Market Strategies in Renewable District Heating

Engaging Prosumers and Enhancing Demand Response

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Abstract

Heating accounts for approximately half of the global final energy consumption, making its decarbonization essential for achieving climate and energy targets. Renewable District Heating (RDH) systems provide a collective and technically mature pathway to supply low-carbon and flexible heat. However, in countries such as Italy, RDH expansion remains constrained by fragmented regulation, limited consumer incentives, and the lack of coherent market frameworks that encourage prosumer participation and demand-side flexibility.

This thesis examines how market design and policy mechanisms can enhance prosumer engagement and operational flexibility in RDH systems. The research integrates an extensive literature review with a scenario-based modeling analysis of Italy's district heating (DH) sector. Financial and non-financial instruments, including pricing models, taxation, subsidies, regulations, and behavioral incentives, along with ownership models, are assessed for their effectiveness. Following this, a scenario design for Italy is presented: the RDH 60 scenario. This scenario aims to increase the share of the total heat demand satisfied by DH to 13% and achieve 60% renewable share in the DH fuel mix by 2035. The analysis of the RDH 60 scenario is conducted in comparison to the Base scenario, which represents the current stagnant state.

Results indicate that the RDH 60 pathway achieves an annual reduction of approximately 3 Mtoe in natural gas use and avoids about 600 ktCO_2 of gas-related emissions by 2035. Natural gas import savings are projected to reach about €1.5 billion annually by 2035, following an increasing trend. The findings demonstrate that technological progress alone is insufficient without proper market design and regulatory frameworks. Integrating dynamic pricing, cooperative ownership, and supportive policy and financial instruments emerges as the most effective strategy to strengthen prosumer participation, enhance demand response, and establish RDH as a cornerstone of Europe and Italy's sustainable energy transition.

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1 Introduction

1.1 Context and Motivation

Climate change represents one of the most pressing challenges confronting humanity in the forthcoming decades. Extensive scientific research demonstrates that the combustion of fossil fuels for energy significantly contributes to alterations in the Earth's climate [1]. In light of this consideration, one of the most effective strategies to meet human energy demands and mitigate climate change is transition from non-renewable to renewable energy sources. "Renewable energy sources, also called renewables, are energy sources that replenish (or renew) themselves naturally." is the definition given by the official website of the European Union [2].

Approximately 50% of the global final energy consumption is attributed to heat utilized in the residential and industrial sectors [3]. The heating sector holds significant importance and necessitates decarbonization. In 2022, approximately 78% of the energy consumption of households in EU-27 countries was allocated to heating [Fig. 1].

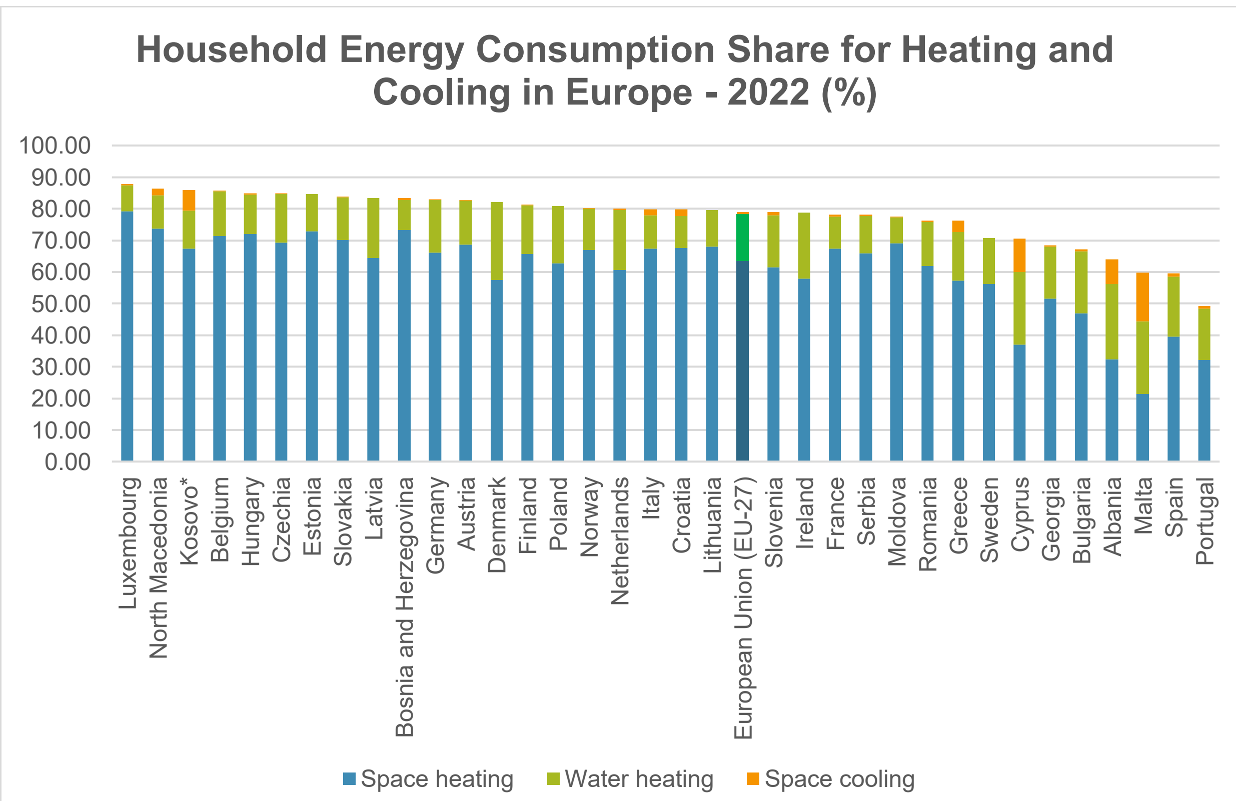

Fig. 1. Share of energy consumption by households used for heating and cooling in selected European countries and territories in 2022 [4]

The transition toward renewable-based heating and cooling has become a central pillar of the European Union's energy policy, reflecting both climate objectives and the need for greater energy security. Based on 2023 data [Fig. 2], more than 26% of heating and cooling in EU-27 are sourced from renewable energy. This share highlights both the steady progress made in diversifying heat supply and the significant potential still remaining for further expansion of renewables.

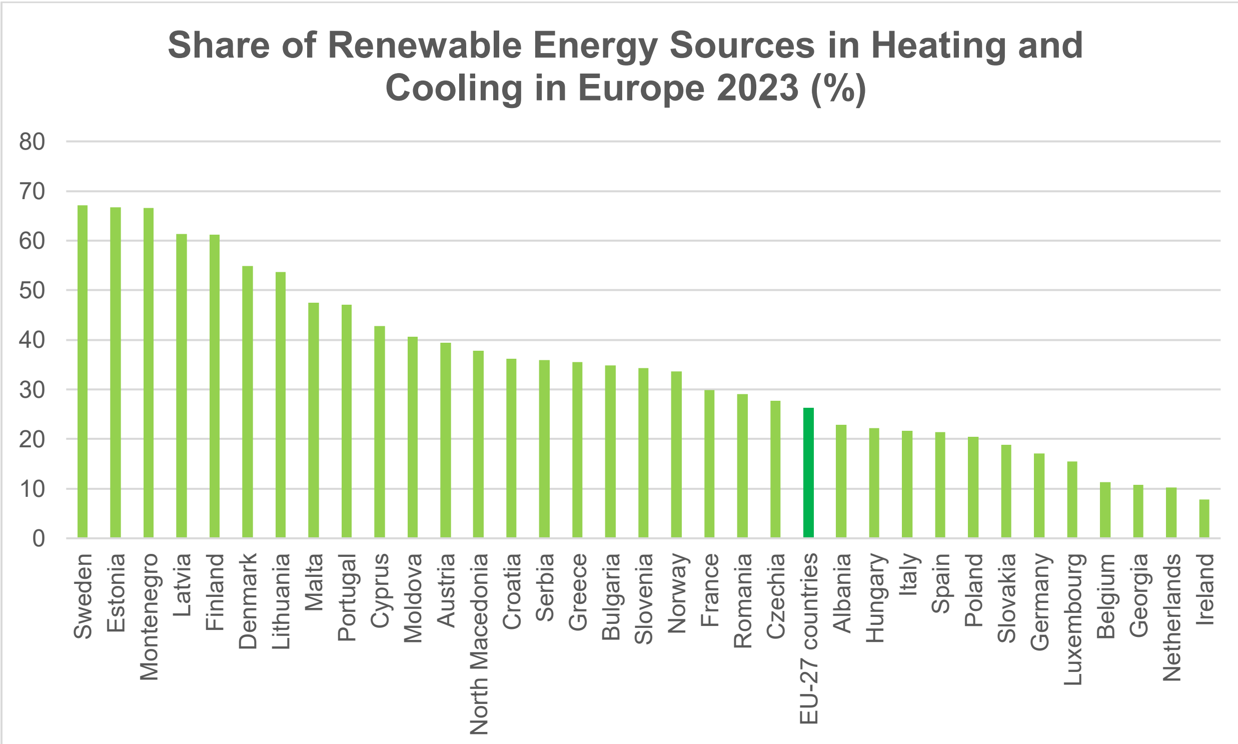

Fig. 2. Share of renewable energy sources in heating and cooling in selected European countries in 2023 [5]

District Heating plays a key role in the decarbonization of the energy systems by enabling the collective and efficient supply of thermal energy to buildings and industries. DH systems can integrate a wide range of renewable and alternative energy sources. Solar thermal, biomass, geothermal, waste heat from industrial processes, and waste-to-energy are the primary renewable heat sources employed in District Heating Networks (DHN) [6]. By harnessing these diverse resources within a shared infrastructure, district heating emerges as a cornerstone of sustainable energy transitions, delivering environmental benefits while enhancing overall system flexibility.

