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Review article

Business and pricing models for district heating and cooling: A review

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ABSTRACT

In recent decades, district heating and cooling has become a more and more relevant topic in the context of smart energy, and novel business models have been developed. However, while review papers have been written already on business models tied to specific contexts of district heating, there is the need for a generic review that encompasses all the most recent works on this field, giving an overview on the whole horizon of business and pricing models for district heating and cooling. In this work, we conduct a comprehensive review of business and pricing models for the use of flexible energy consumption in district heating and cooling, including their coupling with electricity systems. We examine both review papers on the topic and papers introducing novel models or enhancing existing ones. We identify key features to classify these papers, analyze how each work aligns with these criteria, and provide insights based on this analysis. Our research points out the need for novel business models targeting district cooling, devices different from heat pumps, non-European countries, machine-learning based algorithms and peak shaving.

1. Introduction

Heating and cooling account for nearly 50% of the EU's total gross final energy consumption. As of 2022, only around 25% of this energy came from Renewable Energy Sources (RES).[1] District Heating and Cooling (DHC) and electricity systems both provide key infrastructure for delivering decarbonized energy services. DHC delivers heating, hot water, and cooling through a network of insulated pipes from a central generation point to end users (Lettenbichler et al., 2023), while electricity increasingly supports heating and cooling through technologies such as heat pumps. However, as of 2023, DHC only accounted for 12% of Europe's heating demand. Increasing this share to 20% by 2030 is achievable and would result in significant fossil fuel savings (equivalent to 24 billion m^3 of gas), especially given that RES already constitutes 41.3% of existing DHC networks.[2]

DHC, particularly when coupled with electricity systems, serves as a key pathway for introducing RES into neighborhood and urban energy systems:

- It can draw on the use of locally available sources, including RES, heat from cogeneration, and industrial waste heat.
- DHC can use renewable electricity to generate renewable heating and cooling, making it a valuable tool for sector coupling.
- As a demand aggregator for a large number of end users, DHC can leverage renewable electricity to produce renewable heating and cooling, thus enhancing demand-response opportunities for Distribution System Operators (DSOs) and Transmission System Operators (TSOs).
- DHC and electricity integration reduce reliance on foreign energy sources, aligning with the REPowerEU initiative.

However, meeting European Union (EU) regulatory targets by constructing new networks, modernizing existing ones, and strengthening DHC–electricity interactions presents economic and financial challenges. Increasing the share of waste and renewable heat in DHC networks requires substantial investment and added operation and maintenance costs. For example, the payback period for urban waste heat recovery through DHC is lengthy and difficult to estimate (Wynn et al., 2019). Additionally, carbon pricing is being extended to more countries and user typologies, and represents an additional problem to solve.

With rising shares of renewable energy in the electricity grid, grid balancing through enhanced flexibility is essential. Meanwhile, the current trend towards electrification of energy end-uses offers new opportunities to provide that flexibility (Nuffel et al., 2018). Looking in particular into the heating and cooling sector, heat demand can often be

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[1] EUROSTAT.

[2] https://www.euroheat.org/news/fit-for-2050-unleashing-the-potential-of-efficient-district-heating-and-cooling-to-decarbonise-europe.

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shifted more readily than electricity demand, using thermal storage or even the thermal mass of buildings, which are more cost-effective than electric storage solutions. Flexibility in coupling heating/cooling with electricity is mainly achieved through heat pumps, which allow energy utilities to reduce costs by using electricity when it is less expensive and using the heat obtained from that electricity when heating (or cooling) is actually required. Conversely, utilities that fail to modernize their energy management will likely face higher costs. Flexible tariffs have been used for decades in the energy sector, but are generally based on fixed parameters, such as season, day, and time of consumption. The emerging challenge is to implement a flexible mechanism that accounts not only for changes in load patterns but also for the impact of volatile and unpredictable energy sources.

As the adoption of district heating and electricity-based heating and cooling grows and new policies, measures, and tariffs are introduced, novel business and pricing models are emerging. These models aim to address challenges arising from increased district heating use, improve profitability, and enhance environmental outcomes in specific settings. Over time, these business models have encountered challenges stemming from an evolving energy market, the introduction of environmental regulations, and the integration of new technologies. As a result, they have had to adapt — for example, by incorporating biomass and waste heat utilization, and by supporting sector coupling and the use of flexibility mechanisms (Johansen, 2022). As such developments unfold, review papers have emerged to document new business models for district heating within specific contexts (e.g., business models that only refer to the building level, or pertaining only to the specific case of energy communities). However, to date, there are no comprehensive reviews covering this topic in a general context. Thus, this paper presents a review of business and pricing models for district heating and cooling, analyzing both recent models from the past five years and existing review papers on this topic.

We analyzed 11 review papers and 17 technical papers proposing novel business and pricing models, assessing their relevance to the criteria we have chosen for investigating them. Following this, we synthesized the key findings and emerging patterns from our analysis, identifying potential research directions. Specifically, the main unexplored research areas include: (i) specific devices and scenarios, such as CHP in review papers; (ii) studies focusing specifically on district cooling; (iii) novel models leveraging methods other than mathematical optimization, such as machine learning-based approaches; and (iv) innovative models with the objective of achieving peak shaving and energy self-consumption.

The remainder of this paper is organized as follows. Section 2 gives a quick overview of the basic technology principles of district heating, and how they integrate with pricing models. Section 3 reviews the state of the art on business models in smart energy. Section 4 outlines the methods used for research and paper selection, detailing our inclusion and exclusion criteria. Section 5 presents identified review papers, describing how they address business and pricing models based on a set of defined features. Section 6 categorizes and describes novel models, using a separate set of model-specific features. Section 7 discusses the main results and takeaways, highlighting emerging trends, and showcases direction for future research on this field. Finally, Section 8 concludes the paper.

2. Background

Before delving further into our review, we outline the basic technological principles of district heating and how they integrate with business and pricing models.

District heating systems operate by generating heat at a central facility and distributing it to consumers via a network of insulated pipes. The main components of such systems include (Dalipi et al., 2016):

- Heat generation units, such as combined heat and power (CHP) plants or boilers.
- The distribution network, where heat is transported — typically as hot water — through insulated pipes to buildings. After transferring its heat, the cooled water is returned to the generation units.
- Customer substations, where heat is exchanged from the network to the end users' internal heating systems.

The heat delivered by the system is determined by the mass flow rate of the water and the temperature difference between the supply and return lines. The supply temperature is typically regulated at the production site, while the return temperature is influenced by end-user consumption patterns and other operational parameters. The total heat load on the network is the aggregate of all connected consumer demands, in addition to system heat losses.

Over time, district heating technology has evolved, driving the development of new business models. For example, low-temperature district heating systems require models that accommodate decentralized heat sources and more sophisticated control strategies (Lygnerud, 2019). Similarly, the integration of excess industrial heat (Yuan et al., 2021), increased digitalization, and the deployment of smart meters (Schmidt, 2021) have contributed to a paradigm shift in how heat is managed and monetized. Technological advancements — particularly the integration of heat pumps (Lygnerud, 2019) — enable the conversion between heat and electricity, providing district heating systems with a potential interface to electricity markets. As in the electricity sector, flexibility has become a core component of many modern district heating business models (Xu et al., 2020). Finally, the growing adoption of thermal energy storage has further emphasized this importance, enabling the integration of dynamic pricing schemes (Mokhtari et al., 2025) and demand-side management strategies (Guelpa and Verda, 2021). These approaches not only enhance operational efficiency but also help align heat production with fluctuating energy prices.

3. Related work

3.1. Context - EU regulations

DHC and electricity are both emphasized in European policy frameworks. The European Green Deal, through its *Fit for 55* package, proposes revisions to relevant EU directives and introduces new policies:

- Energy Efficiency Directive (EED): This directive defines efficient DHC systems as those with at least 50% RES, 50% waste heat, 75% cogenerated heat, or a 50% combination of these sources. In the near future, the threshold for cogenerated heat will rise to 80% and will only qualify if it comes from high-efficiency systems. From January 1, 2035, DHC systems will need to use at least 50% RES and waste heat and at least 20% RES, in order to be considered efficient. High-efficiency cogeneration from gas will be permitted until 2050, after which cogeneration must use green hydrogen or biomass.
- Renewable Energy Directive (RED) III: Article 24 sets a non-binding target for DHC, stating that *Member States shall endeavor to increase the share of energy from renewable sources and from waste heat and cold in district heating and cooling by an indicative 2.2 percentage points annually on average for the period 2021 to 2030*. Additionally, DHC utilities are encouraged to allow third parties generating RES or waste heat to access DHC networks with a capacity above 25 MWth.

3.2. Context - project

The analysis was performed in cooperation with the European research project HYPERGRYD (Hybrid coupled networks for thermal-electric integrated smart energy Districts),[3] which investigated innovative technologies to increase digitalization and increase the share of renewable energy in district heating networks.

Several of the technologies developed in the project target flexibility in the sector coupling of electricity and heating/cooling.

- A sorption storage designed for medium-scale applications, for example in DHC systems, allows for long-term and high-density heat storage, which increases the flexibility potential in generating heat at times when it is not required, storing it until it is needed.
- A modular heat pump designed for DHC-connection. The heat pump is equipped with a Phase Change Material (PCM) heat exchanger, which also operates as a compact and high-density heat storage.
- A reversible micro CHP system designed for small- and medium-sized applications, connected to a steam storage. This technology allows to use of electricity to generate steam even in times when no heat is required. The steam is stored and used for heating purposes when necessary. Additionally, the same steam can be re-used to generate electricity again. Although the latter operational mode works at low efficiency, it allows for a very high degree of flexibility.
- A demand-response management service to optimally balance the utilization of heat and electricity in real-time, taking into account both locally available distributed energy resources (renewables, storage, heat pumps) and electricity grid resources.

The use of one or more of these technologies within a DHC system can increase the capability of DHC operators to access convenient electricity prices by offering flexibility services, which can range from network balancing to demand-response services. The above-listed innovative technologies, along with other technologies already available on the market (such as industrial heat pumps), make this sector coupling technically possible. The main challenge is on the financial side, i.e., whether flexibility services are rewarding enough to trigger DHC operators investing in further power-to-heat devices. Analyzing this opportunity is an important activity in HYPERGRYD exploitation and replication activities. In particular, investigating existing pricing models is part of the business modeling task in the HYPERGRYD project. If flexibility pricing is appealing, DHC systems powered by power-to-heat technologies such as heat pumps can offer significant flexibility capacity given their size. Financial incomes deriving from offering flexibility services to electric grids are therefore expected to become an important part of district heating operators' future business plans.

3.3. Literature

In the realm of smart energy, district heating has become an increasingly popular solution in the last few years. There are numerous works describing its evolution: for instance, Johansen (2022) details the history of district heating and combined heat and power in Denmark, explaining how and why this sector emerged, the values and principles guiding its development, and potential future challenges. More recently, Sporleder et al. (2022) offers an overview of the last decade's advancements in district heating system design and optimization, highlighting gaps in stakeholder decision-making, efforts to reduce computational load, handling uncertainties, and integrating diverse devices and technologies. Other works focus on specific aspects: for example, Gong et al. (2023) reviews literature on 5th-generation district heating systems, addressing both development and practical applications, and discusses the economic factors and core components impacting the district heating systems. Meanwhile, Munćan et al. (2024) provides an overview of recent district heating developments in Europe, covering technological, market, and regulatory aspects, and offers insights into commonly used performance indicators and energy models.

