publishing in the topic of DHNs (DHN) with integrated renewable energy supply. Figure 4 presents a map of top high occurrence keywords that appear 15 times or more. It is shown that there are mainly 3 clusters, 42 items, with a total of 1347 link-strength in the network that the researcher can take in the research field of DHN. The most common keywords are district heating, renewable energy, biomass, geothermal energy and cogeneration. Table 3 reports the results of 10 top high concurrence keywords based on a list of 43 keywords. It should be noted here that this first analysis only highlighted main renewable energies used, without diving into each specific technology specification.

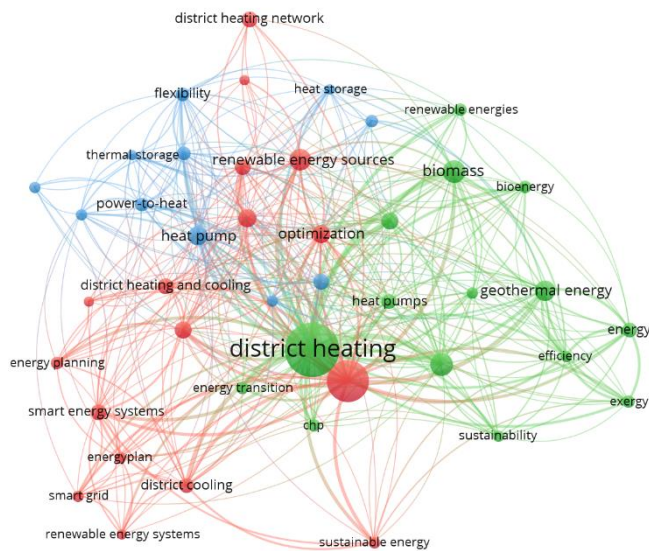


Figure 4. Co-word network visualization using VOSviewer.

### C. Countries' collaboration world map

Figure 5 represents the countries' collaboration world map related to DHN research, we analyze the relationship between countries based on Bibliometrix software. The shade of the color represents a country's production. Based on this figure, it is found that the Denmark, Italy, Germany, China, Sweden, Finland, United Kingdom, Austria, United Stat and Canada dominate, with 238, 162,

189, 141, 87, 86, 74, 66, 65, and 50 articles, respectively. Therefore, the scientific production related to DHN with integrated renewable energy supply is mainly distributed in North America, Europe and Asia. Table 4 represents the 7 highly collaborative countries. Next figures would also explain some countries dominance in the literature.

Table 3. Occurrence of keywords in the network.

Keyword	occurrences	Total link strength
District heating	381	502
Renewable energy	225	343
Biomass	69	117
Energy efficiency	66	93
Geothermal energy	57	87
Cogeneration	41	76
Optimization	45	71
District cooling	29	69
Heat pump	53	69
Energy storage	37	67

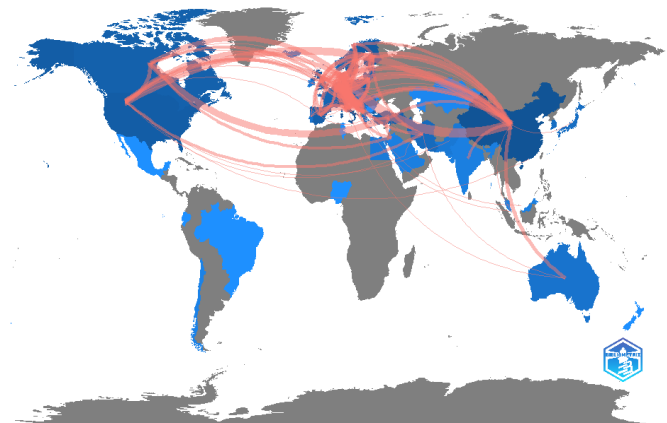


Figure 5. Countries' collaboration map of publications related to DHN research.