1.2 Problem Statement and Research Gap

Heating represents the largest share of final energy use in Europe [3], making its decarbonization central to achieving climate neutrality and energy security. District heating provides a technically proven and collective solution for decarbonizing urban heat supply, especially when integrated with renewable and waste heat sources. However, in many countries, including Italy, DH development remains limited and heavily dependent on fossil fuels. Existing systems often operate as centralized networks with little flexibility, while market and regulatory structures rarely incentivize prosumer participation, demand response, or transparent pricing mechanisms.

Most of the available research and policy analyses have focused primarily on technological optimization such as network efficiency or renewable integration, without fully addressing the market, ownership, and behavioral dimensions that determine the pace of transition. The result is a lack of integrated frameworks linking technical, economic, and social factors. In the Italian context, although the potential for renewable and waste heat integration is substantial, there is still no comprehensive assessment of how specific market strategies, investment models, and governance structures could stimulate prosumer engagement and system flexibility.

This defines the main research gap addressed in this thesis: the absence of an analytical link between market design and prosumer-driven renewable district heating. The study therefore investigates how market mechanisms, incentive structures, and policy frameworks can be configured to achieve large-scale renewable integration and active consumer participation in Italy's DH sector.

1.3 Research Objectives and Scope

The overarching aim of this research is to move beyond the conventional focus on technological feasibility and quantify the impact of institutional and market innovation on the energy transition. Specifically, this study evaluates how targeted market strategies and policy mechanisms can overcome regulatory and financial barriers to accelerate the deployment of RDH in Italy.

Overall Objective:

To design, evaluate, and recommend market strategies that enhance prosumer engagement and demand response (DR) while promoting the expansion of RDH. These findings are subsequently applied and assessed within the context of the Italian district heating sector.

Core Research Questions:

This thesis addresses three interconnected questions using a mixed-methods approach:

1. **Market & Governance:** Which financial and non-financial strategies are most effective in RDH with focusing on enhancing prosumers' role and system flexibility?
2. **Scenario Design Analysis:** What are the techno-economic and environmental impacts of increasing the share of the Italian heat demand satisfied by DH to 13% and achieving 60% renewable share in the DH fuel mix by 2035?
3. **Market & Policy Strategy:** What combination of market and regulatory strategies is required to reach the RDH 60 pathway in Italy?

Scope and Contribution:

This research integrates a structured qualitative review (Chapters 3 & 4) of Europe best practices (e.g., Nordic governance, German regulation) with a quantitative scenario modeling analysis (Chapter 6) applied specifically to the Italian energy system. The study's scope is focused on system-level market and policy evaluation, and its primary contribution is:

- Linking qualitative strategy to system-level impacts: The thesis connects strategic mechanisms identified in the literature to Italy's DH development by quantifying their aggregated effects through the RDH 60 scenario, including natural gas displacement, CO_2 reduction, and annual import-cost savings.
- Defined analytical boundary: The work focuses on market structures, incentive schemes, policy frameworks, and national-level fuel displacement. It does not include detailed network engineering, hourly dispatch optimization, or plant-level thermohydraulic modeling.

1.4 Thesis Structure

The thesis is organized into seven chapters that follow a logical progression from theoretical foundations to applied analysis. Chapter 1 introduces the background, research problem, objectives, and scope of the study. Chapter 2 reviews the evolution of District Heating technologies and their crucial role in the energy transition. Chapter 3 examines the critical market frameworks, ownership models, and various incentive schemes that support proactive prosumer participation and effective Demand Response integration. Chapter 4 synthesizes and comparatively assesses these market strategies for their impact on prosumer involvement and flexibility enhancement. Chapter 5 presents the comprehensive mixed-methods research methodology and the specific data sources utilized for the scenario modeling. Chapter 6 develops and evaluates the Italian case study through comparative scenario analysis and provides tangible market strategy recommendations. Finally, Chapter 7 concludes the research by summarizing the main findings, discussing their policy implications, and proposing avenues for future research.

2 District Heating: Background and Context

2.1 Overview and Trends in Europe

District energy systems have emerged as a key focus for advancing technology, business operations, management strategies, and environmental sustainability in the built environment. As a result, these systems present numerous opportunities for engineers across various disciplines, as well as for economists, investors, and policymakers. Research findings suggest that district energy systems exhibit superior efficiency and financial savings compared to individual heating and cooling systems. These systems are often more environmentally friendly and financially viable when combined with building retrofitting and network efficiency improvements. Furthermore, district energy systems are cost-effective for densely populated areas, whereas they may not be as economically advantageous in rural regions [7].

[Fig. 3] illustrates the final energy consumption of district heating in European countries for the year 2018, representing the most recent and comprehensive EU-wide data available. District heating predominantly serves the residential and service sectors, with a relatively limited presence in the industrial sector. Germany emerged as the leading nation in terms of overall district heating final consumption.

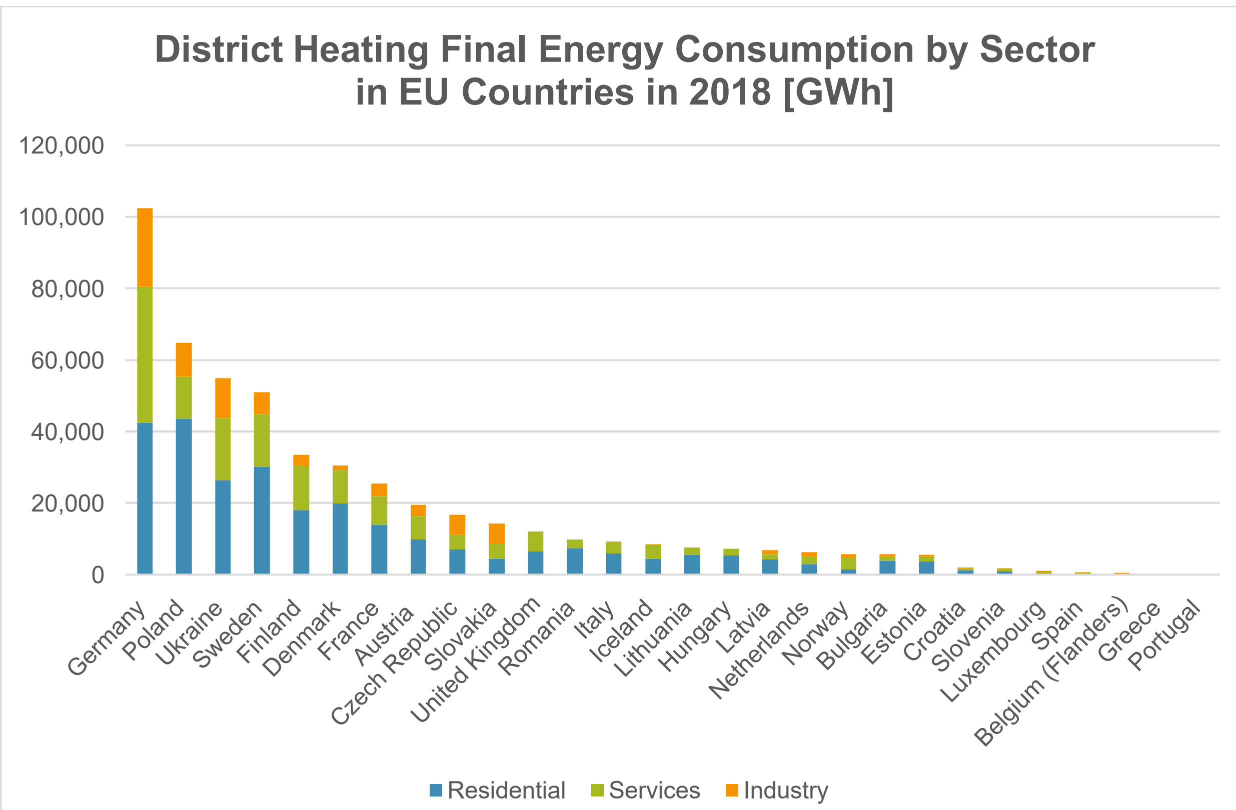

Fig. 3. District heating final energy consumption by sector (GWh)in European countries in 2018 [8]

A more accurate illustration comparing DH penetration across European countries is provided in [Fig. 4]. Although Germany leads in total district heating (DH) final energy consumption due to its larger size, Denmark comes out on top in terms of DH coverage relative to household heating demand. In Denmark, over 65% of household heating needs are satisfied through district heating (by 2020), emphasizing the country's high DH integration compared to other European countries [9].