Since much of the literature on district heating is recent, there are relatively few review papers on district heating business or pricing models specifically, and existing reviews, which we present in detail in Section 5, are also recent. Nonetheless, numerous reviews focus on business models for electricity and smart energy more broadly. Examples include (Paukstadt and Becker, 2019; Paukstadt et al., 2019), which review smart energy business models up to 2020 and classify them by model type; however, they remain fairly generic and are not specific to particular contexts. Similarly, Lilliu et al. (2024) classifies the models according to specific features; however, this work concentrates on business models related to buildings, exploring models tied to three key smart energy topics: energy flexibility, demand response, and energy communities. Energy communities also play a central role in F.G. Reis et al. (2021), where reviewed models focus on this theme and are categorized by archetype and business model canvas, with flexibility and its aggregation also being emphasized.

Indeed, many smart energy pricing models leverage flexibility (Lilliu et al., 2019a) to operate and achieve their objectives. An example is Wang et al. (2022b), in which flexibility, achieved through load shifting, enables a control strategy for a Heating, Ventilation, and Air Conditioning (HVAC) system in a transactive energy grid and supports the creation of a pricing model to assess its peak-shaving effectiveness. Another relevant example is Lilliu et al. (2019b), a model where pricing is based on total energy consumption and production within a local energy community, structured to promote or discourage certain behaviors among community users. This concept is further explored in Lilliu et al. (2020), Denysiuk et al. (2020), Lilliu et al. (2023) and Lilliu and Reforgiato Recupero (2024), which examine other user behaviors and develop the model with a game-theory approach. However, business models targeting other aspects do not always rely on flexibility; for instance, Roberts et al. (2022) addresses a shared Photovoltaic (PV) system in an apartment complex, aiming to fairly distribute costs and benefits among owners and residents and examining the model's sustainability based on the specific benefits pursued.

Being more specific regarding district heating business models, some works are also centered on potential future developments. For example, Lygnerud et al. (2023) identifies key elements in business models based on literature and interviews with building owners and prosumers, outlining anticipated crucial aspects in district energy business models of 2050 and how they may differ from current models. Likewise, Lygnerud et al. (2019) examines challenges and business models for low-temperature district heating, identifying obstacles to large-scale urban waste recovery, challenges in contract design, and the impact of urban waste heat recovery on business models, providing insights from numerous stakeholders on these issues.

3.4. Comparison with state of the art

In this section, we aim to highlight the unique contributions and novelty of our paper in comparison to the existing literature.

Our paper presents a broad, in-depth review of business and pricing models for district heating and cooling, covering both prior review papers and studies proposing new models. We have compared our paper with the most recent state-of-the-art review papers (Popovic et al., 2024; Abugabbara et al., 2023; Williamsson, 2023; Moser and Jauschnik, 2023; Arpagausa et al., 2023; Johansen and Johra, 2022; Sieverts Nielsen et al., 2022; Selvakkumaran et al., 2021; Torvanger, 2021; Tschopp et al., 2020; Leoni et al., 2020). Table 1 shows this comparison.

[3] https://hypergryd.eu/.

Table 1
Topics comparison between our paper and the state of the art.

Paper	Importance	Main topic
Popovic et al. (2024)	Mostly all (One subs.)	Funding for DH
Abugabbara et al. (2023)	One subs.	5th-gen. Heating and Cooling
Williamsson (2023)	Whole paper	Digitalization in Sweden
Moser and Jauschnik (2023)	Mostly all (Two subs.)	Industrial waste heat
Arpagausa et al. (2023)	Whole paper	Industrial heat pumps
Johansen and Johra (2022)	One subs.	Short-term energy storage
Sieverts Nielsen et al. (2022)	Mostly all (One sect.)	Excess heat in Denmark
Selvakkumaran et al. (2021)	Whole paper	Capturing flexibility
Torvanger (2021)	Whole paper	Waste-to-energy plants
Tschopp et al. (2020)	One subs.	Solar thermal systems
Leoni et al. (2020)	Mostly all (Two sect.)	Return temp reduction
Our paper	Whole paper	Generic

Four review papers that we have analyzed later in our work (Williamsson, 2023; Arpagausa et al., 2023; Selvakkumaran et al., 2021; Torvanger, 2021) primarily focus on business or pricing models for district heating. Four other works (Popovic et al., 2024; Moser and Jauschnik, 2023; Sieverts Nielsen et al., 2022; Leoni et al., 2020) address this topic as a significant but secondary focus. Other studies (Abugabbara et al., 2023; Johansen and Johra, 2022; Tschopp et al., 2020) touch on business and pricing models only marginally, centering instead on topics like 5th-generation district heating and cooling (Abugabbara et al., 2023), socio-technical aspects of short-term thermal energy storage (Johansen and Johra, 2022), and large-scale solar thermal systems (Tschopp et al., 2020). Among the papers where business models are a relevant but secondary topic, Popovic et al. (2024) explores strategies for increasing funding for district heating in Europe, while Moser and Jauschnik (2023) investigates industrial waste heat utilization in district heating with a focus on business models. Additionally, Sieverts Nielsen et al. (2022) discusses contracts, regulations, and business models for excess heat, with a particular focus on Denmark. Furthermore, Leoni et al. (2020) is more pertinent to business models compared to the previous three works, but concentrates on barriers and solutions in the context of reducing return temperatures.

About the four works mentioned earlier that are centered on business and pricing models, we can see that their focus and objectives are different from our work. Specifically, Williamsson (2023) reviews digital business model innovation specific to Sweden, focusing on the impact of digitalization, barriers to model development, and current views on the topic. Selvakkumaran et al. (2021) analyzes business models for prosumers from trying to understand how they capture flexibility, and issues key features tailored to this task; also, it considers district energy as a whole, not exclusively district heating and cooling. In Torvanger (2021), the review is specific to business models on waste-to-energy plants, examining the benefits and challenges of incorporating carbon capture and storage. Finally, Arpagausa et al. (2023) is the closest work to ours, as its main purpose is to review business models for district heating; however, Arpagausa et al. (2023) targets industrial heat pumps specifically and includes interviews with high-temperature heat pump manufacturers. In contrast to the papers described above, this work generically targets all the business and pricing models relative to the district heating and cooling domain, aiming to illustrate the state of the art, highlight literature insights and gaps, and propose directions for future research in this field. To the best of our knowledge, no previous work in the literature has conducted a comprehensive review of business and pricing models for district heating and cooling without focusing on a specific use case or scenario. This paper fills this gap by providing a broad overview of the topic, identifying common patterns across existing studies, offering insights into their findings, and outlining future research directions, including opportunities to explore unexamined areas.

Table 2
Number of total papers found, and eligible papers.

Total papers found	69
Papers relevant to our study	28

4. Papers retrieval

In this section, we outline the process used to select the papers for our review. The literature search was conducted on Scopus[4] in June 2025. The search query consisted of two primary keyword groups: the first group included either *District heating* or *District cooling*, while the second group included either *Business model* or *Pricing model*. We performed the search using all four possible keyword combinations. Specifically, the search query was:

$$(\text{“}business\ model\text{”} AND \text{“}district\ heating\text{”}) OR$$

$$(\text{“}business\ model\text{”} AND \text{“}district\ cooling\text{”}) OR$$

$$(\text{“}pricing\ model\text{”} AND \text{“}district\ heating\text{”}) OR$$

$$(\text{“}pricing\ model\text{”} AND \text{“}district\ cooling\text{”})$$

Our search focused on papers published between 2020 and 2024, where the specified keywords appeared in the *title*, *abstract*, or *keywords* fields. As shown in Table 2, we initially identified a total of 69 papers.

We then conducted a detailed review of all the papers to determine their relevance to our research. Out of the 69 papers, only 28 were able to fit our research purpose. Of these, 11 were review papers that addressed business or pricing models for district heating or presented best practices for implementing such models. The remaining 17 papers introduced new business or pricing models or discussed the integration of existing models in broader contexts. We will discuss these papers in detail in the following sections and categorize them based on features relevant to our study.

As a result, 41 papers were excluded from further consideration. Below, we outline the reasons for their exclusion:

- 15 papers were marginally related to business or pricing models, such as review articles that highlighted the need for developing pricing models but did not offer concrete solutions or case studies. For example, Lygnerud et al. (2024) describes the necessity of establishing efficient business models for excess heat recovery, but does not actually provide an example of such a model.
- 25 papers did not address business or pricing models for district heating or cooling and were therefore not aligned with our research focus. An example is Chen et al. (2024), which performs a profitability analysis on a novel technology in combined heat and power plants, but does not actually describe business models.
- 1 paper was written in Chinese, which made it inaccessible for our review.

[4] http://www.scopus.com.

Table 3
Review papers.

Code	Paper	Title
R1	Popovic et al. (2024)	Blended finance as a catalyst for accelerating the European heat transition?
R2	Abugabbara et al. (2023)	How to develop fifth-generation district heating and cooling in Sweden? Application review and best practices proposed by middle agents
R3	Williamsson (2023)	Business model innovation for digitalization in the Swedish District Heating Sector
R4	Moser and Jauschnik (2023)	Using industrial waste heat in district heating: Insights on effective project initiation and business models
R5	Arpagausa et al. (2023)	Review of business models for industrial heat pumps
R6	Johansen and Johra (2022)	A niche technique overlooked in the Danish district heating sector? Exploring socio-technical perspectives of short-term thermal energy storage for building energy flexibility
R7	Sieverts Nielsen et al. (2022)	Excess heat regulations, contracts and business models — with a special focus on excess heat opportunities in Denmark
R8	Selvakkumaran et al. (2021)	How do business models for prosumers in the district energy sector capture flexibility?
R9	Torvanger (2021)	Business models for negative emissions from waste-to-energy plants
R10	Tschopp et al. (2020)	Large-scale solar thermal systems in leading countries: A review and comparative study of Denmark, China, Germany and Austria
R11	Leoni et al. (2020)	Developing innovative business models for reducing return temperatures in district heating systems: Approach and first results

5. Reviews

This section presents the review papers identified in our research. We will describe these papers, highlight the features we found interesting, and assess how each paper aligns with these features. Table 3 lists the titles of the papers, also providing a reference code for future use throughout the paper.

The work (Popovic et al., 2024) discusses the European energy transition and the role of district heating, focusing on the challenge of securing funding outside the public sector and the potential role of financial markets in bridging this gap. It emphasizes the need to design business models that attract investors. Similarly, Abugabbara et al. (2023) is focused on 5th-generation district heating and cooling in Sweden, presenting key takeaways from early implementations and outlining best practices for various aspects, including prevailing business models for energy communities. Another study focused on the Swedish district heating sector is Williamsson (2023), which explores the impact of digitalization on business models, identifying innovation barriers arising from the conflict between two opposing perspectives: the *restrictive* and the *comprehensive* approach. In contrast, Moser and Jauschnik (2023) addresses a more specific aspect and targets the case where industrial waste heat is used for district heating. This work investigates how such cases have been implemented specifically in Austria, and which business models have been used for them, to be replicated and further improved. The review paper (Arpagausa et al., 2023) shares some similarities with our work, as it reviews heat-related business models; however, their focus is on industrial heat pumps, whereas ours covers district heating and cooling more broadly. Additionally, their review categorizes papers by business model type and highlights a few relevant factors such as value proposition, revenues, and key activities, whereas we analyze a broader range of features. Meanwhile, Johansen and Johra (2022) focuses on short-term thermal energy storage for building energy flexibility, exploring the benefits of this approach and analyzing the possibility of business models to incentivize sustainable heat use behaviors, rather than just focusing on users' economic benefit. The work (Sieverts Nielsen et al., 2022) investigates the barriers and enablers for utilizing excess heat, analyzing regulations, contracts, and business models, with a particular focus on the current situation in Denmark and the challenges encountered so far on its implementation. In contrast, Selvakkumaran et al. (2021) focuses on the problem of utilizing business models for prosumers for capturing flexibility, specifically referring to the heating sector, and analyzes 15 papers, in a similar fashion to our review; the main difference is that Selvakkumaran et al. (2021) explicitly focuses on usage of flexibility and categorizes papers by the methodology used, key actors and objective. As we will see in Section 6, this is a subset of the features we will use. In another example, Torvanger (2021) examines business models for waste-to-energy plants, specifically those that incentivize plant owners to install Carbon Capture and Storage (CCS) facilities, given the existence of CO2 transportation and storage infrastructure. The study performed in Tschopp et al. (2020) provides an overview of large-scale solar thermal systems, analyzing cases in Denmark, China, Germany, and Austria, and focusing on market and technological solutions, as well as country-specific factors (e.g., solar resources, heat supply systems, business models) that played a role in making those countries leaders in the field. Lastly, Leoni et al. (2020) explores the topic of reducing temperatures in district heating systems, focusing on business models that encourage this solution, particularly models that implement demand-side measures to lower return temperatures.