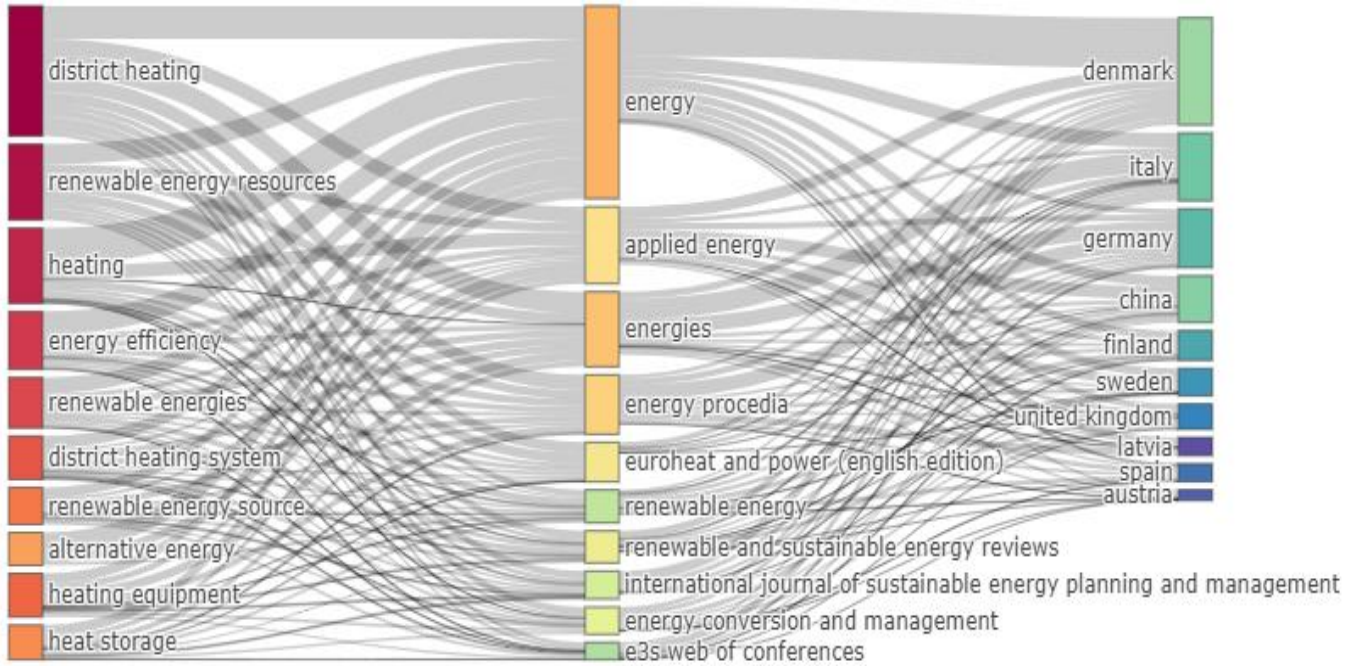
Table 4. Bibliographic coupling of countries.

Country 1	Country 2	Collaboration frequency
Denmark	Croatia	26
Denmark	Germany	19
Germany	Austria	16
Denmark	China	16
Denmark	Sweden	13
China	USA	13

### D. Sources analysis

Figure 6 presents the 10 journals that publish the largest numbers of publications in the field of DHN with integrated renewable energy supply, in terms of keywords and countries. Journal of energy,

applied energy, energies and energy procedia are the leading number of a citations of a cited reference is set at twenty, of the



journals on this list.

Figure 7 showed the top 10 most highly cited journals of paper related to DHN. The most three highly cited journals are ranked as follows: the Journal of Energy (37.32% ; 8237 citations), Applied energy (19.45% ; 4293 citations), and renewable and sustainable energy review (15.15% ; 3344 citations).

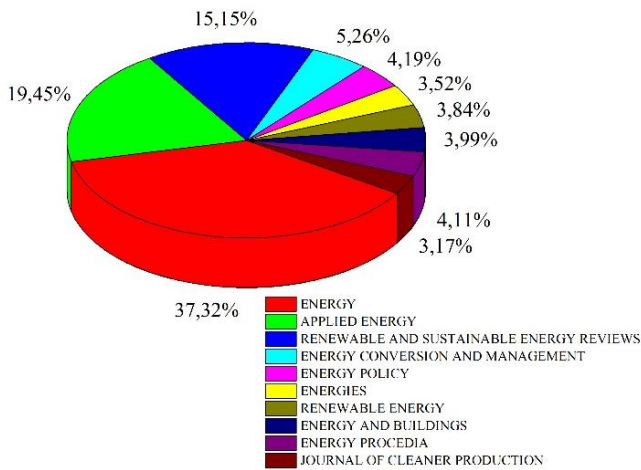


Figure 7. Most cited sources

49600 cited references, 12 meet the threshold.