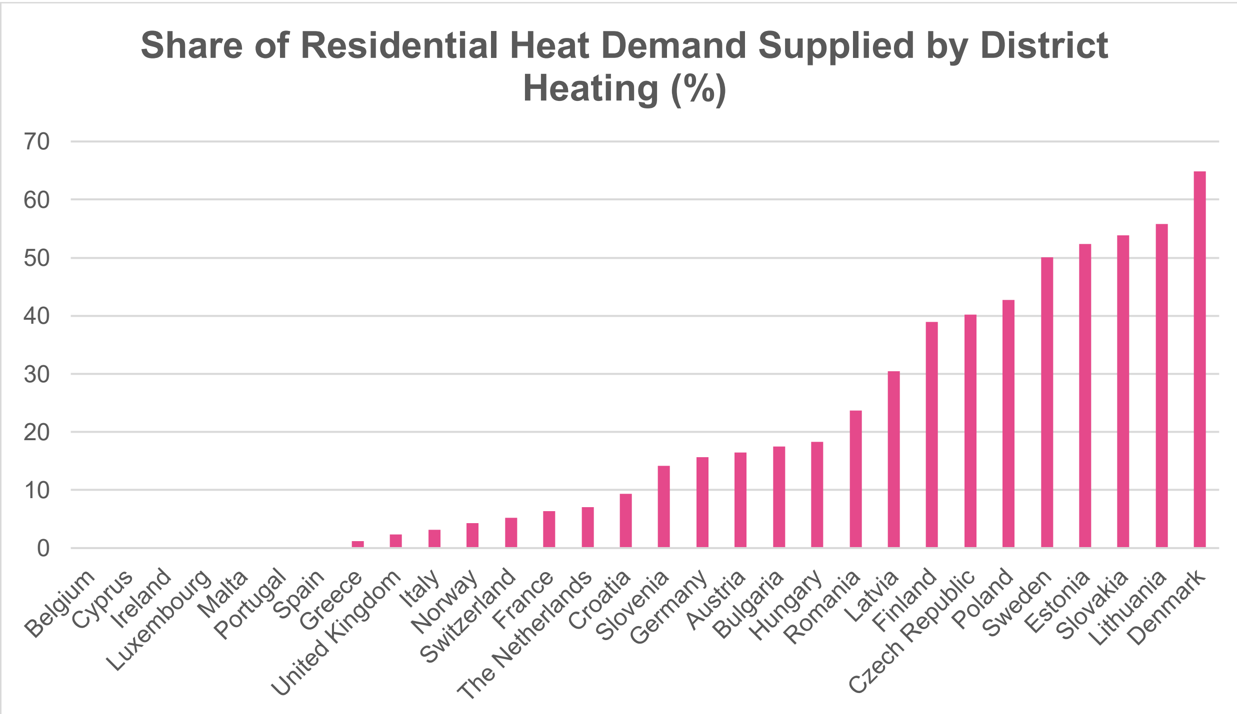

Fig. 4. Share of total residential heat demand satisfied by DH in selected European countries, 2020 (estimated from [9])

[Fig. 5] shows the district heating fuel mix in various European countries for the year 2018. As can be observed, natural gas and coal remain the largest contributors among fossil fuel sources for district heating, reflecting the continued reliance on traditional energy systems fuels. On the other hand, renewable sources are also present in the mix, with bioenergy standing out as the most significant contributor.

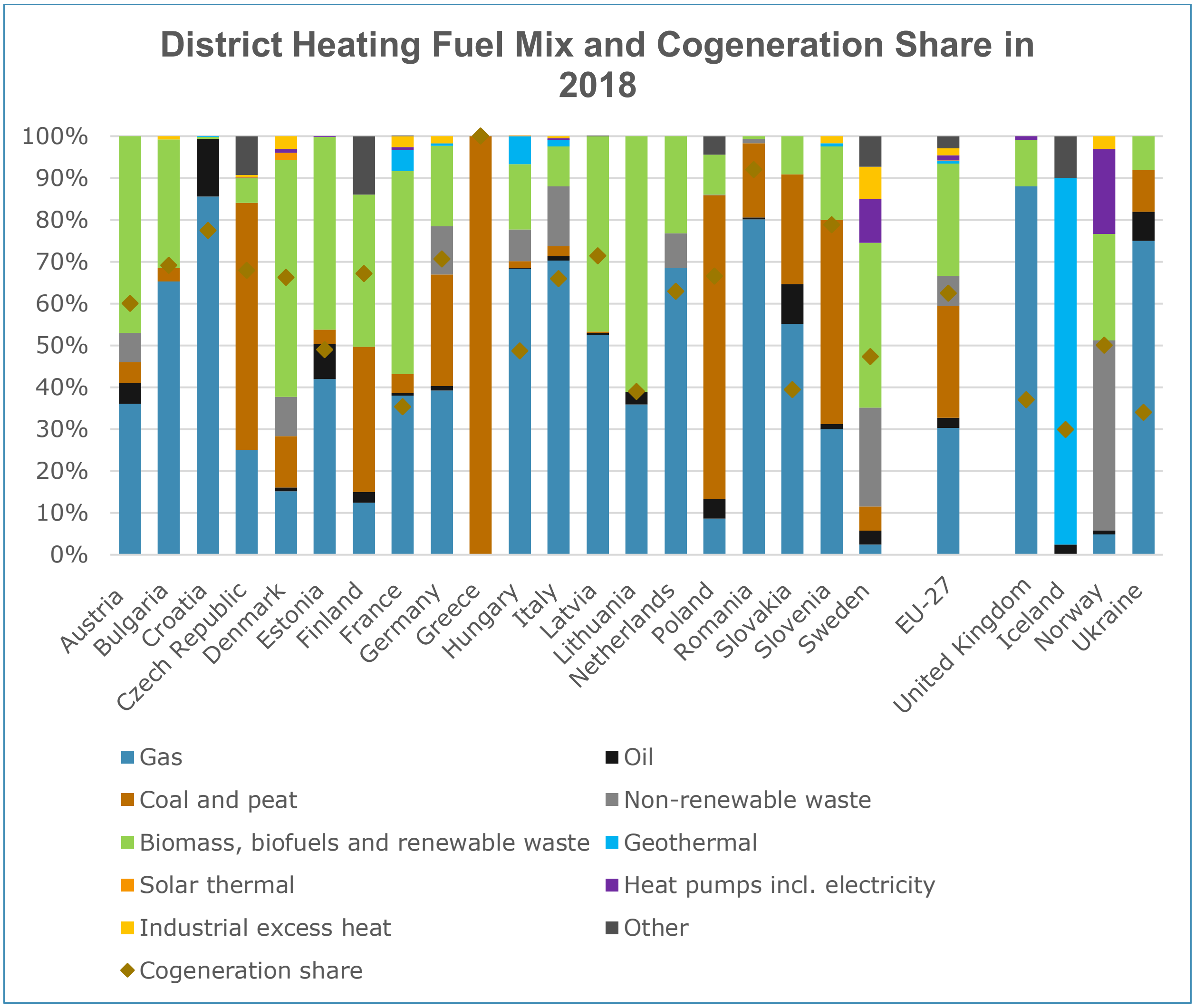

Fig. 5. District heating fuel mix and cogeneration share in 2018 [8]

The visual representation [Fig. 6] illustrates the distribution of renewable fuels utilized in DH production across European nations in 2018. A significant portion of DH, about 88% of total renewable was sourced in bioenergy. Furthermore, industrial excess heat and geothermal energy are evident at the subsequent level, however, the utilization of solar thermal energy is limited. In the presence of substantial waste or excess heat, solar thermal heat supply typically is less attractive [10].