We have analyzed the content of these papers and classified them based on their adherence to some features: we chose them as they give crucial information about the described business models, except *importance*, which describes how relevant it is to our topic. The features are the following:

- **Importance**: Assesses the prominence of business/pricing models in the paper. Some papers dedicate only a section or subsection to business models, while others make it the main focus.
- **Devices**: Describes which devices the paper focuses on, if any, or if any device is specifically mentioned in the paper.
- **Domain**: Specifies whether the review targets or mentions a specific domain and, if so, which one.
- **Use case**: Describes the use case discussed in the paper, such as for example building or district.
- **Location**: Indicates the geographical focus of the paper, if any.
- **H/C**: Determines whether the paper addresses heating, cooling, or both.

We show in Table 4 how each paper complies with each feature. Some of the entries of the table are abbreviated: their meaning is explained in Table 5. To provide a clearer overview, Fig. 1 presents each paper according to the features it addresses, while Fig. 2 shows, for each feature, the distribution of papers that adhere to it.

We now provide an analysis of how the papers align with each feature and highlight any notable patterns observed during this analysis.

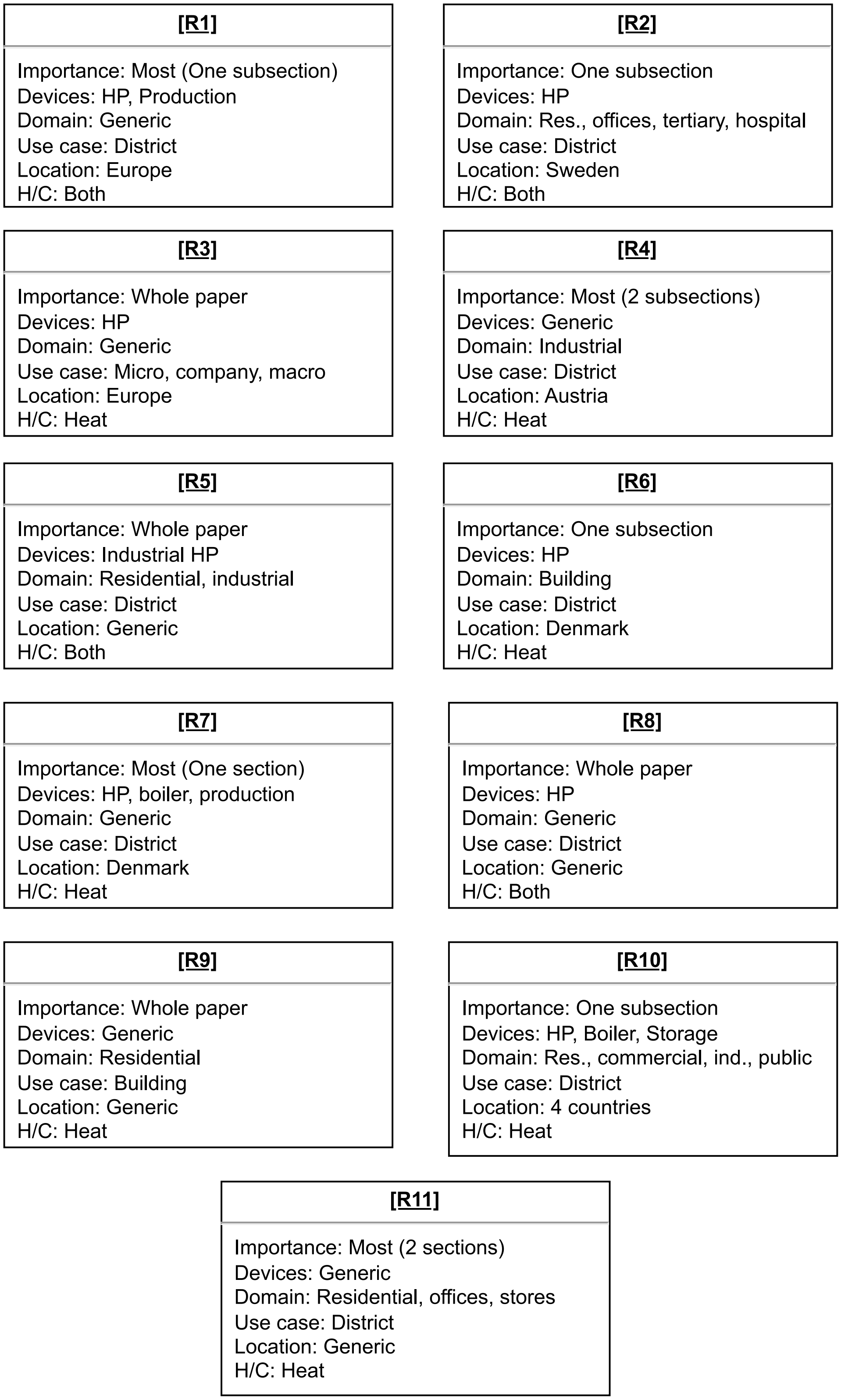

Fig. 1. Review papers by features.

5.1. Importance

There are four papers that have business models as their main topic (Williamsson, 2023; Arpagausa et al., 2023; Selvakkumaran et al., 2021; Torvanger, 2021). Specifically, Williamsson (2023) examines the impact of digitalization on business models for district heating, showing how this effect varies by digitalization area (infrastructure, offerings, customers, finances). Similarly, Arpagausa et al. (2023) specializes in a specific aspect, although in this case the focus is on the device: this review focuses on business models for industrial heat pumps, covering

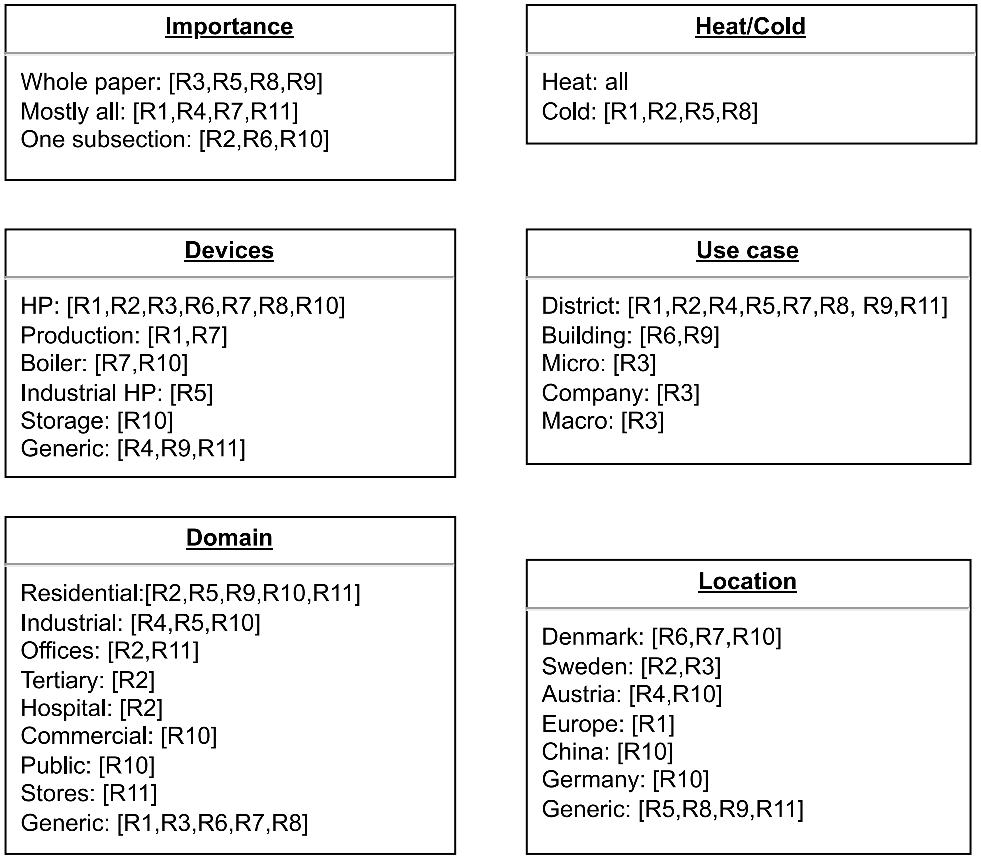

Fig. 2. Features by review papers.

Table 4
Classification of the review papers according to the six defined features.

Code	Paper	Importance	Devices	Domain	Use case	Location	H/C
R1	Popovic et al. (2024)	Mostly all (One subs.)	HP Prod.	Generic	District	Europe	Both
R2	Abugabbara et al. (2023)	One subs.	HP	Res. Offices Tertiary Hospital	District	Sweden	Both
R3	Williamsson (2023)	Whole paper	HP	Generic	Micro Company Macro	Sweden	Heat
R4	Moser and Jauschnik (2023)	Mostly all (Two subs.)	Generic	Ind.	District	Austria	Heat
R5	Arpagausa et al. (2023)	Whole paper	Ind. HP	Res. Ind.	District	Generic	Both
R6	Johansen and Johra (2022)	One subs.	HP	Generic	Building	Denmark	Heat
R7	Sieverts Nielsen et al. (2022)	Mostly all (One sect.)	HP Boiler Prod.	Generic	District	Denmark	Heat
R8	Selvakkumaran et al. (2021)	Whole paper	HP	Generic	District	Generic	Both
R9	Torvanger (2021)	Whole paper	Generic	Res.	Building	Generic	Heat
R10	Tschopp et al. (2020)	One subs.	HP Boiler Storage	Res. Comm. Ind. Public	District	Denmark China Germany Austria	Heat
R11	Leoni et al. (2020)	Mostly all (Two sect.)	Generic	Res. Offices Stores	District	Generic	Heat

case studies of district heating networks, waste heat recovery, and combined heat and power generation. Meanwhile, Selvakkumaran et al. (2021) centers on business models for prosumers, investigating how these models capture flexibility using classification features similar to ours. Finally, Torvanger (2021) specializes in business models for waste-to-energy plants, aiming to incentivize plant owners to install CCS facilities. Four other papers (Popovic et al., 2024; Moser and Jauschnik, 2023; Sieverts Nielsen et al., 2022; Leoni et al., 2020) do not have business models as their main focus but consider them a significant element throughout. For example, Popovic et al. (2024) has only one subsection specifically focused on business models, but the rest of the work is still tied to the topic, as the other sections still analyze financial or investment aspects related to the European green transition. Similarly, Moser and Jauschnik (2023) dedicates two subsections

Table 5
Acronyms used in Table 4.