The references " International review of district heating and cooling [10] " and "The role of district heating in future renewable energy systems [11]" are in the center of Figure 6 being a leading tow papers with the highest number of co-citations received in this research area (51 citations).

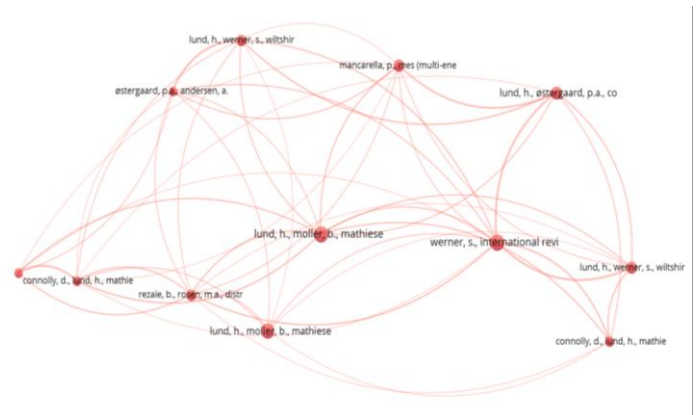


Figure 8. Bibliometric map based on co-citation network

Keywords-Sources-Countries

E. Co-citations analysis

Co-citation analysis is a scientific mapping method that assumes that articles cited together most often are thematically similar, it occurs when two publications are cited by a third article. Figure 8 represents the most representative co-citations networks, the minimum

F. Most relevant affiliations

Figure 9 provides an overview of the most relevant affiliations in the topic of district heating network (DHN) with integrated renewable energy supply. It is clearly noticeable that two Danish universities have the largest share of scientific production (42.14%), namely Aalborg university (28.62%, 273 publications) and Technical university of denmark (13,52% , 129 publications ). This explains why Danish district heating stands out globally in terms of heat planning strategies, energy efficiency and sustainability [12].

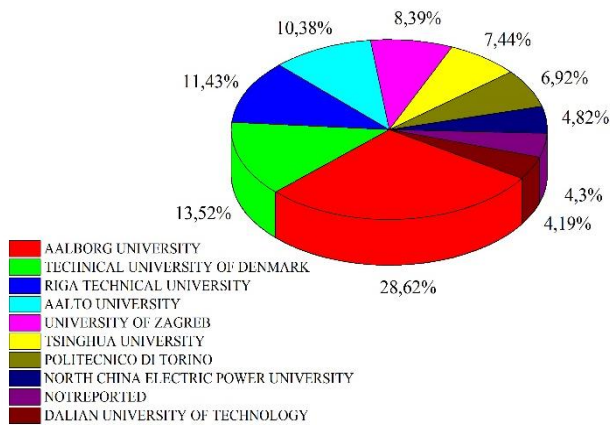


Figure 9. Most relevant affiliations

### G. Analysis of Authors

Table 5 presents the most top four frequent authors (according to the author data set of the papers included in our study). Henrik Lund Professor in energy planning at Aalborg University, Denmark, authored (or co-authored) the most papers (42 papers) followed by Brian Vad Mathiesen of Aalborg University, Denmark, (34 papers). Such analysis would be useful for instance in case of expert spotting or to help identify the main contributors to the updated topic literature.

Table 5. Top four authors.