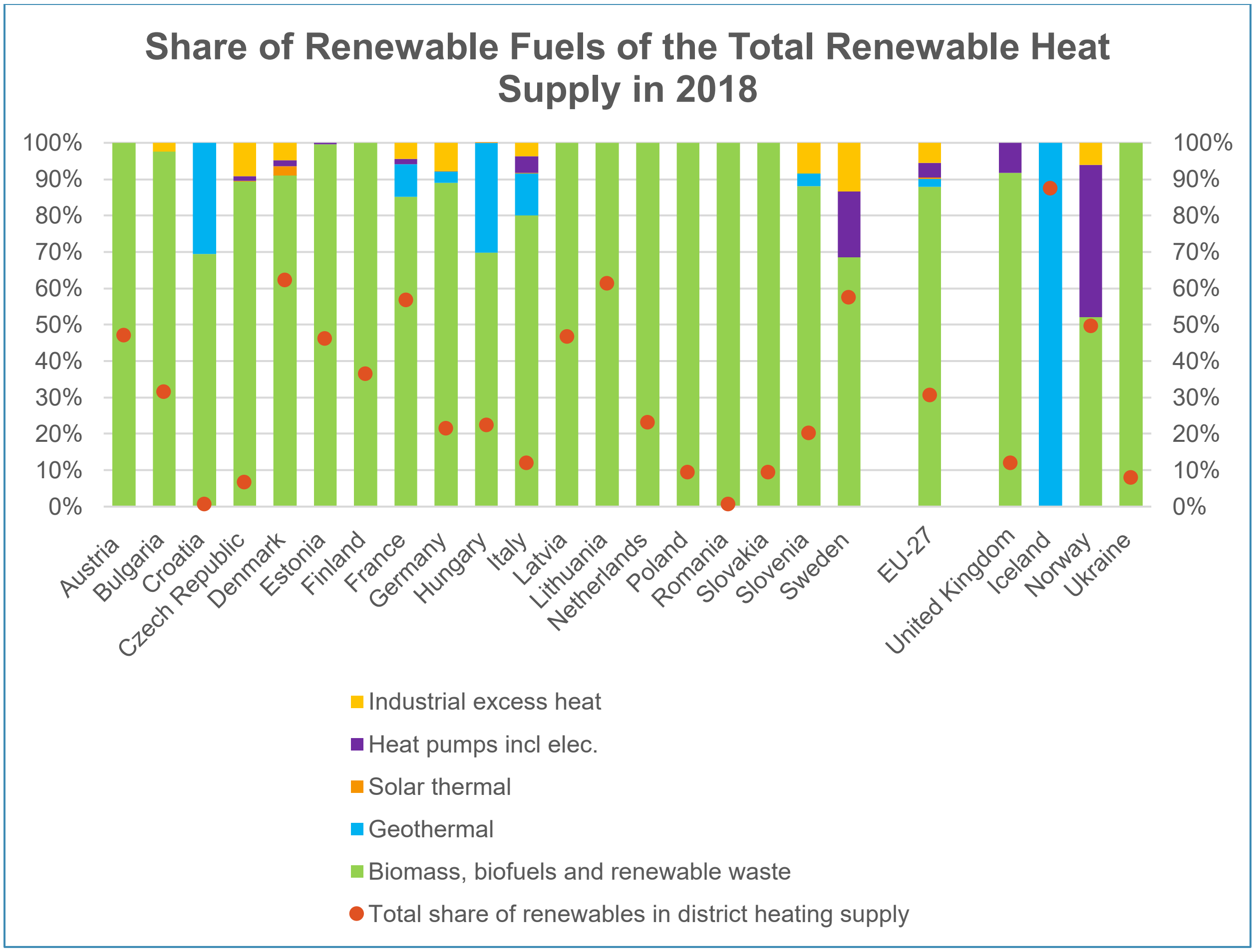

Fig. 6. Share of renewable fuels of the total renewable heat supply in 2018 [8]

The red dots signify the total share of renewable energy within each country's district heating system [Fig. 6]. Iceland is particularly notable, with around 88% of its DH supplied by renewable energy as of 2018 (which is all from geothermal), demonstrating how a country with abundant amount of a specific renewable resources can achieve very high shares of clean energy in their heating networks. Notably, Denmark ranks second in terms of renewable penetration in DH (62%), highlighting its strong commitment to integrating renewables into its heating infrastructure.

A comprehensive overview of the DH fuel mix within the European Union (EU) in 2018 and 2023 is presented in [Fig. 7]. In 2018, natural gas predominated in DH production by the largest share, relating to 30% of the total fuel mix. Surprisingly, it had lost its domination to bioenergy in 2023, which contributed to 35%. This change demonstrates the diversity of energy sources within European DH networks and emphasizes the potential to further enhance renewable integration to mitigate carbon emissions and promote sustainability. This highlights the gradual shift toward cleaner and more sustainable options, even though non-renewable fuels were still dominating in 2023 contributing to about 55% of the total fuel mix.

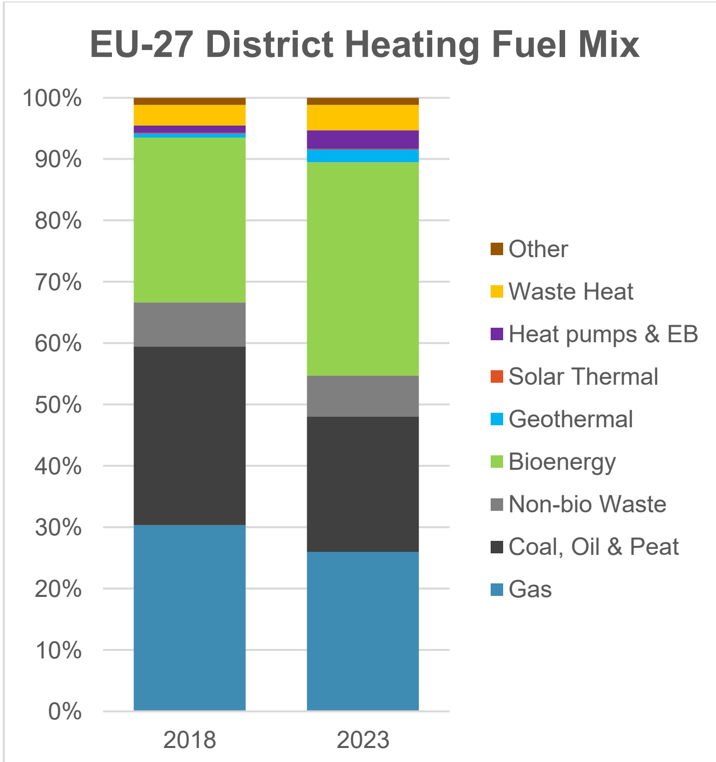

Fig. 7. EU-27 district heating fuel mix in 2018 and 2023 [8][11]

In summary, the analysis of district heating trends in Europe reveals both progress and challenges. Nordic countries, such as Denmark and Sweden, represent how high shares of renewables can be achieved in heating networks. Conversely, the EU27 remains reliant on fossil fuels, particularly natural gas and coal. To mitigate emissions, enhance energy security, and advance the sustainability of DH systems, it is crucial to increase the share of renewable sources. This objective can be accomplished through the implementation of effective market strategies and mechanisms, complemented by the utilization of modern technological advancements.

2.2 Technological Foundations of Modern District Heating

District heating systems are evolving from traditional centralized networks to more integrated and flexible energy infrastructures. This section explores the technological foundations that enable this transformation, including the key role of the energy efficiency, energy networks integration, control strategies, heat pumps, heat storage. Understanding these elements is essential to assess the technical feasibility, performance, and adaptability of modern DH systems.

- Efficiency of the Heating Networks and Buildings

Integrating renewable energy into district heating systems can significantly reduce emissions. However, without improvements in system efficiency, such as reducing distribution losses and enhancing the quality of heat generation, the benefits of renewable integration may be limited. “Energy Efficiency First” aligns with EU objectives in sustainability, climate neutrality, and green growth. It ensures that only needed energy is produced, avoids investments in stranded assets, and reduces energy demand cost-effectively, while considering security of supply and market integration [12].

Transitioning to a sustainable heating sector necessitates not only the replacement of fossil fuels with more environmentally friendly energy sources but also the investment in energy efficiency measures to reduce overall demand [13]. By simultaneously enhancing energy efficiency on both the building side (through retrofitting) and the heating network side, we achieve two objectives concurrently: reducing emissions and conserving energy. Additionally, the enhanced energy efficiency of an integrated energy system can lead to reduced consumer prices in the medium to long term [14].

Sweden's strong building codes on energy performance, in place since the 1970s, have led the country to have the most efficient buildings in the European Union. However, high energy efficiency together with low electricity prices has stagnated their DH sector due to the decline in heat demand and market saturation and has eroded the business case for some DH investments. [15].

- Integrated Energy Networks (Sector Coupling)

District heating networks (DHN) traditionally have strong links to electricity and gas networks via combined heat and power (CHP) processes. Energy sector integration within Smart Energy Systems (SESs) enhances renewable efficiency by linking electricity and heating. In Denmark, co-ownership of wind turbines and power-to-heat units in DH reduces grid costs and boosts local acceptance, showing the value of cross-sector cooperation and integrated energy models [16].

Schmidt et al. (2021) [17] provide first insights into possible strengths, weaknesses, opportunities, and threats for Hybrid Energy Networks. Strengths include the potential to cost-efficiently support the integration of Wind and PV electricity as well as to decarbonize heating and cooling demands. Weaknesses include their complexity, the required investments into coupling points and (current) regulatory restrictions. Opportunities include the increasing incentives for flexibility and efficiency services, upcoming green financing options, and regulations. Threats include possible disruptions of existing business models and uncertainties of the future development including the regulatory framework as well as competing flexibility services.

- Control Strategies

Upon the integration of energy systems, their complexity will undoubtedly increase. In this context, control strategies must be bold and innovative [18]. Accordingly, a primary focus should lie on developing effective control strategies, which present significant challenges. Energy storage systems play a crucial role in mitigating these challenges.

Advanced control strategies, particularly model predictive controllers (MPC), are essential in integrated energy systems to manage uncertainties from renewable generation, electricity prices, and consumer behavior [19]. These controllers optimize both short- and long-term operation, unlocking the system's flexibility for applications such as balancing, peak shaving, and ancillary services, whereas conventional controllers fail to handle intermittency and market volatility effectively.

In the context of sector integration, heat pumps will play a major role, but also power-to-gas (e.g. electrolysis) processes can contribute via recovering its waste heat, thus creating different coupling points between the district heating and cooling (DHC), electricity and gas system.

- Smart Metering and Digitalization

Digitalization is increasingly shaping modern DH systems by enabling continuous monitoring, automated fault detection, and optimized control of networks. Smart meters, programmable thermostats, digital heat cost allocators, and data from heat pumps allow operators to keep system temperatures low while maintaining user comfort and hot water safety. More advanced solutions such as smart radiator thermostats with return temperature limiters, IoT-enabled devices, machine learning algorithms, and dynamic thermal models support automatic balancing and temperature optimization. These technologies reduce the need for manual adjustments, improve system efficiency, and lower operational costs, making them essential for the transition to low-temperature DH [20].

Integration of electricity, heating, and gas networks through digital platforms can further improve system performance. Smart controllers using Model Predictive Control (MPC) coordinate multiple energy conversion units and distribution systems in real time. By adjusting set-points via existing building management systems, MPC enables both short-term optimization and long-term economic planning. A demonstration project in an Italian hospital showed that MPC not only increased economic returns and revenues from incentives but also reduced electricity demand, illustrating the value of advanced control strategies for enhancing system efficiency and reducing grid dependency [21].