Devices	
HP	Heat pump
Prod.	Production
Ind. HP	Industrial heat pump
Domain	
Res.	Residential
Comm.	Commercial
Ind.	Industrial

specifically to business models, although this study is centered on a survey where business models have a key role, which still makes them a central aspect of this work. The work performed in Sieverts Nielsen et al. (2022) also includes a dedicated section on business models but covers related topics such as regulations and contracts, with the aim of providing policy guidelines for excess heat utilization. As for Leoni et al. (2020), it has the purpose to propose new business models for reducing return temperatures, and it analyzes existing models in order to do so, dedicating one section to each of those two tasks, although this is the core point of the study. Regarding the other papers, Abugabbara et al. (2023) allocates only a subsection to district heating business models, plus another one for best practices for those models, but is mostly centered on the broader scope of implementing 5th-generation heating and cooling in Sweden. Similarly, Johansen and Johra (2022) has its main focus on socio-technical perspectives on short-term thermal storage, and only dedicates a subsection to the role of business models, while Tschopp et al. (2020) primarily discusses large-scale solar thermal systems, with business models only covered in one subsection.

5.2. Devices

All papers that explicitly mention one or more devices (Popovic et al., 2024; Abugabbara et al., 2023; Williamsson, 2023; Arpagausa et al., 2023; Johansen and Johra, 2022; Sieverts Nielsen et al., 2022; Selvakkumaran et al., 2021; Tschopp et al., 2020) reference heat pumps. This is expected, as these studies focus on district heating, where heat pumps are the most commonly used device, particularly given the importance of heat-to-electricity conversion in this context. The study in Arpagausa et al. (2023) is more specialized, focusing specifically on industrial heat pumps. Some papers also address energy production in general terms (Popovic et al., 2024; Sieverts Nielsen et al., 2022), referring either to production units (Popovic et al., 2024) that serve as energy providers or to waste heat producers (Sieverts Nielsen et al., 2022), whose heat reuse is central to the study. Regarding energy production, boilers are also a recurring mentioned device, discussed in Sieverts Nielsen et al. (2022) and Tschopp et al. (2020) as main suppliers of heat. Finally, despite being relevant in the context of district heating, energy storage devices are notably underrepresented, with only (Tschopp et al., 2020) explicitly mentioning them. Although energy storage is the main topic of Johansen and Johra (2022), this work focuses on using the buildings themselves as energy storage facilities, rather than using specific storage devices. The works (Moser and Jauschnik, 2023; Torvanger, 2021; Leoni et al., 2020) do not explicitly mention devices.

5.3. Domain

Energy-related business models can target several domains, and this holds true also for models focusing on district heating. Most domain-specific papers focus on the residential sector (Abugabbara et al., 2023; Arpagausa et al., 2023; Torvanger, 2021; Tschopp et al., 2020; Leoni et al., 2020), which is the most common one. This makes sense, as many heating systems target houses or residential buildings, and most of the business models for energy in general are specifically designed for residential buildings. Energy business models are also quite common for some other domains, such as industries and offices. Industry-related models can be found, for example, in Arpagausa et al. (2023) and Tschopp et al. (2020). The case of Moser and Jauschnik (2023) is different, as no domain is specifically targeted, but the context in which the paper operates addresses generation from industrial waste heat. Regarding office-related models, they are discussed in Abugabbara et al. (2023) and Leoni et al. (2020). There are other domains, however, which are less common but still considered in some of the papers, such as tertiary (Abugabbara et al., 2023), hospital (Abugabbara et al., 2023), or public in general (Tschopp et al., 2020), commercial (Tschopp et al., 2020), and stores (Leoni et al., 2020). Finally, some papers (Popovic et al., 2024; Williamsson, 2023; Johansen and Johra, 2022; Sieverts Nielsen et al., 2022; Selvakkumaran et al., 2021) do not specify a domain, focusing instead on broader energy or business model topics.

5.4. Use case

Since we are examining business models in the context of district heating, it is reasonable to expect that many of the review papers we analyzed focus on cases operating at the district, community, or grid level. Indeed, the majority of them do so Popovic et al. (2024), Abugabbara et al. (2023), Moser and Jauschnik (2023), Arpagausa et al. (2023), Sieverts Nielsen et al. (2022), Selvakkumaran et al. (2021), Tschopp et al. (2020) and Leoni et al. (2020). However, there are exceptions: in some cases, business models in energy are more tailored toward individual customers rather than the entire grid or community. Consequently, we found review papers focused on this particular use case, such as Johansen and Johra (2022) and Torvanger (2021). Lastly, Williamsson (2023) stands out as it addresses three distinct levels: micro, meso/company, and macro. The micro level pertains mainly to individual consumers or living units, the meso level focuses on single or multiple buildings, and the macro level encompasses the utility company or municipality.

5.5. Location

Not all of the review papers we encountered focus on a specific geographical area, with some remaining more general in this regard (Arpagausa et al., 2023; Selvakkumaran et al., 2021; Torvanger, 2021; Leoni et al., 2020). However, many of the papers that do reference specific locations primarily focus on European regions, either broadly (Popovic et al., 2024) or on particular countries, most often in northern or central Europe. Northern European cases predominantly cover Sweden (Abugabbara et al., 2023; Williamsson, 2023) and Denmark (Johansen and Johra, 2022; Sieverts Nielsen et al., 2022), while the Central European cases we identified pertain to Austria (Moser and Jauschnik, 2023). Additionally, the work performed in Tschopp et al. (2020) focuses on four leading countries in large-scale solar thermal systems: Denmark as the frontrunner, followed by China, Germany, and Austria.

5.6. H/C

All of the papers we reviewed deal with heating, which is expected given that district heating is far more prevalent than cooling, and there are various ways to generate it, such as through heat pumps or biomass combustion. As a result, we did not find any studies that focus exclusively on district cooling. However, several papers (Popovic et al., 2024; Abugabbara et al., 2023; Arpagausa et al., 2023; Selvakkumaran et al., 2021) discuss both heating and cooling. Specifically, Popovic et al. (2024) and Selvakkumaran et al. (2021) refer to district heating and cooling networks in general, without separating them, while Abugabbara et al. (2023) actually mentions district heating

Table 6
Papers about novel business models in district heating and cooling.

Code	Paper	Title
N1	Lygnerud and Yang (2024)	Capturing flexibility gains by price models for district heating
N2	Yang et al. (2023)	Optimal planning of energy storage system under the business model of cloud energy storage considering system inertia support and the electricity-heat coordination
N3	González et al. (2023)	Thermal energy community-based multi-dimensional business model framework and critical success factors investigation in the mediterranean region of the EU
N4	Monsberger et al. (2023)	Profitability of biomass-based district heating considering different technology combinations and building flexibility
N5	Jiang et al. (2023)	Business model based on bidding strategy for the Wind Power Plant and District Heating System portfolio considering ancillary services
N6	Wang et al. (2023)	A Business model for Strategic Bidding of Wind Power Plant and District Heating System Portfolio
N7	Pakere et al. (2023)	Comparison of Suitable Business Models for the 5th-Generation District Heating System Implementation through Game Theory Approach
N8	Huang et al. (2022)	Economical heat recovery dynamic control and business model for supermarket refrigeration system coupled with district heating system
N9	Tan et al. (2022)	Strategic investment for district heating systems participating in energy and reserve markets using heat flexibility
N10	Faria et al. (2022)	Liberalized market designs for district heating networks under the EMB3Rs platform
N11	Wang et al. (2022a)	A new business model for coordinated operation of wind power plant and flexible district heating system
N12	Lygnerud et al. (2021)	Business models combining heat pumps and district heating in buildings generate cost and emission savings
N13	Liu et al. (2021)	District Heating Business Models and Policy Solutions: Financing Utilization of Low-Grade Industrial Excess Heat in the People's Republic of China
N14	Kontu et al. (2020)	Individual ground source heat pumps: Can district heating compete with real estate owners' return expectations?
N15	Tunzi et al. (2024)	Economic viability and scalability of a novel domestic hot water substation for 4th generation district heating: A case study of temperature optimization in the Viborg district heating network
N16	Christensen et al. (2025)	Multi-agent based modeling for investigating excess heat utilization from electrolyzer production to district heating network
N17	Steinegger et al. (2025)	Economic feasibility of supra-regional district heating networks: Addressing technical and economic considerations

and cooling separately, emphasizing the cooling aspect in terms of geographic relevance, use cases, and significance within the case studies analyzed. Finally, Arpagausa et al. (2023) touches on specific uses of heat pumps for cooling or temperature regulation, and explores the potential business model of cooling-as-a-service.

6. Novel business/pricing models

In this section, we discuss the papers that present novel business or pricing models for district heating or cooling, classifying them based on the features we consider relevant. Table 6 outlines the titles of these papers, also providing a reference code for future use throughout the paper.

We now briefly summarize the content of these papers. Lygnerud and Yang (2024) compares pricing models for integrating heat pumps into district heating networks in two Swedish case studies, demonstrating how heat pumps increase network flexibility, reduce costs and environmental impact, and how the lowest risk for district heating companies is achieved when the building owner invests in the heat pumps while the company operates them. In contrast, Yang et al. (2023) proposes an optimal planning strategy for an energy storage system within the Cloud Energy Storage (CES) model, organized in two layers: the upper layer model evaluates the battery station's installed capacity, while the lower layer model determines the CES system's optimal schedule. The study in González et al. (2023) focuses on identifying the main obstacles and success factors for thermal energy communities. It proposes a multi-dimensional business model framework, categorizing models based on geographical configuration (rural/urban) and demand profile (low/high seasonality), showing how clustered locations and industrial demand lead to the best results, and identifying the minimum natural gas tariff required to make the model feasible. Similarly, Monsberger et al. (2023) provides a profitability analysis of a heat pump/CHP unit in a biomass-based heating network. It shows that incorporating a heat pump capable of operating in the energy market increases system profitability and that government-supported use cases are economically advantageous. The works (Jiang et al., 2023; Wang et al., 2023) are closely related, as both propose business models based on bidding strategies for Wind Power Plant and District Heating System (WPP-DHS) portfolios. The primary difference is that Jiang et al. (2023) focuses on the ancillary service market by leveraging the flexibility of the district heating system, while Wang et al. (2023) targets the day-ahead market and addresses wind power production uncertainty. Similar to Lygnerud and Yang (2024) and Pakere et al. (2023) compares three business models, but in this case, they refer specifically to 5th-generation district heating and cooling. A feasibility study outlines the requirements for making the model profitable for stakeholders and highlights key aspects that will be important for future models. The target use case in Huang et al. (2022) is different from the other works and refers to a Supermarket Refrigeration System (SRS) coupled with a district heating system. Specifically, it first develops a cost-effective heat recovery control model for a heat recovery unit and, after that, it proposes business models of heat recovery based on two transactional strategies between the SRS and the district heating system. In contrast, Tan et al. (2022) introduces a strategic investment scheme for district heating systems participating in energy and reserve markets using a bi-level optimization approach. The upper-level problem estimates capacities and optimal offering and bidding strategies, while the lower-level problem models market clearing over specific days. Faria et al. (2022) draws inspiration from the electricity market innovation to propose market designs for the district heating networks, showing how those models compare within a specific use case in Denmark, and which revenues can be obtained by participating in the market. Wang et al. (2022a), similarly to Jiang et al. (2023) and Wang et al. (2023), proposes a business model for the coordinated operation of wind power plants and district heating to meet the heating demand for a local heating system. This model aims to reduce wind generation curtailment by better utilizing generated power, thereby increasing energy generation profits and cutting heat supply costs. A different approach is taken in Lygnerud et al. (2021), which presents a business model involving the widespread usage of heat pumps in district heat networks. The study compares cost and environmental benefits with other heat sources, highlighting improvements in these metrics under this model, but also acknowledging the challenges of large-scale implementation. Liu et al. (2021) reviews solutions adopted in China to improve the district heating market. This work analyzes three different business models aimed at increasing energy efficiency and four pricing options for industrial excess heat; after that, this study examines the effect of those models on district heating prices. Meanwhile, Kontu et al. (2020) compares the economic benefits of district heating versus ground source heat pumps, investigating whether district heating pricing can remain competitive against heat pump systems. It shows that new pricing models can boost district heating competitiveness and attract more customers. Tunzi et al. (2024) investigates 4th-generation district heating, addressing the challenges of operating low-temperature networks and proposing a business model in which the district heating company owns the substations. This ownership structure enables production cost savings and, consequently, a reduction in heating prices. A less conventional case is presented in Christensen et al. (2025), which focuses on Power-to-Hydrogen (P2H) technology and evaluates three business models for selling electrolyzer-generated energy to district heating grids. The study analyzes different scenarios for hydrogen production, with the goal of reducing both costs and CO2 emissions. Finally, Steinegger et al. (2025) considers the context of supra-regional district heating networks involving multiple heat suppliers. It proposes a solution to the associated challenges by implementing a merit-order bid pricing system based on the levelized cost of heat.