Author	Documents	Citations
Henrik Lund	42	5968
Brian Vad Mathiesen	34	5358
Poul Alberg Østergaard	30	1159
Peter Sorknæs	11	746

## IV. CONCLUSION

Bibliometric analysis is considered as scientific useful methodology within the research and applied science fields. In this paper, bibliometric analysis is used for the topic of district heating network (DHN) with integrated renewable energy supply. From the results of this paper, it is possible to identify some keys in this topic in terms of journals, countries, documents, authors and their affiliations. Such analysis would help researchers to tighten their links and efficiently contribute to the scientific novelty of the field, while updating the inventory of the literature. It is also useful to investigate experts or groups of individual/organization leading the scientific novelty in the topic. One limitation of this study would be the sole use of Scopus to identify main publications related to the topic, while a wider coverage database, also including non-English types of materials, would be more relevant for further analysis. Besides, although the main aim of such framework would be to assist researchers dealing with large, fragmented and disparate research flows, it can also be used as a policy support tool to represent and illustrate the scientific state of play and outputs, promote a science for policy perspective, and assist drafting suitable policy directions that promote energy optimization and the use of renewable energies in heating.

## V. ACKNOWLEDGMENTS

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## VI. REFERENCES

- [1] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance <http://data.europa.eu/eli/dir/2012/27/oj>
- [2] Danhong Wang, Kristina Orehounig, Jan Carmeliet, Investigating the potential for district heating networks with locally integrated solar thermal energy supply, *Energy Procedia*, Volume 122, 2017, Pages 1057-1062, ISSN 18766102, <https://doi.org/10.1016/j.egypro.2017.07.432>.
- [3] Paardekooper, S., Lund, R. S., Mathiesen, B. V., Chang, M., Petersen, U. R., Grundahl, L., David, A., Dahlbæk, J., Kapetanakis, I. A., Lund, H., Bertelsen, N., Hansen, K., Drysdale, D. W., & Persson, U. (2018). *Heat Roadmap Europe 4: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps*. Aalborg Universitetsforlag.
- [4] Sarbu, Ioan, Matei Mirza, and Daniel Muntean. 2022. "Integration of Renewable Energy Sources into Low-Temperature District Heating Systems: A Review" *Energies* 15, no. 18: 6523. <https://doi.org/10.3390/en15186523>
- [5] Dave Olsthoorn, Fariborz Haghighat, Parham A. Mirzaei, Integration of storage and renewable energy into district heating systems: A review of modelling and optimization, *Solar Energy*, Volume 136, 2016, Pages 49-64, ISSN 0038092X, <https://doi.org/10.1016/j.solener.2016.06.054>.
- [6] Peter Sorknæs, Poul Alberg Østergaard, Jakob Zinck Thellufsen, Henrik Lund, Steffen Nielsen, Søren Djørup, Karl Sperling, The benefits of 4th generation district heating in a 100% renewable energy system, *Energy*, Volume 213, 2020, 119030, ISSN 0360-5442, <https://doi.org/10.1016/j.energy.2020.119030>.
- [7] Şebnem Yılmaz Balaman, Hasan Selim, Sustainable design of renewable energy supply chains integrated with district heating systems: A fuzzy optimization approach, *Journal of Cleaner Production*, Volume 133, 2016, Pages 863-885, ISSN 09596526, <https://doi.org/10.1016/j.jclepro.2016.06.001>.
- [8] Irene Bartolozzi, Francesco Rizzi, Marco Frey, Are district heating systems and renewable energy sources always an environmental win-win solution? A life cycle assessment case study in Tuscany, Italy, *Renewable and Sustainable Energy Reviews*, Volume 80, 2017, Pages 408-420, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2017.05.231>.
- [9] Blanco, Ignacio, Daniela Guericke, Anders N. Andersen, and Henrik Madsen. 2018. "Operational Planning and Bidding for District Heating Systems with Uncertain Renewable Energy Production" *Energies* 11, no. 12: 3310. <https://doi.org/10.3390/en11123310>
- [10] Sven Werner, International review of district heating and cooling, *Energy*, Volume 137, 2017, Pages 617-631, ISSN 0360-5442, <https://doi.org/10.1016/j.energy.2017.04.045>.
- [11] H. Lund, B. Möller, B.V. Mathiesen, A. Dyrrelund, The role of district heating in future renewable energy systems, *Energy*, Volume 35, Issue 3, 2010, Pages 1381-1390, ISSN 0360-5442, <https://doi.org/10.1016/j.energy.2009.11.023>.
- [12] Katinka Johansen, Sven Werner, Something is sustainable in the state of Denmark: A review of the Danish district heating sector, *Renewable and Sustainable Energy Reviews*, Volume 158, 2022, 112117, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2022.112117>.