- Heat Pump (HP): A Friend but Also a Rival to District Heating

Heat pumps are increasingly recognized as a pivotal technology for heating systems powered by clean electricity which carries a substantial amount of renewability based on its production source. Beyond their primary function of supplying heat, they facilitate the integration of variable electricity generation, thereby contributing to an effective decarbonization process. However, their high capital costs and relatively low running costs tend to push operation toward continuous rather than flexible modes limiting their usefulness for balancing fluctuating electricity [22].

Conversely, when individual heat pumps deployed outside of DHN, it can hinder the expansion of DH systems. Individual heat pumps are particularly appealing when electricity prices are low, making them a favored choice for households disconnected from DH infrastructure [23]. In Sweden, it’s widely believed that HP is gaining market share from DH because consumers are becoming more aware of the financial, energy-saving, and environmental benefits of HP technology, as well as their desire for more autonomy and control [23].

- Heat Storages

  Heat storages significantly enhance cost efficiency and system flexibility by enabling the storage of energy during periods of low demand or low cost and its release during times of higher demand or higher cost [24]. This capability effectively balances the inequality between energy production and consumption, thereby mitigating the necessity for costly peak energy supply and averting system overloads.

  Sneum et al. (2018) [25] analyzed various types of DH plants, ranging from fully integrated with an electricity system (combined heat and power and electric boiler) to those without integration with an electricity system (wood chip boiler), Heat Storage (HS) emerges as a cost-effective solution in all cases. It enables the increased utilization of the most economical technologies, thereby generally reducing the levelized cost of heat (LCOH).

  Furthermore, heat storages facilitate the integration of renewable energy sources by compensating for their inherent variability, ultimately augmenting the overall resilience and performance of energy systems while reducing operational expenditures.

In summary, the modernization of district heating systems relies on the interplay between efficiency improvements, digitalization, and integration with other energy networks. Technologies such as heat pumps, storage systems, and smart control enable greater flexibility and the use of renewable and waste heat sources. These developments form the technical backbone for more dynamic, consumer-oriented, and low-carbon DH systems, setting the stage for the market and policy strategies explored in the later sections.

2.3 Role of Prosumers

In the context of district heating, the term prosumer refers to an end-user who not only consumes heat from the network but also contributes to its production, typically by supplying excess or renewable heat [26]. The integration of prosumers into existing DHNs introduces new challenges for both market design and system operation. Prosumers can alter thermal flows within the network and increase competition in the DH market, requiring adjustments in regulation, pricing mechanisms, and operational strategies [27].

Data centers are major prosumers in district heating, consuming large amounts of electricity while producing substantial waste heat. Effective integration of their waste heat, combined with renewable energy supply, can improve DH efficiency, though current systems lack global optimization to fully exploit this potential [28]. A study in Trondheim, Norway, showed that integrating local prosumers such as a data center and retail stores into low-temperature DH can reduce heat demand, lower environmental impact, and decrease heat losses due to shorter transport distances [18].

The most effective and suitable generation of district heating systems, specifically the 4th and 5th generations, employ low temperatures, resulting in significantly reduced energy loss. These systems are particularly well-suited for incorporating prosumers. 4th generation DH (4GDH) can benefit from prosumers, particularly in regions with dispersed waste heat [29]. Prosumers contribute to energy trading, grid flexibility, and decarbonization efforts. However, meticulous network design, control strategies, and thermal storage are crucial to mitigate technical and economic challenges associated with 4GDH. 5th generation district heating (5GDH), which uses lower network temperature, enables heat sharing among prosumers via bidirectional networks [30]. Distributed optimization and transactive energy frameworks can coordinate prosumer interactions efficiently, reduce electricity consumption, and support fair energy allocation, making large-scale 5GDH systems more practical.

Decentralized and smart district heating solutions are important for a sustainable heat supply. A promising concept is decentralized feed-in by prosumers with small production units which can improve supply security, reduce emissions, and enhance economic welfare [31]. Achieving these benefits requires not only advanced control strategies but also appropriate market models. Decentralized, agent-based approaches are advantageous for larger systems but involve trade-offs in solution quality, computational effort, and scalability compared to centralized optimization [31].

2.4 Demand Response in District Heating

Demand Response (DR) in district heating refers to the modification of heat consumption patterns by end-users in response to external signals, such as dynamic pricing or control signals, with the objective of enhancing system efficiency, mitigating peak demand, and facilitating the integration of renewable and adaptable heat sources. In district heating, DR enhancement requires optimizing the way end-users (e.g. buildings, households, industries) adjust their heat demand in response to signals from the system operator, including:

- **i.** Price signals (e.g., reduced heat prices during low demand periods, increased prices during peak demand hours)
- **ii.** Incentives (financial rewards, comfort adjustments, or participation benefits)
- **iii.** Control signals (automatic thermostatic or smart controller adjustments)

The objective is to enhance the flexibility of the DH System (e.g., boosting its capacity to adapt to fluctuations in heat demand and supply, and market conditions), thereby enabling the DH System to operate more efficiently, integrate a larger share of renewable energy sources, and mitigate costs and emissions.

Demand side management (DSM) in district heating, including demand response, can significantly improve network performance by shifting or reducing thermal demand. According to Guelpa et al. (2021) [32], DSM can achieve peak load shaving up to 30%, double the load factor, reduce primary energy use by up to 5%, and lower emissions and costs by up to 10%, supporting urban decarbonization and more efficient DH operation.

DR in district heating can shift consumer heat demand to better utilize variable waste heat sources. A case study in Trondheim, Norway, demonstrated that applying price-driven DR across the entire residential building stock could reduce operational costs by 13%, with only a 1% increase in energy consumption, highlighting its potential for improving DH efficiency and waste heat integration [33].

Below, several accelerating technological solutions for DR are presented.

Energy Storage in DR:

In DH systems, demand response combined with distributed energy storage, such as electric thermal storage, can improve network efficiency and reliability while enabling market-based coordination [34]. Studies show that using storage tanks allows shifting energy use from peak to base generation, substantially lowering the required generation capacity, though consumer costs may increase unless appropriate incentives are provided [35]. Optimally managing electric thermal storage under dynamic pricing can reduce operational costs, peak loads, and reliance on fossil fuels, while maximizing the integration of renewable energy and providing economic benefits to consumers. According to Salo et al. (2019) [36] simulations from a district heating operator's perspective concluded that heat storage tank enables peak load balancing over longer periods, thereby improving the applicability of DR strategies across a larger share of the building stock.

Smart DR Devices:

Demand response in DH systems has become increasingly cost-effective with the introduction of smart, communicating devices that allow external control of buildings' energy consumption [36]. A field test in Tampere, Finland, showed that installing a DR system in central heating systems can significantly reduce peak loads and energy consumption [37]. By adjusting space heating based on weather forecasts, indoor temperatures, and domestic hot water demand, the system achieved a 14-15% peak load reduction and an 11% cut in normalized energy use over the heating season, corresponding to an estimated 9% annual reduction in energy costs and greenhouse gas emissions.

Heat Pumps and Integrated Heat and Power:

Demand response for residential heat pumps in district heating, combined with thermal energy storage, can reduce peak electricity loads and improve system flexibility [35]. District Heating Systems (DHS), particularly those integrated with large-scale Heat Pump Systems (HPS), offer significant potential to enhance demand-side flexibility within power systems [19]. By leveraging thermal storage, dynamic heat production, and advanced control strategies, District Heating Systems (DHS) integrated with Heat Pump Systems (HPS) can mitigate renewable energy intermittency, shift loads to off-peak periods, enhance grid stability, and support the decarbonization of urban energy networks [19].

Integrated demand response (IDR) in integrated energy systems enables the coordinated management of electricity and heat demand, allowing both consumers and demand-side energy stations to function as flexible resources [38]. Through market-based bidding and transactive control mechanisms, IDR optimizes energy allocation, enhances renewable energy utilization, and improves overall system efficiency. Wang et al. (2019) [38] demonstrate that such approaches can absorb up to 80-90% of available wind power and reduce energy costs by nearly 19% while maintaining user comfort.

2.5 Economic and Policy Frameworks

The expansion and sustainability of DH systems depend not only on technology but also on economic incentives, regulatory structures, and market models. This section examines the financial, policy, and market factors that shape the development of district heating, highlighting how well-designed tariffs, regulatory support, and innovative business models can encourage investment, prosumer engagement, and renewable energy integration.

District heating expansion is hindered by high upfront costs and static tariffs that weaken incentives for flexibility, especially in smaller municipalities. However, long-term financing tools such as green bonds and low-cost loans, combined with well-designed tariffs that reflect temporal costs, can lower investment barriers and attract private capital while promoting prosumer engagement.

DH systems as local natural monopolies, face regulatory risks; weak oversight can lead to unfair pricing, and rigid rules may discourage innovation. However, stable policy frameworks that ensure transparency, set renewable targets, and support community ownership, alongside coordinated municipal planning and recognition of thermal energy communities, can reduce risk, build public acceptance, and accelerate renewable DH adoption.