As in Section 5, we have defined some features used to classify the presented papers and business models: we chose features that define either

- Nature of the model: for example, which energy vectors are considered, or whether it regards heat or cold.
- Purpose of the model: for example, which service is provided, which benefit is pursued.
- Relevant information for implementation: for example, which granularity it uses, or whether it is market-ready or not.

The features are the following:

- **Granularity**: Refers to the time granularity considered by the business or pricing model, or in other words, the length of the time steps considered. It is expressed in minutes.
- **Vector**: Describes the energy vectors utilized or considered in the model, such as heat and electricity.
- **H/C**: Indicates whether the model focuses on heating, cooling, or both.
- **Devices**: Specifies the devices required for the model to function or mentioned in the use cases used to test the model.
- **Service**: Describes the services offered by the model (e.g., demand management, ancillary).
- **Network**: Identifies the type of network used to deliver the service (district heating, cooling, heating, and cooling).
- **Location**: Specifies whether the model is designed for a particular place or country, or where it has been implemented or simulated.
- **Provider type**: Describes the type of provider implementing the model, typically an actor serving multiple customers or the district heating system/network itself.
- **Benefits**: Outlines the goals of the business or pricing model, such as profit, environmental impact, or reduced consumption.
- **Constraints**: Describes whether the model has specific constraints needed for its functioning, or if it has been implemented under specific constraints and it is unknown whether it can work outside of them.
- **Market ready**: Indicates whether the model has been implemented in a real-world market or context, as opposed to just being simulated.
- **Methods**: Describes the methods used to define the business or pricing model, such as mathematical formulation or game theory.

For each feature, the compliance of each model is detailed in Table 7. Additionally, Table 8 explains the abbreviations used in Table 7. As in Section 5, we show how the features are applied to each paper in Fig. 3 and conversely, how each feature is addressed by the papers in Fig. 4.

In the following subsections, we analyze how each paper aligns with key features, identifying specific patterns and trends that arise from this analysis.

6.1. Granularity

The dominant time granularity for energy business models is hourly, which makes sense since electricity markets, the most prominent in the energy sector, typically experience hourly price fluctuations. This trend is also evident in heat business models: of the 17 models reviewed, 11 (all except (Monsberger et al., 2023; Pakere et al., 2023; Huang et al., 2022; Liu et al., 2021; Tunzi et al., 2024; Steinegger et al., 2025)) adopt an hourly granularity. In some works (Lygnerud and Yang, 2024; González et al., 2023; Jiang et al., 2023; Wang et al., 2023; Tan et al., 2022; Faria et al., 2022; Lygnerud et al., 2021; Kontu et al., 2020), the model itself is constructed with hourly granularity, while others are more time-generic but have been tested within hourly granularity scenarios (Yang et al., 2023; Wang et al., 2022a). The preference for hourly resolution is often linked to the operation of the day-ahead electricity market (Christensen et al., 2025), which uses this granularity, and many models involve electricity through energy conversion, thus needing to align with this standard. Furthermore, finer time resolutions complicate year-long simulations by significantly increasing the data points. Among the outliers, Monsberger et al. (2023) employs a rolling horizon approach to simulate operations for a full year with a 15 min resolution, while Steinegger et al. (2025) considers costs for fuel and CO2 which have a 15 min resolution and Huang et al. (2022) provides minute or sub-minute graphical results without specifying a time horizon. Lastly, Pakere et al. (2023), Liu et al. (2021) and Tunzi et al. (2024) do not specify any time granularity, which is not evident in their experiments.

6.2. Vector

Given that we are exploring business and pricing models for district heating and cooling, it is no surprise that all the reviewed papers include heat as a key energy vector. Similarly, every paper also considers electricity: this is logical because of the widespread use of heat pumps, and the fact that many heat-focused business models are still linked to the electricity market. Heat-to-electricity conversion is essential for models to interact with these markets. However, the significance of electricity varies across papers. For instance, as shown in Section 6.4, many of the works (all but Yang et al. (2023), González et al. (2023), Huang et al. (2022), Christensen et al. (2025) and Steinegger et al. (2025)) include or at least reference heat pumps, devices that convert electricity into heat. Furthermore, several papers (Lygnerud and Yang,

[N1]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP
Service: DM
Network: Heating
Location: Sweden
Provider type:Platform supplier
Benefits: Consumption
Constraints: No
Market readiness: Yes
Methods: Mat. Opt.

[N2]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: Storage
Service: DM
Network: Heating
Location: China
Provider type:Storage operator
Benefits: Profit
Constraints: CES
Market readiness: No
Methods: Mat. Opt.

[N3]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: Boiler
Service: DM
Network: Heating
Location: Spain
Provider type: LEC, ESCO
Benefits: Profit,CO2
Constraints: No
Market readiness: Yes
Methods: N/A

[N4]
Granularity: 15m
Vector: Heat, electricity
H/C: Heat
Devices: HP, CHP
Service: DM
Network: Heating
Location: Austria
Provider type: DH utility
Benefits: Profit
Constraints: Biomass
Market readiness: No
Methods: Mat. Opt.

[N5]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP, Storage
Service: Ancillary
Network: Heating
Location: Denmark
Provider: WPP-DHS company
Benefits: Profit, freq.
Constraints: WPP
Market readiness: No
Methods: Mat. Opt.

[N6]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP, Storage
Service: DM
Network: Heating
Location: Denmark
Provider: WPP-DHS company
Benefits: Profit
Constraints: WPP
Market readiness: No
Methods: Mat. Opt.

[N7]
Granularity: N/A
Vector: Heat, electricity
H/C: Both
Devices: HP
Service: DM
Network: Heat, cooling
Location: N/A
Provider: DH system operator
Benefits: Profit
Constraints: 5th gen
Market readiness: Yes
Methods: Game theory

[N8]
Granularity: 1m
Vector: Heat, electricity
H/C: Both
Devices: HRU, SRS
Service: DM, Ancillary
Network: Heating
Location: Denmark
Provider type: DH system
Benefits: Profit
Constraints: SRS
Market readiness: No
Methods: Mat. Opt.

[N9]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP, CHP, storage
Service: DM, Ancillary
Network: Heating
Location: N/A
Provider type: DH system
Benefits: Profit
Constraints: No
Market readiness: No
Methods: Mat. Opt.

[N10]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP, CHP, data center
Service: DM
Network: Heating
Location: Denmark
Provider type: DH network
Benefits: Profit, CO2
Constraints: No
Market readiness: No
Methods: Mat. Opt.

[N11]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP, storage
Service: DM
Network: Heating
Location: Denmark
Provider: WPP-DHS company
Benefits: Profit
Constraints: WPP
Market readiness: No
Methods: Mat. Opt.

[N12]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP
Service: DM
Network: Heating
Location: Sweden
Provider type: DH network
Benefits: Profit, CO2
Constraints: No
Market readiness: No
Methods: N/A

[N13]
Granularity: N/A
Vector: Heat, elec.,gas
H/C: Heat
Devices: HP, boiler, SH
Service: DM
Network: Heating
Location: China
Provider: Heat utility, ESCO
Benefits: Profit
Constraints: Industrial heat
Market readiness: Yes
Methods: N/A

[N14]
Granularity: 60m
Vector: Heat, electricity
H/C: Heat
Devices: HP
Service: DM
Network: Heating
Location: Finland
Provider type: DH system
Benefits: Cust. increase
Constraints: Ground HPs
Market readiness: No
Methods: Mat. Opt.

[N15]
Granularity: N/A
Vector: Heat, electricity
H/C: Heat
Devices: HP, storage, boiler
Service: DM
Network: Heating
Location: Denmark
Provider: Users, DHSO
Benefits: Temperature
Constraints: 4th gen, HWS
Market readiness: No
Methods: Mat. Opt.

[N16]
Granularity: 60m
Vector: Heat, electricity, hydr.
H/C: Heat
Devices: Electrolyzer
Service: DM
Network: Heating
Location: Denmark
Provider type: P2HC
Benefits: Profit, CO2
Constraints: P2H
Market readiness: No
Methods: N/A

[N17]
Granularity: 60m
Vector: Heat, electricity, gas
H/C: Heat
Devices: HGU
Service: DM
Network: Heating
Location: Austria
Provider type: DH network
Benefits: Profit
Constraints: No
Market readiness: No
Methods: Mat. Opt.

Fig. 3. Papers about business models by features.