District heating systems face challenges as the energy landscape changes. Traditional revenue structures based on volumetric sales and fixed charges risk financial sustainability in declining heat demand and penalize energy efficiency. Competition from individual heating technologies, especially heat pumps with falling costs and policy incentives, threatens DH's customer base and economies of scale. However, these challenges also offer opportunities for innovation. New business models like Energy Service Companies (ESCOs), cooperatives, and public-private partnerships can combine expertise, capital, and local legitimacy to expand RDH. These models can also integrate prosumer-supplied heat and flexibility services, enhancing system resilience. DH can complement individual heating solutions with hybrid configurations that leverage waste heat, serve high-density urban areas, and meet the needs of large consumers like industry and data centers, where centralized systems are more efficient and cost-effective.

The subsequent chapter explores a comprehensive analysis of the market strategies, economic frameworks, and policy dimensions that govern district heating systems.

3 Market Strategies in District Heating

Accompanied by technological aspects, market and policy considerations are crucial for promoting prosumer participation and enhancing demand response in RDH systems. These mechanisms incentivize households, businesses, and local energy producers to contribute renewable heat, modify consumption patterns, and invest in storage solutions, thereby enhancing system efficiency and sustainability.

In this thesis, market strategies are broadly categorized into financial and non-financial. Financial strategies, such as pricing models, taxes, and subsidies, are widely applied in practice. Non-financial strategies, described in separate sections of policy and behavioral tools. These elements collectively contribute to the integration of prosumers and enhancing DR within RDH systems.

In this chapter, the market structure of DH systems is first reviewed, encompassing ownership models and governance types that establish the context within which strategies operate. Subsequently, market strategies and mechanisms are examined.

3.1 Market Structure

3.1.1 Ownership Models

Ownership models are important for how well DH systems work and are accepted. Who owns the system affects decisions, prices, trust, investment, and how well it meets goals like affordability, sustainability, and reliable supply. Across Europe, DH ownership varies widely, ranging from consumer-owned cooperatives to municipal and fully private companies, each offering distinct advantages and challenges. Understanding these models provides valuable insight into how governance structures can affect the success and future development of DH systems. The following text provides description of the various ownership models within the DH Market.

A. Public (Municipal) Ownership

Public or municipal ownership of DH systems is common in several European countries. In Finland, DH markets are often dominated by monopolies, typically owned by local municipalities [39]. These municipal ownership structures control both the supplying plants and the distribution networks, with rigid pricing mechanisms usually fixed annually [39]. While this model ensures stability, it can create barriers for third-party access, limiting opportunities to inject excess heat or utilize more cost-effective heating sources.

Limited financial capacity and lack of experience in the energy sector have frequently hindered municipalities from further developing and effectively utilizing existing DH infrastructure [40]. While municipal ownership can support the expansion of DH, it requires that municipalities possess sufficient expertise and resources to manage an energy supplier successfully. In the United Kingdom, public ownership of DH systems has faced significant challenges, as some local authorities have struggled to effectively manage their energy companies [41]. As a result, between 2016 and 2020, eight such companies collectively incurred losses of approximately £114 million, with three of these ultimately entering liquidation or administration.

Public ownership of DH production and distribution networks, along with regulatory oversight, can protect consumers and encourage efficiency. However, unlike standardized investments like wind or solar projects, small-scale DH systems are diverse and locally specific, making them less appealing to large institutional investors without detailed regulatory and project frameworks [14].

B. Private Ownership

Private ownership of DH systems shifts control from municipalities to commercial entities, often introducing greater competition and efficiency in the market. In Sweden, for example, DH systems were initially municipally owned, but the 1996 energy market deregulation enabled third-party participation in production and sales, fostering a more competitive environment [42]. While this model can encourage innovation and cost-effective operations, it may also reduce the direct influence of municipal, regional, or national authorities. However, to safeguard public interests, regulatory frameworks are essential to oversee pricing, service quality, and investment decisions [42].

C. Consumer / Cooperative Ownership

Consumer co-ownership can play an important role in smart energy systems, particularly in DH. In Denmark, for instance, co-ownership of wind turbines and power-to-heat units within DH systems has been shown to improve local acceptance and investment attractiveness compared to conventional ownership [16]. Such arrangements help address institutional and organizational challenges, support cross-sector integration, and encourage more efficient and locally supported renewable energy deployment.

Citizen (consumer) ownership has also been central to the development of decentralized sustainable energy technologies, including DH systems. Between 1975 and 2016, Denmark saw the emergence of diverse citizen ownership models, shaped by institutional incentives and differing in geographical scope, profit type, and benefit distribution [43] and consequently most of the DH companies in Denmark are consumer-owned monopolies [42]. They are considered monopolies because each consumer-owned cooperative serves a defined geographic area where building parallel networks would be economically inefficient, giving it exclusive control over heat supply within that zone despite its non-profit, community ownership.

These models demonstrate how citizen participation can meaningfully contribute to energy transitions. Experts emphasize that Denmark's consumer-owned DH model has achieved remarkable success due to the sense of pride and empowerment that consumers derive from their active participation, influence over company decisions, and oversight of changes [42].

Considering all models presented above, a representative form is Public-Private Partnership (PPP) model. In this arrangement, the DH infrastructure remains publicly owned, while operational responsibilities are delegated to private companies through long-term contracts [14]. This approach is particularly useful when municipalities lack experience in efficient operation, business development, or when the legal framework for public management is limited. Moreover, when private enterprises are contracted to develop or operate public DH systems, appropriate incentives and performance indicators must be embedded within agreements to ensure accountability and alignment with broader policy objectives [14].

3.1.2 Governance and Regulation

In terms of governance, DH markets are usually divided into regulated and deregulated structures, each with unique benefits and drawbacks. Regulation ensures stability, consumer protection, and transparency but limits efficiency and discourages new entrants. Deregulation promotes competition and innovation but introduces risks of market power and reduced consumer safeguards. Below, we provide further details an examples on each of these concepts.

A. Regulated Market

Regulated DH markets are characterized by strict oversight of pricing and operational frameworks, designed to ensure affordability and consumer protection. Such systems often provide stability, transparency, and public trust, but they may also limit competition and reduce incentives for innovation. Different countries apply regulation in distinct ways, reflecting national priorities and market conditions.

Denmark's DH companies operate under a non-profit principle, prohibiting profits [42]. This arrangement ensures low consumer prices, high service quality, customer satisfaction, and few complaints. However, it may reduce incentives for efficiency and discourage new ownership or investment.

The Netherlands' "no more than otherwise" principle caps DH prices based on natural gas benchmarks, providing consumers with a clear price reference [42]. However, it may discourage companies from investing in new systems or upgrading existing ones, restrict innovation, and reduce the attractiveness of DH connections, leading to disconnections or a shift toward cheaper alternatives.

These cases illustrate how regulation can safeguard consumer interests but also highlight the trade-offs in efficiency, innovation, and long-term investment that policymakers must address.

B. Deregulated (Liberalized) Market

Another option is to fully liberalize the consumer prices of DH, which can be determined by market forces driven by supply and demand. The theoretical advantage of this approach is that market forces are fully engaged in fostering competition and reducing costs. However, the disadvantage lies in the fact that DH operates as a natural monopoly, where market forces can be exerted and potentially misused against consumer interests [14]. Deregulation introduces risks and challenges for smaller municipal companies, forcing them to compete for customers they previously served and creating uncertainty about market access for their services [44].

In a deregulated DH market, the price of DH is commonly determined by the marginal cost pricing method [45]. In this type of markets, DH producers reduce financial risk through a two-part tariff: a fixed charge based on installed capacity covering stable operating costs, and a variable charge linked to actual consumption, often adjusted seasonally [46]. This balance ensures stable revenues while reflecting energy use, though high fixed charge may lower efficiency incentives. This model is widely used in Sweden, where companies like Göteborg Energi base fixed charges on past consumption, and in Finland, where prices vary by consumer type [46]. Since private houses can easily switch to alternative heating, they usually face higher charges than apartments or industrial users.

Overall, a dedicated DH regulator is essential for ensuring a well-functioning market. Achieving fair pricing in deregulated systems like Sweden's is difficult, requiring strong regulation [42]. Existing pricing approaches, while imperfect, offer valuable lessons for improving governance and consumer trust. Without such balance, DH risks losing customers to more flexible and affordable alternatives, particularly individual heat pumps. Consequently, numerous scholars believe that a hybrid model, integrating open competition with regulatory oversight, emerges as the most successful strategy to uphold fairness and consumer trust [47].

3.2 Financial Strategies

Financial strategies in this literature are measures that directly affect costs, revenues, and investment decisions, such as pricing models, taxes, and subsidies. We'll discuss some of the most effective financial mechanisms for promoting RDH in the following subsections.

3.2.1 Pricing Models

Energy costs for end-users depend on tariff structures and pricing models; tariffs set fixed and variable charges, while pricing models define how these charges vary with costs, demand, and market conditions. DH systems often operate as local monopolies, leading to higher consumer prices without effective regulatory oversight [14]. Low price elasticity suggests market competitiveness may be hindered, as producers can raise prices without fear of demand reduction [46]. Tariffs for DH systems vary by country based on fuel type and pricing regulations [46].

The findings show that new pricing models often fail to meet key customer expectations, particularly when energy savings do not lead to financial benefits for them or when costs appear unpredictable and uncontrollable [45]. While structural risks such as weather dependency, sunk costs, and growing market competition remain significant, consumer dissatisfaction poses an equally serious threat. If prices are perceived as unfair or unreliable, customers may shift to alternative heating options, creating long-term risks for the DH Industry.