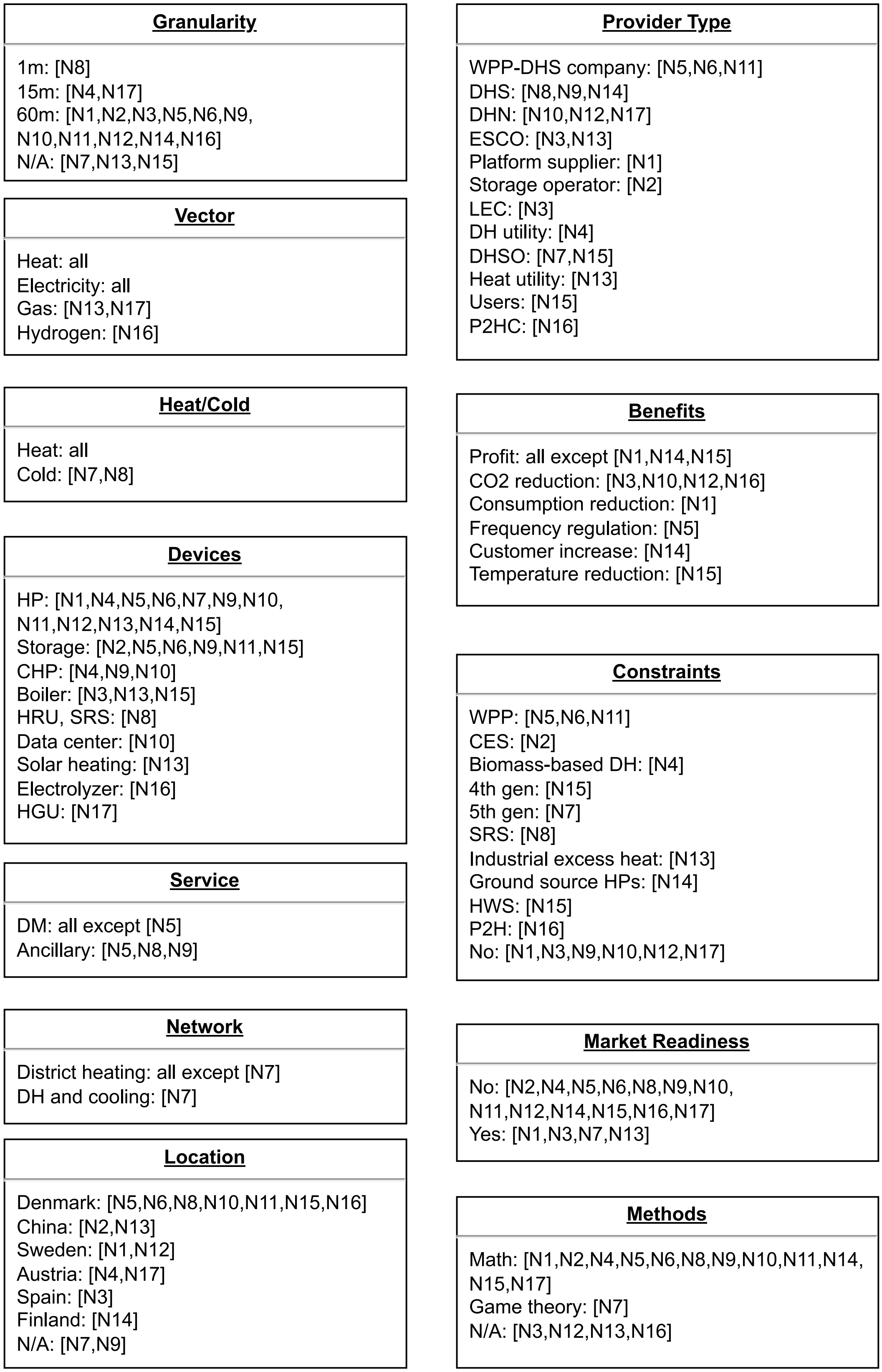

Fig. 4. Features by papers about business models.

2024; Monsberger et al., 2023; Jiang et al., 2023; Wang et al., 2023; Huang et al., 2022; Tan et al., 2022; Faria et al., 2022; Wang et al., 2022a; Lygnerud et al., 2021; Tunzi et al., 2024) utilize electricity to engage with markets, while others (Yang et al., 2023; González et al., 2023; Tan et al., 2022; Faria et al., 2022; Wang et al., 2022a; Liu et al., 2021; Kontu et al., 2020; Steinegger et al., 2025) feature models that regard both heat and electricity, such as CHP. Electricity plays a minor role in Pakere et al. (2023), where it is limited to heat pump operation.

Table 7
Classification of the papers about business models.

Code	Paper	Gran.	Vector	H/C	Devices	Service	Network	Location	Provider type	Benefits	Constr.	Market ready	Methods
N1	Lygnerud and Yang (2024)	60 m	Heat Elec.	Heat	HP	DM	DH	Sweden	Suppl.	Cons.	No	Yes	Mat.
N2	Yang et al. (2023)	60 m	Heat Elec.	Heat	ES	DM	DH	China	CESO	Profit	CES	No	Mat.
N3	González et al. (2023)	60 m	Heat Elec.	Heat	Boiler	DM	DH	Spain	LEC ESCO	CO2 Profit	No	Yes	N/A
N4	Monsberger et al. (2023)	15 m	Heat Elec.	Heat	HP CHP	DM	DH	Austria	DHU	Profit	Biom.	No	Mat.
N5	Jiang et al. (2023)	60 m	Heat Elec.	Heat	H ES	Anc.	DH	Denmark	WPP-DHS company	Freq. Profit	WPP	No	Mat.
N6	Wang et al. (2023)	60 m	Heat Elec.	Heat	HP ES	DM	DH	Denmark	WPP-DHS company	Profit	WPP	No	Mat.
N7	Pakere et al. (2023)	N/A	Heat Elec.	Both	HP	DM	DHC	N/A	DHSO	Profit	5th-gen	Yes	GT
N8	Huang et al. (2022)	1 m	Heat Elec.	Both	HRU SRS	DM Anc.	DH	Denmark	DHS	Profit	SRS	No	Mat.
N9	Tan et al. (2022)	60 m	Heat Elec.	Heat	HP CHP ES	DM Anc.	DH	N/A	DHS	Profit	No	No	Mat.
N10	Faria et al. (2022)	60 m	Heat Elec.	Heat	HP CHP DC	DM	DH	Denmark	DHN	CO2 Profit	No	No	Mat.
N11	Wang et al. (2022a)	60 m	Heat Elec.	Heat	HP ES	DM	DH	Denmark	WPP-DHS company	Profit	WPP	No	Mat.
N12	Lygnerud et al. (2021)	60 m	Heat Elec.	Heat	HP	DM	DH	Sweden	DHN	CO2 Profit	No	No	N/A
N13	Liu et al. (2021)	N/A	Heat Elec. Gas	Heat	HP Boiler SH	DM	DH	China	Utility ESCO	Profit	Ind.	Yes	N/A
N14	Kontu et al. (2020)	60 m	Heat Elec.	Heat	HP	DM	DH	Finland	DHS	Cust.	Ground	No	Mat.
N15	Tunzi et al. (2024)	N/A	Heat Elec.	Heat	HP ES Boiler	DM	DH	Denmark	Users DHSO	Temp.	4th-gen HWS	No	Mat.
N16	Christensen et al. (2025)	60 m	Heat Elec. Hydr.	Heat	ELE	DM	DH	Denmark	P2HC	CO2 Profit	P2H	No	N/A
N17	Steinegger et al. (2025)	15 m	Heat Elec. Gas	Heat	HGU	DM	DH	Austria	DHN	Profit	No	No	Mat.

Few studies incorporate other energy vectors. For instance, Liu et al. (2021) includes gas boilers, while Steinegger et al. (2025) considers gas-powered cogeneration units, requiring the model to account for gas prices. A unique approach is presented in Christensen et al. (2025), which focuses on hydrogen as an energy vector. In this case, electricity is used to produce hydrogen via electrolysis, with the resulting excess heat subsequently supplied to the district heating grid.

6.3. H/C

All the reviewed papers, including those in Section 5, are focused on district heating and therefore consider the heating part. Again, this is to be expected, heating being more common than cooling in the regions where the research on this topic is more active. As we will see in Section 6.7, many of these research works refer to scenarios in northern Europe. Also, in general, district heating is way more common than district cooling. Nevertheless, two papers do address both heating and cooling. Specifically, Pakere et al. (2023) refers generically to district heating and cooling, noting that cooling prices are 20% higher than heating prices. Additionally, Huang et al. (2022) examines supermarket refrigeration systems and the waste heat generated by them, so it must take into account both the heating and the cooling demand.

6.4. Devices

Heat pumps are common in contexts where heating is central, or district heating is used: we can see that all works, except for Yang et al. (2023), González et al. (2023), Huang et al. (2022), Christensen et al. (2025) and Steinegger et al. (2025), either include or mention them. As noted, electricity plays a vital role in district heating, since the electricity market is the most common energy market; this makes energy conversion and electricity market operations attractive for many business models that also provide heat to customers. Another use of electricity, discussed in Section 6.2 is CHP, which, while not a device per se, is a key technology in Monsberger et al. (2023), Tan et al. (2022), and Faria et al. (2022). Boilers, referenced in González et al. (2023), Liu et al. (2021) and Tunzi et al. (2024), are also common for generating heat in district heating systems. Energy storage is widely employed in business models (Yang et al., 2023; Wang et al., 2023; Tan et al., 2022; Wang et al., 2022a; Tunzi et al., 2024), whether for heating or electricity. Batteries and storage devices in general are key sources of flexibility, which can be leveraged to operate in the energy market. In cases of energy production, storage allows for increased self-consumption by shifting energy use to different times. Less common devices are also explored: for instance, Liu et al. (2021) is the only model that considers solar heating. Additionally, Faria et al. (2022)

Table 8
Acronyms used in Table 7.

Gran.		H/C	
Gran.	Granularity	H/C	Heating/Cooling
Vector		Methods	
Elec.	Electricity	Mat.	Mathematical formulation
Hydr.	Hydrogen	GT	Game theory
Devices			
HP	Heat pump		
CHP	Combined heat and power		
ES	Energy storage		
HRU	Heat recovery unit		
SRS	Supermarket refrigeration system		
DC	Data center		
SH	Solar heating		
ELE	Electrolyzer		
HGU	Heat generation unit		
Service		Network	
DM	Demand management	DH	District heating
Anc.	Ancillary	DHC	District heating and cooling
Provider type			
Suppl.	Platform supplier		
CESO	Cloud energy storage operator		
LEC	Local energy community		
ESCO	Energy Service Company		
DHU	District heating utility		
WPP-DHS	Wind Power Plant and District Heating System		
DHSO	District Heating System Operator		
DHS	District Heating System		
DHN	District Heating Network		
Utility	Heat utility		
P2HC	Power-to-Hydrogen company		
Benefits			
Cons.	Consumption decrease		
Profit	Profit increase or cost decrease		
CO2	CO2 emission reduction		
Freq.	Frequency regulation		
Cust.	Customer increase		
Temp.	Temperature reduction		
Constr.			
Constr.	Constraints		
CES	Cloud energy storage		
Biom.	Biomass-based District Heating		
WPP	Wind Power Plant		
Xth-gen	Xth-generation District Heating and Cooling		
SRS	Supermarket refrigeration system		
Ind.	Industrial excess heat		
Ground	Ground source heat pumps		
HWS	Hot water substation		
P2H	Power-to-Hydrogen		

includes heat produced by data centers, along with heat from heat pumps and CHP units. Lastly, there are some works considering unique devices: Huang et al. (2022) focuses primarily on SRS and the design of control units for heat recovery systems, which are the main devices in that study, while Christensen et al. (2025) explores the P2H technology and therefore analyzes the case of electrolyzers, and Steinegger et al. (2025) adopts the perspective of heat suppliers and therefore considers heat generation units.

6.5. Service

Most services either focus on demand management or indirectly achieve it by exploiting flexibility. Lygnerud and Yang (2024), González et al. (2023) and Kontu et al. (2020) explicitly address it, while Yang et al. (2023) specifically targets inertia support demand: this is because system inertia support is one of its key topics. Monsberger et al. (2023) covers demand-side management for six buildings, and Wang et al. (2023) handles demand while also operating in the day-ahead market, rather than in frequency markets, which handle ancillary services. Demand is similarly discussed in Pakere et al. (2023), though in the context of DHC services. Meeting the demand load is the focus in Faria et al. (2022), Wang et al. (2022a), Liu et al. (2021), Tunzi et al. (2024), Christensen et al. (2025) and Steinegger et al. (2025), while Lygnerud et al. (2021) has the objective of covering peak heat demand in both the considered use cases, by using either heat pumps or district heating. In addition to this, two papers also address ancillary services: such is the case of Jiang et al. (2023), which proposes a business model operating on the frequency regulation market, and Huang et al. (2022). This work retains the objective of supplying heating and cooling for supermarkets, noting that SRS is a good flexibility source for providing ancillary services, although this specific case is not treated by the proposed model. Finally, Tan et al. (2022) highlights the balance between heat generation and demand in district heating systems, operating in both the energy and reserve markets and, therefore, effectively offering ancillary services.