The costs of district heating are primarily Influenced by three factors [48]:

1) customer connection costs
2) expenses of building and operating the distribution network, which vary with the network's size and heat demand,
3) thermal energy production costs.

The choice of price-setting regime and ownership model depends on various factors, including the scale of the heat market, local waste heat availability, existing housing ownership, access to cheap financing, a stable regulatory framework, and confidence-building measures for investors [14].

In the following subsections, a concise overview of some of the most prevalent pricing models employed in the DH market is presented. For better understanding they are categorized in four different categories: 1) Cost-Based Pricing, 2) Market-Based Pricing, 3) Dynamic / Time-Based Pricing and 4) Hybrid and Regulatory Approaches

3.2.1.1 Cost-Based Pricing

In cost-based pricing, prices are set by adding a markup to the total production and operational costs to ensure cost recovery and profit.

A. True Cost Pricing

The true-cost principle states that consumer prices should reflect all production and distribution costs [14]. This ensures that only necessary costs are covered by consumers, protecting them from potential misuse of natural monopolies. Denmark has implemented this mechanism for most of its DH supply, with national independent authorities overseeing prices and delivery conditions [14]. The Danish non-profit principle guarantees that DH prices solely reflect the essential costs of production, operation, and maintenance (Danish Energy Agency, 2017), with any surplus being returned to consumers. This model safeguards users from concealed taxation, maintains relatively low prices, and fosters high service quality with robust customer satisfaction. Nevertheless, it may diminish incentives for efficiency and discourage private investment or new market entry, thereby restricting competition and innovation [42].

B. True Cost + Investor Return

Another approach to setting DH consumer prices is the regulated return on investment model. Under this scheme, heat prices are based on actual costs but adjusted to include a capped investor return, incentivizing external investment in the system [14]. For example, in Denmark, industries supplying waste heat to DH are permitted to apply an 8% real return on top of true costs, provided that prices remain below the cost of alternative heating sources and are approved by regulators [14].

C. Cost-Plus Pricing

In regulated markets, DH prices are determined based on the total recoverable costs plus a reasonable profit margin for DH companies represented in [Eq. 1] [46]:

$$Price_{DH} = OA + AD + PP \qquad (1)$$

where OA represents operating costs, AD is annual depreciation, and PP denotes the permitted profit. This pricing approach is known as the cost-plus pricing method.

This pricing method has been criticized for discouraging energy savings because producers have little incentive to reduce heat losses, and the cost structure is not transparent [46]. Operating costs are set at the regional level rather than based on actual local expenses and investments, which can create opportunities for corruption. As a result, DH tariffs may be manipulated by local authorities for political purposes. The funds to cover cost gaps can come from other DH business activities, such as profits from territorial generation companies, industrial heat, or municipal revenues from other sectors like heat-only boiler houses. DH tariffs also vary widely across regions, depending on infrastructure conditions, fuel types, heat demand distribution, negotiation power of stakeholders, and institutional arrangements [46].

D. Marginal Cost Pricing

In deregulated DH markets, pricing is often determined by the marginal cost method [46]. Marginal cost is the expense of producing one more unit of output, in this case, generating one more unit of heat. Economic theory states that the market price is at equilibrium when total heat supply equals total heat demand. In a DH system where prices are tied to marginal costs, suppliers are incentivized to reduce expenses, improve efficiency, and invest in infrastructure and technology. This benefits producers and contributes to environmental gains by lowering CO_2 emissions and other pollutants.

Marginal cost MC is calculated by dividing total costs into fixed and variable components. It represents the expense of producing one additional unit of DH output. It can be expressed as [Eq. 2]: [46]

$$MC = (dVC/dQ) + (dFC/dQ) \qquad (2)$$

where VC is the variable cost, FC the fixed cost, and Q the production quantity. In the short run, $dFC/dQ = 0$, since fixed costs remain constant regardless of changes in output.

Fuel costs directly influence the marginal cost of a DH plant, with the marginal cost responding proportionally to variations in fuel prices.

Several tools calculate marginal costs, and computer models implement them. These tools analyze input parameter changes' effects on marginal costs and incorporate detailed time-dependent information [46].

E. Incremental Cost Method

Marginal-cost pricing faces challenges in accurately determining each producer's marginal cost, leading to frequent market price setting equal to the last consumer's willingness to pay [46]. This can result in overpricing or underpricing. To address this, an incremental cost approach is used, considering current and future replacement or expansion costs, discounted to present value. This ensures prices remain close to true costs while avoiding unfair profits or losses. Incremental costing also makes the system self-financing, as replacement costs are charged to current users and future updates are funded. It adapts to cost changes, but forecasts may be challenging due to new technologies or regulations. Extra production beyond demand should be carefully managed; if buyers are absent, it’s better to keep excess capacity idle than lower prices.

F. Shadow Price Method

A shadow price represents the highest price consumers are willing to pay for an extra unit of heat when the market is balanced. In a multi-plant system, it comes from the plant with the highest operating cost. Unlike marginal cost, it may also include the investment costs of potential new plants. Shadow prices show how small changes in demand or system capacity affect the DH system’s profitability. They help decide system behavior, cost allocation, and the value of new plants. However, finding shadow prices in practice is hard because market equilibrium is rare. [46]

3.2.1.2 Market-Based Pricing

In market-based pricing, prices are determined by supply and demand conditions, reflecting market competition and consumer willingness to pay.

A. Substitution Pricing

Substitution pricing regulates DH tariffs by linking them to the cost of the nearest alternative heating option, such as individual natural gas boilers or electric heating. This approach ensures that the price of DH cannot exceed what consumers would pay if they produced heat themselves, protecting households from potential monopoly pricing by DH operators [14]. This model’s simplicity and transparency make DH competitive and easy to compare, but tariffs depend on volatile gas or electricity prices, and renewable-based DH may struggle against artificially cheap fossil alternatives. While effective for consumer protection, substitution pricing can hinder renewable integration and prosumer incentives unless supported by policies like carbon pricing or subsidies.

B. Pay-as-Bid Pricing

Pay-as-bid pricing is a system where participants receive the exact amount they bid, instead of a fixed market price [49]. Each accepted bid is paid at its proposed value, which can help show real costs during busy times. However, it may reduce the motivation to bid truthfully compared to a uniform pricing system.

In Maurer et al. (2021) [50], the proposed hybrid market model for coupled electric power and DHN uses pay-as-bid pricing during network congestion to supplement uniform marginal pricing. While uniform pricing ensures incentive compatibility, pay-as-bid mitigates uplift costs associated with redispatch by compensating participants based on their bid values. Although this introduces inefficiency, the trade-off is justified when the avoided redispatch costs exceed the loss of full incentive compatibility, ensuring efficient allocation and secure network operation.

3.2.1.3 Dynamic / Time-Based Pricing

In dynamic (time-based) pricing, prices fluctuate over time based on real-time demand, supply, or system conditions to optimize efficiency and balance consumption.

A. Time of Use (ToU) Pricing

Time-of-use pricing is a dynamic tariff mechanism which varies energy prices based on predefined periods, reflecting demand and system fluctuations. It encourages prosumers to shift consumption to lower-cost or stressed periods, supporting network efficiency, energy savings, and renewable resource integration. ToU pricing in DH, supported by advanced metering and control technologies, allows consumers to respond to price variations, significantly influencing 5^{th} generation systems by enabling dynamic thermal demand management [30]. Prosumers adjust consumption patterns as a DR action to price signals, helping network balance while enhancing cost efficiency. This demonstrates ToU pricing's potential as an effective tool for demand-side flexibility in community-based DH markets. For small and medium prosumers, DR business models include explicit services sold to system operators and implicit services based on price incentives like ToU [51]. These models offer flexible energy consumption, cost optimization, and active participation in the energy market.

B. Seasonal Pricing

Seasonal pricing is a tariff mechanism where energy prices vary depending on the seasons of the year, reflecting changes in demand, supply conditions, and system costs across different seasons.

In Sweden, where seasonal temperature differences are large, district heating (DH) production costs are low in summer and high in winter. Incorporating marginal costs into the price model means customers pay higher prices in winter, when demand is high, and lower prices in summer, when only hot water is needed [45]. [Fig. 8] shows seasonal DH price variations under cold, normal, and warm periods [52]. Prices are typically set at three levels high in winter, medium in spring/fall, and low in summer to reflect production costs and weather-related demand fluctuations.