6.6. Network

In Section 6.3, we noted that heating is central to all the papers we reviewed. Since this work focuses on district heating and cooling, heating is more prevalent for the reasons outlined in that section; primarily geographical location, which will be discussed in detail in Section 6.7, and the fact that, in general, district heating is more common than cooling. Because of these reasons, all the works consider the district heating network. The only exception to this can be found in Pakere et al. (2023), which specifically targets 5th-generation district heating and cooling networks, discussing local market business models and comparing them to existing high-temperature district heating systems. As mentioned in Section 6.3, Huang et al. (2022) also addresses cooling, given its focus on SRS; however, since these systems provide cooling, the only network discussed in this work is district heating.

6.7. Location

Almost all the works we found either refer to contexts in Europe or have run their simulations based on data from Europe. The country with the highest number of tested models is Denmark (Jiang et al., 2023; Wang et al., 2023; Huang et al., 2022; Faria et al., 2022; Wang et al., 2022a; Tunzi et al., 2024; Christensen et al., 2025), although this is influenced by the fact that works (Jiang et al., 2023; Wang et al., 2023, 2022a) were developed from the same core idea, within the same context (as highlighted in the following sections), and share some common authors. Nonetheless, many of these works stem from research conducted in northern Europe: for instance, Lygnerud and Yang (2024) and Lygnerud et al. (2021) refer to data from Sweden, while Kontu et al. (2020) simulates a scenario from Finland. Regarding other European countries, the work performed in González et al. (2023) specifically addresses Spain, while Monsberger et al. (2023) and Steinegger et al. (2025) describe models developed specifically in Austria. Outside of Europe, the only representation we found is from China: Yang et al. (2023) validates its model using data from that country, and Liu et al. (2021) focuses on specific Chinese cases and scenarios. Finally, Pakere et al. (2023) and Tan et al. (2022) do not reference specific geographical locations. However, Pakere et al. (2023) analyzes obstacles to the development of 5th-generation heating and cooling in the Baltic States (i.e., Estonia, Latvia, and Lithuania). Conversely, Tan et al. (2022) discusses previous work done in Denmark, though it does not pertain specifically to that model.

6.8. Provider type

Providers may vary depending on the work considered, the targeted use case, and the scenario examined. They can be referred to as the district heating system (Huang et al., 2022; Tan et al., 2022; Kontu et al., 2020), network (Faria et al., 2022; Lygnerud et al., 2021) or utility (Monsberger et al., 2023) itself, although in Pakere et al. (2023) it is explicitly designated as the district heating system operator. A similar situation applies to works (Jiang et al., 2023; Wang et al., 2023), and Wang et al. (2022a): they all refer to the specific case of a WPP-DHS, as previously noted in Section 6.7, and the provider is identified as the energy company owning the WPP-DHS. Other works reference different entities: in Lygnerud and Yang (2024), this role is attributed to the platform supplier, while Yang et al. (2023) designates it as the cloud energy storage operator, which is also the actor whose perspective the work adopts. Furthermore, in González et al. (2023), the two main proposed models have the local energy community itself to play this role, either by itself or in cooperation with the energy service company. Lastly, for Liu et al. (2021), the energy service company is recognized as responsible for this task in one of the proposed models, and the heat utility for the others. More generally, the involved stakeholders depend on the selected model and are not always specified in the papers. The work performed in Lygnerud and Yang (2024) identifies four key stakeholders: the digital tool provider, the aggregator, the district heating company, and the building owner. Those stakeholders interact based on their respective responsibilities. In Yang et al. (2023), the involved parties are the energy storage suppliers, the CES operator, and the CES users, with the CES operator interacting with the others, while González et al. (2023) only describes them generically within its bottom-up framework, focusing on specific use cases in the section describing the state of the art. Similarly, Monsberger et al. (2023) remains vague, mainly mentioning the district heating utility at the center of the model. As noted earlier, the wind power plant and district heating system are the main actors for Jiang et al. (2023), Wang et al. (2023), and Wang et al. (2022a), along with the day-ahead energy market and the ancillary service market in the specific case of Jiang et al. (2023). Likewise, Pakere et al. (2023) explicitly identifies its main stakeholders as consumers/prosumers, energy producers, and system operators. The study in Huang et al. (2022) is very specific, identifying the main actors as the district heating system and supermarket refrigeration systems, while Tan et al. (2022) outlines two main layers: one with district heating system investors as the primary stakeholders, and another where the market operator is the main actor. Faria et al. (2022) only refers to stakeholders generically without further specification. In contrast, Lygnerud et al. (2021) identifies district heating customers and operators as the main stakeholders, while Liu et al. (2021) describes the energy service company and the heat utility as significant parties and Kontu et al. (2020) recognizes the district heating system and its customers as the principal actors. The scenario in Tunzi et al. (2024) is more nuanced, as it explores two distinct business models: a user-based model, in which end-users act as investors in the substation and bear the operational costs; and a company-owned model, where the district heating provider assumes both capital and operational expenditures. In Christensen et al. (2025), multiple stakeholders are involved, with the P2H company responsible for selecting the hydrogen production method and defining the operational strategy. Lastly, Steinegger et al. (2025) addresses the complexities of supra-regional district heating networks by proposing a model that manages interactions among multiple heat suppliers.

6.9. Benefits

The most evident benefit that a business model can pursue is profit increase or cost reduction. This holds true for the majority of models we have encountered, as each model seeks to maximize profit as a primary objective, with only three exceptions (Lygnerud and Yang, 2024; Kontu et al., 2020; Tunzi et al., 2024). This is accomplished by leveraging the existing energy market, primarily for electricity, such as the day-ahead and frequency regulation markets. Consequently, electricity is a very common vector in the models we have found, as described in Section 6.2. Specifically regarding energy-related business models, CO2 emission reduction is also a crucial target, as the energy transition aims primarily to reduce emissions and generally has an environmental rationale for its development. We can observe that four models explicitly pursue this goal (González et al., 2023; Faria et al., 2022; Lygnerud et al., 2021; Christensen et al., 2025), where profit is a parallel objective. However, in contexts outside district heating, there have been instances where pricing models also depend on CO2 emissions, making profit maximization an objective that simultaneously minimizes environmental impact. Among others, Lygnerud and Yang (2024) aims for a reduction in consumption: this is also common in electricity models, which more often search for increased self-consumption. However, renewable production is considered less often in district heating models, so self-consumption does not appear in any of the considered works. We have seen that Jiang et al. (2023) targets ancillary service and frequency regulation markets; thus, the model proposed there lists frequency regulation as one of its main objectives. Regarding (Kontu et al., 2020), the aim is to increase the number of customers for district heating, attempting to counteract the trend of existing customers leaving district heating and the scarcity of new customers, largely due to the presence of heat pumps. Finally, Tunzi et al. (2024) has the main objective of lowering the operational temperature of the district heating network, and ensuring operations while this happens.

Diving deeper into the economic benefits of each model, Lygnerud and Yang (2024) records a 20% decrease in heating costs and a 25% reduction in system costs, with the potential to enhance profits by between 0 and 30% at one site, achieving even better results at another. Meanwhile, Yang et al. (2023) demonstrates a profit increase of 15.26% via the installation of energy storage, although the effectiveness of the business model is evidenced by the reduction in the needed installed capacity for storage. In González et al. (2023) we see some profit for users when gas prices are high, although not quantified as a percentage, while Monsberger et al. (2023) reports profitability increases of 65% and 61% for the operational and investment support use cases, respectively. Two similar works (Jiang et al., 2023; Wang et al., 2023) show a 2.44% revenue increase from the ancillary service market and an increase in revenue of 1,005 EUR (not quantified as a percentage) from the day-ahead market, respectively. Likewise, Pakere et al. (2023) demonstrates increases in revenue across various scenarios; however, those increases are dependent on energy prices and not quantified as percentages. Meanwhile, Huang et al. (2022) identifies two transactional strategies, and a cost reduction of up to 93% and 41% in the best cases, respectively. In Tan et al. (2022), a profit increase for the district heating system of around 2.23% is noted, while Faria et al. (2022) does not indicate specific revenue increases or cost reductions, and Wang et al. (2022a) implies a decrease in heating system costs of about 35%. Similarly, Lygnerud et al. (2021) shows cost savings of up to 33% for the optimal use of heat pumps in the district heating network, and Liu et al. (2021) indicates a financial return rate of 10% by savings on fuel costs. Regarding (Kontu et al., 2020), it illustrates how optimized heat pumps result in lower costs compared to district heating, by up to 33%, while Tunzi et al. (2024) reports temperature reductions of 4.6 °C and 0.43 °C for supply and return lines, respectively, along with a 2.7% decrease in heating costs for users. Finally, Christensen et al. (2025) achieves a 5.6% reduction in hydrogen production costs through the sale of excess heat, while Steinegger et al. (2025) analyzes variations in unit energy cost based on several parameters and demonstrates a potential cost reduction of up to 44%.

6.10. Constraints

Several works are generic and do not specify constraints, target particular devices or use cases, or require specific equipment (Lygnerud and Yang, 2024; González et al., 2023; Tan et al., 2022; Faria et al., 2022; Lygnerud et al., 2021). Among the others, Yang et al. (2023) is dedicated to cloud energy storage, focusing specifically on this use case. Similarly, as discussed in Section 6.8, Jiang et al. (2023), Wang et al. (2023), and Wang et al. (2022a) all pertain to WPP-DHS, each addressing specific instances where wind power plants are utilized. Additionally, Monsberger et al. (2023) is focused on biomass-based district heating, as this study aims to explore this case. Likewise, Pakere et al. (2023) targets 5th-generation district heating and cooling, proposing models to address the challenges this new technology faces, while Tunzi et al. (2024) refers to 4th generation district heating, and specifically to the case of the presence of domestic hot water substations. We have also noted in Sections 6.4 and 6.6 that the central theme of Huang et al. (2022) is SRS, and the model directly pertains to that. Regarding (Liu et al., 2021), it explicitly targets industrial excess heat, and the model is tailored to this specific scenario, whereas Kontu et al. (2020) is a more generic model that specifically employs ground source heat pumps, which are integral to the model as one of the considered heating systems. Finally, Christensen et al. (2025) is a model that refers specifically to the context of the usage of P2H technology.

6.11. Market ready

Among the papers we have found, four of them Lygnerud and Yang (2024), González et al. (2023), Pakere et al. (2023) and Liu et al. (2021) describe models that have actually been implemented in real scenarios, while the remaining ten detail models that have been simulated but not yet applied in practice. Specifically, Lygnerud and Yang (2024) compares two pricing models that have been employed in Sweden across two sites, although these models have not been widely adopted, and this work emphasizes that the results pertain to a small-scale case. In contrast, González et al. (2023) describes existing business models and evaluates their economic viability in various scenarios, comparing them based on specific Key Performance Indicators (KPIs). A similar evaluation of existing business models is conducted by Pakere et al. (2023), albeit within the novel context of 5th-generation district heating and cooling. Lastly, Liu et al. (2021) analyzes three business models aimed at improving profits from excess heat utilization, specifically within the Chinese context. Regarding models that have not yet been implemented in real cases, Yang et al. (2023) and Tan et al. (2022), and the three similar models (Jiang et al., 2023; Wang et al., 2023, 2022a) have only been tested in simulations thus far. As for Monsberger et al. (2023), it will need to incorporate market participation charges and costs before real implementation, consider use cases without a central storage tank, and include technical details about CHP and heat pumps. Meanwhile, Huang et al. (2022) will address the SRS's flexible demand response to specific ancillary service requirements, examining integration with both the electric grid and the district heating system. Furthermore, Faria et al. (2022) asserts that the model is ready for implementation in real cases but would benefit from exploring larger networks and conducting a full thermal characterization of the network. Kontu et al. (2020) will need to analyze different locations and various prosumer profiles for real-case implementation, while Tunzi et al. (2024) would benefit from investigating scenarios involving stricter penalties for constraint violations and greater incentives for reducing operating temperatures. Christensen et al. (2025) requires a more detailed modeling of the district heating network and electrolyzer operation. Lastly, Steinegger et al. (2025) should consider additional market strategies, year-to-year weather variability in heat costs, and the implications of the proposed pricing model on existing contractual and infrastructural arrangements.

6.12. Methods

Mathematical formulation is the most common approach for novel business models, as the majority of them have adopted it; specifically, every model except (González et al., 2023; Lygnerud et al., 2021; Liu et al., 2021; Tunzi et al., 2024; Christensen et al., 2025) adopted this approach, while these five works do not explain in detail how the models work. This trend arises from the relative novelty of models for district heating, which diminishes the need for complex or unconventional methods: in many cases, a straightforward mathematical definition of the agents' behavior is, although simple, sufficiently novel to establish a new model. A particular mention should be made of Pakere et al. (2023), which employs an approach based on game theory: as in this case, many game-theoretical approaches allow players and competitors to achieve the best outcome for all by optimizing their individual gains. Regarding the other models, all define optimization problems, where an objective function is either minimized or maximized according to the given constraints. More specifically, Lygnerud and Yang (2024) calculates marginal costs and emissions, defining an optimization problem for cost minimization while satisfying the heat demand constraints; similarly, Yang et al. (2023) formulates two optimization problems aimed at maximizing the annual profit and operational revenue of the CES system, by outlining the operational constraints of the energy storage. The model presented in Monsberger et al. (2023) is more complex, defining the generation and storage technologies, building flexibility, and electricity and balance markets before minimizing the cost function. The works (Jiang et al., 2023; Wang et al., 2023, 2022a) all aim to maximize Wind Power Plant (WPP) profit while applying bid, device, and network constraints, which vary across the works. In Huang et al. (2022), the heat recovery process is defined and optimized, presenting two transactional strategies: one prioritizing energy self-consumption and the other prioritizing buying and selling energy. In Tan et al. (2022), there are two levels: one optimizing investment and operational costs, while taking into account investment, operational, network, and device constraints, and the other maximizing the total social welfare in both energy and reserve markets, while considering operational, market, and device constraints. The case of Faria et al. (2022) is different, as the objective function to be minimized is the transaction cost, again subject to operational and trading constraints. On the other hand, in Kontu et al. (2020), the problem involves optimizing the heat pump side for maximum economic revenue, taking into account all costs and various input data for the heat pump specifications. Finally, Steinegger et al. (2025) defines levelized costs of heat depending on the amount of heat provided across the years and operational/capital costs, along with three different operation modes, aiming for prices from each heat generation unit to converge.

7. Discussion

This section presents the key findings from this study, covering both review papers on district heating business models and papers describing the models themselves.

7.1. Reviews

In Section 5, we discussed the 11 review papers identified.

Although all these reviews meet the search criteria outlined in Section 4, only four explicitly focus on business or pricing models, highlighting a scarcity of reviews dedicated to these aspects in the DHC sector. Those papers have significant differences from this work, as discussed in Section 3.4. Additionally, most reviews center on district heating, with some covering both heating and cooling, yet none specifically address district cooling. Another key observation is the frequent mention of heat pumps, as discussed in Section 5.2. Conversely, relatively few reviews omit device-specific discussions or focus on energy production, boilers, or energy storage, indicating a gap in device-specific business model reviews beyond heat pumps. Furthermore, the geographical distribution of these reviews reveals a strong focus on Northern European countries, with some coverage of China and other European nations. However, research on business and pricing models for heating remains largely unexplored in other Asian countries and, more broadly, across continents outside Europe.

These insights point to several potential research directions. First, there is a lack of review papers dedicated specifically to analyzing and comparing business models for district heating or cooling. Given the increasing number of studies in this domain, targeted reviews could provide valuable syntheses. In particular, district cooling remains underexplored, and as research on this topic expands, a comprehensive review will be necessary. Second, most existing reviews are not device-specific, apart from those focusing on heat pumps. Notably, there is an absence of reviews dedicated to CHP systems, despite their significance in district heating networks. Finally, as district heating expands to new regions, future reviews should address the adoption of business models in countries beyond the current Northern European and Chinese focus.

7.2. Technical papers about business and pricing models

This subsection presents findings from the 17 papers analyzed in Section 6, which introduce novel business and pricing models or enhancements to existing ones. A key pattern concerns device focus: most studies center on heat pumps, with only a few exceptions (Yang et al., 2023; Huang et al., 2022; Christensen et al., 2025; Steinegger et al., 2025), which refer to extremely specific scenarios oriented towards one precise device or technology. This highlights a gap in research on business models tailored to other devices. Moreover, similar to review papers, nearly all studies focus exclusively on district heating, with the exception of Pakere et al. (2023), which considers both heating and cooling.

Other notable trends include the widespread adoption of a 60 min time granularity and the common inclusion of electricity as an energy vector alongside heat. This is expected, given that electricity markets operate predominantly on an hourly basis (e.g., day-ahead markets), making finer granularity unnecessary except in specific cases such as Monsberger et al. (2023), which employs a rolling horizon approach, Huang et al. (2022), which requires real-time operation for a supermarket refrigeration system, and Steinegger et al. (2025), which also considers CO2 and fuel costs, which have a 15 min granularity. This pattern aligns with the prevalent use of mathematical optimization models, as the identified models naturally lend themselves to optimization frameworks with well-defined constraints. The correlation between time granularity and modeling approaches has been explored in Lilliu et al. (2024), which examines business models for electricity networks. It was found that finer granularity is more common in machine learning-based models, which require large datasets for training. However, such models have yet to be widely applied to district heating and cooling. Furthermore, several limitations and shortcomings from the current models have emerged. Notably, many have yet to be implemented in real-world scenarios — an expected outcome given their theoretical nature and the need to resolve key practical challenges before market adoption. Common limitations include validation limited to small communities (Lygnerud and Yang, 2024; Faria et al., 2022), insufficient consideration of current market dynamics (Monsberger et al., 2023; Christensen et al., 2025; Steinegger et al., 2025), inadequate integration with existing electricity and heat infrastructures (Huang et al., 2022), and a lack of applicability to broader, more generalized contexts (Kontu et al., 2020; Tunzi et al., 2024).

These findings suggest several promising directions for future research. First, while heat pumps are a natural choice for electricity-to-heat conversion, business models for district heating incorporating other types of devices remain largely unexplored. Investigating tailored models for different devices, building types, and operational scenarios could yield valuable insights. Second, as district cooling becomes more prevalent, dedicated research on its business and pricing models will be essential to support its growth. Third, methodologies widely used in electricity networks, such as machine learning-based modeling (Lilliu et al., 2024), have not been extensively explored in the district heating and cooling context. Given the recent advancements in machine learning, its application to business and pricing models in this sector presents a significant research opportunity, as has already been demonstrated in electricity markets (Tightiz and Yoo, 2023; Balakumar et al., 2023).

An additional avenue for research concerns optimization objectives. A notable distinction between district heating and electricity systems is that, while peak shaving is a common priority in electricity networks (Lilliu et al., 2024), it is largely absent from district heating models, where the primary focus is on thermal energy management. Nevertheless, objectives such as managing peak heat demand and promoting energy self-consumption among decentralized producers could provide valuable new directions for district heating business models.

7.3. Key takeaways

Table 9 summarizes the key insights from our review. The left-hand column outlines the current state of research, while the right-hand column proposes potential future directions to address identified gaps. Specifically, the latest developments of business and pricing models for district heating and cooling point out to:

- A predominant focus on heating rather than cooling.
- Widespread inclusion of heat pumps in model design.
- A concentration on case studies in European countries, particularly in Northern Europe, with a few examples from China.
- Frequent use of mathematical optimization methods, typically with a 60-min time resolution aligned with market pricing intervals.
- Profit maximization as the prevailing modeling objective.

On the other hand, several underexplored areas present opportunities for future research:

- Business models for district cooling.
- Alternative technologies such as CHP systems.
- Case studies beyond the European or Chinese context.
- Integration with machine learning techniques.
- Strategies for peak shaving.

Additionally, there is a need for more systematic reviews specifically focused on business and pricing models for district heating and cooling, as existing literature on this topic remains limited.

7.4. Limitations in our work

While we have aimed to make this review as comprehensive and accurate as possible, certain limitations must be acknowledged:

1. Our search was conducted exclusively through the Scopus database; as a result, relevant studies indexed elsewhere may have been overlooked.
2. We focused on publications from January 2020 onwards to capture the most recent developments, thereby excluding earlier contributions.
3. Only English-language papers were included. As noted in Section 4, this led to the exclusion of a Chinese-language paper and may have resulted in the omission of other non-English works, depending on the database's indexing and keyword filtering.
4. Our keyword selection, while carefully chosen to align with the study's objectives, may have inadvertently excluded relevant papers using alternative terminology.

Table 9
Key findings.

Current state of research	Possible future direction
No papers focusing on district cooling.	Business models on district cooling are needed.
Many papers focus on heat pumps.	Room for research on models targeting CHP or other devices.
All the papers refer to Europe or China.	New models can be developed on scenarios from other countries.
Too few reviews specialized on business or pricing models).	There is room for more reviews specifically on business models.
Almost every paper has a 60-min time granularity. Most papers define a mathematical-based optimization.	ML-based business models should be explored.
Peak shaving is largely unexplored.	Business models for encouraging peak shaving can be built.

8. Conclusion

In recent decades, there have been significant advancements in the field of smart energy. In particular, district heating has seen substantial innovation: the technology supporting its implementation has evolved, expanding the opportunities available in this sector. Over the past few years, various business and pricing models have emerged for district heating and cooling, along with review papers that organize and classify these developments. This work conducts a comprehensive literature review on business and pricing models for district heating and cooling, examining scientific publications from the past five years. Between 2020 and 2024, we identified 28 relevant papers: 11 review papers and 17 papers proposing either novel models or improvements to existing models. Among the reviews, a few patterns stand out: first, they frequently focus on heat pumps, which is expected given that heat pumps convert electricity into heat. Additionally, most reviews address heating alone, with fewer covering both heating and cooling, as district heating is more widespread than district cooling. In the novel models we analyzed, similar patterns appear, with many models aiming for profit maximization or cost reduction, using mathematical optimization to structure these objectives. This approach reflects the novelty of the field, as many potential avenues for development within district heating remain largely unexplored. The current state of business and pricing models reflects the fact that district heating — and even more so, district cooling — remains an emerging technological domain, and most existing models are relatively simple and context-specific. Nevertheless, this evolving landscape presents several promising research directions. Future work is likely to involve the development of models for district cooling, as well as device-specific models that extend beyond heat pumps. Additionally, as the technology gains traction globally, we anticipate increased adoption across a wider range of countries. In parallel, the growing complexity of systems is expected to drive the integration of advanced tools, such as machine learning algorithms, and the design of models with more diverse and multi-objective optimization frameworks. This work highlighted the current state of business and pricing models for district heating and cooling, presenting trends in review papers and novel models, and identifying potential directions for future research. By mapping out the evolving landscape and future possibilities, this study aims to support the development of innovative, sustainable solutions that meet the growing demands of the energy sector.

CRediT authorship contribution statement

Fabio Lilliu: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Marco Calderoni:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Diego Reforgiato Recupero:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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