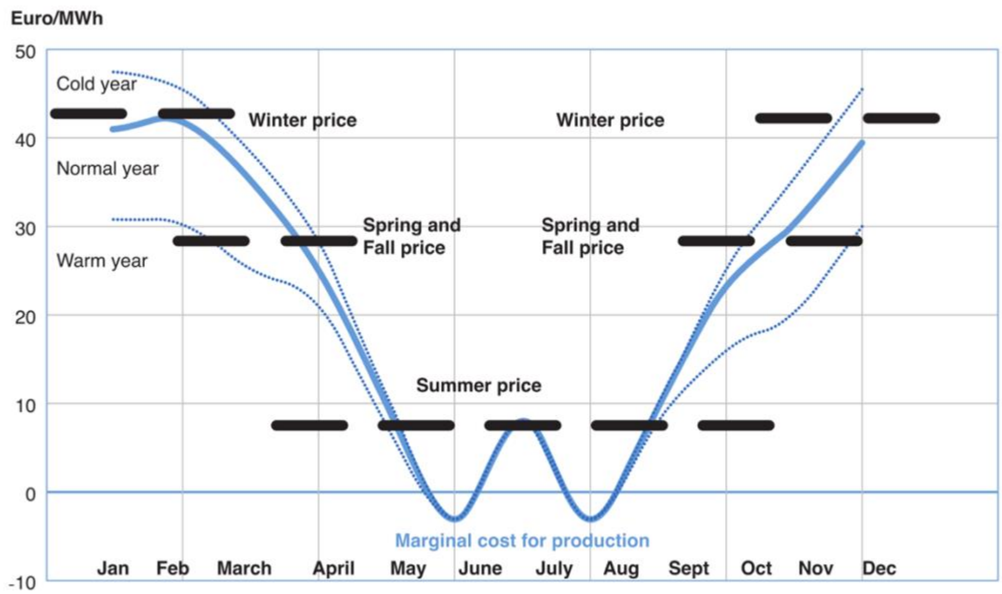

Fig. 8. Marginal cost of district heating production and seasonal pricing, Sweden [52]

C. Real-time Pricing (RTP) / Smart Meter-driven Pricing

Real-time pricing represents a dynamic tariff mechanism in which energy prices fluctuate in accordance with short-term variations in supply and demand conditions. RTP has proven effective in the electricity sector by improving demand-side management, increasing supplier profits, and enhancing pricing transparency [46]. This offers a valuable foundation for exploring its potential adaptation in DH systems. Despite the DH sector's unique characteristics, the increasing focus on efficiency and decarbonization makes RTP a promising avenue for further development in DH. While RTP relies on smart metering, DH systems still lag in this area, despite recent progress in measuring actual heat use. With rising pressure to save energy and cut greenhouse gas emissions, involving consumers on the demand side is essential, making the development of RTP in DH necessary and well supported by lessons from the electricity sector.

3.2.1.4 Hybrid and Regulatory Approaches

In this subsections, a hybrid pricing model and a regulatory-based pricing approaches are introduced.

A. EMCP Model: An Integrated Model of Competitive and Regulated Method

Both cost-plus and marginal-cost pricing have drawbacks: the former reduces incentives for efficiency, while the latter assumes ideal market conditions rarely met in practice. To address this, Zhang et al. [53] proposed the Equivalent Marginal Cost Pricing (EMCP) model, which combines short-run marginal costs, determined through producer bidding, with long-run capacity costs regulated by the heating capacity cost reference. By using exergy as a common standard, the model allows fair comparison of heat production across regions, promoting competition and efficient resource allocation. While EMCP encourages efficiency and secures investment in capacity, it relies on assumptions of rational producer behavior, and its complexity may limit practical application [46].

B. Price Cap Based on Alternative Supplies

This method regulates DH prices by linking them to the cost of alternative heat sources, such as waste or excess industrial heat. It is similar to substitution pricing, but it's regulatory instead of market driven.

In Denmark, a price cap for heat produced from waste incineration is set by the price of heat from the largest combined heat and power (CHP) plants [54]. This guarantees fair prices for consumers and stops waste plants from showing economic preference. However, price caps may discourage efficiency improvements, as producers can simply charge the maximum allowed price. If production costs, such as waste handling, are high, the capped price may not cover true costs, potentially threatening long-term financial sustainability [14]. In such cases, state subsidies might be needed to bridge the gap, creating a fiscal burden.

In the Netherlands, the "no more than otherwise principle" regulates the prices of district heating based on natural gas, with the government annually determining the maximum tariff [42]. Conversely, the United Kingdom does not have a dedicated DH regulator or price cap, resulting in consumers being less protected compared to gas and electricity users. Nevertheless, the relatively low penetration of DH in both countries may facilitate the expansion of low-carbon systems, as establishing new networks is often more straightforward than retrofitting existing ones [42].

3.2.2 Taxes and Levies

Taxes are policy instruments implemented by governments or regulators through official rules or laws, directly affect money flows, and significantly influence DH markets. They influence consumer prices, guide investment decisions, and enhance the competitiveness of renewable technologies, acting as an economic lever that promotes efficient decision-making and supports the transition toward sustainable energy sources.

Taxation policies can encourage cogeneration and biomass-based technologies, which are often the most cost-effective solutions for DH systems [55]. If natural gas is more economically viable than biomass, heat producers may choose it despite its environmental drawbacks. The government could tax natural gas and exempt biomass taxes to make biomass more affordable and align market behavior with environmental goals. According to research by Sneum & Sandberg [25], an absence of taxes and subsidies provides an increased incentive for the operation of the Oil boiler, a consequence which neither increases operation of flexible technologies nor reduces emissions.

Policymakers, therefore, play a crucial role in shaping the economic viability through taxation decisions, which directly influence both energy affordability and the transition to cleaner technologies. Effect of taxes in DH can be direct, through Value Added Tax (VAT) on heat, or indirect through fuel or carbon taxes. The consumer's impact depends on national legislation, fuel type, and system type (municipal or private). The following sections examine the different fuel sources that affect taxation in DH, followed by a discussion of carbon taxes.

3.2.2.1 Energy Source Taxation

A. Electricity

Electricity taxation impacts DH economics, particularly with heat pumps and electric boilers. These technologies depend on electricity for heat, making their competitiveness sensitive to grid tariffs, levies, and fiscal policies. As a result, electricity taxes influence power-to-heat unit costs and district heating's role in electrification and renewable energy integration. Furthermore, it influences individuals' decisions which may not be in favor of DH. For instance, if the post-tax electricity price becomes sufficiently low, individuals may opt to switch from DH to individual electric HP.

In [Fig. 9] electricity price for households in European countries is shown. Denmark's electricity tax (€) was the highest in Europe in the second half of 2024. Its electricity price before taxes is lower than the EU average, but after taxes and levies, it becomes the third highest in the EU.

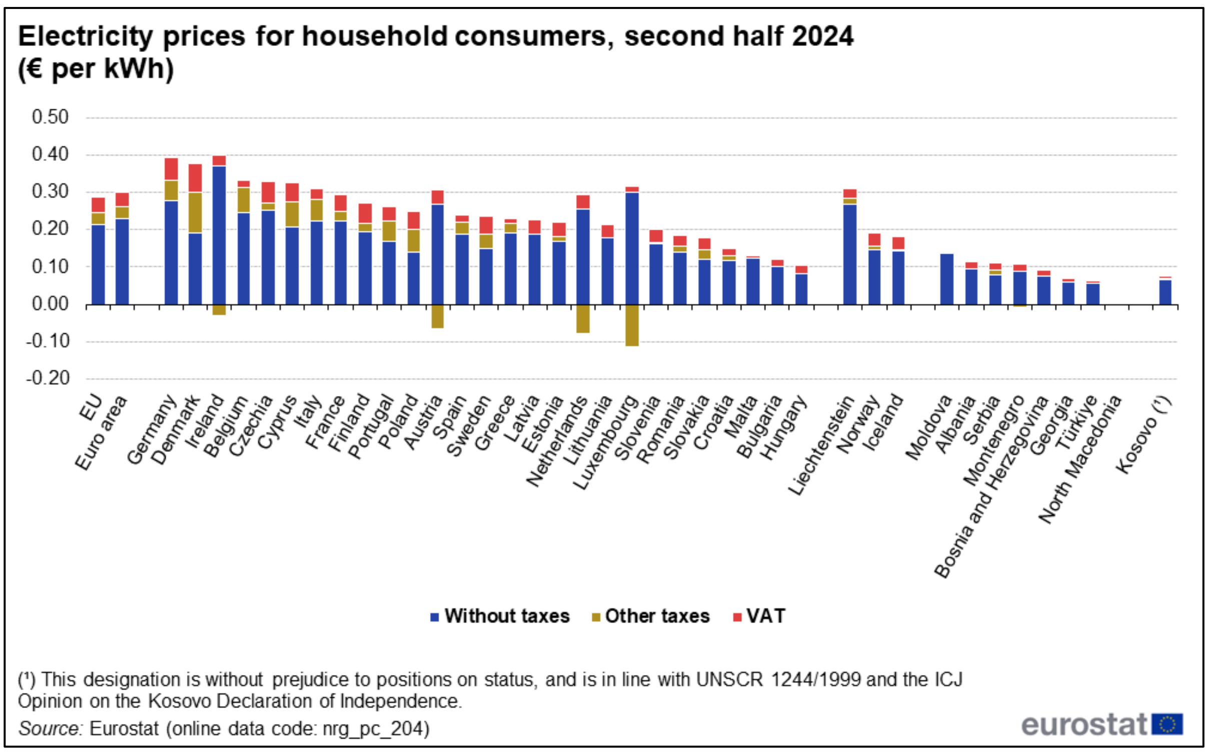

Fig. 9. Electricity prices for household consumers, Euro area countries, 2nd half 2024 [56]

Households of a country, by analyzing electricity prices, might decide to disconnect from the DH and switch to other electricity-sourced heating solutions if they find it more economically advantageous which is not in favor of DH.

Effect of electricity taxation on heat production plants can be observed in integrated energy networks where electricity and heating systems are connected. Heat pumps and electric boilers inject heat into the DH network using electricity. Therefore, the network operator or DH company must generate heat using electricity or other sources. [Fig. 10] illustrates the cost of electricity for non-residential users, including industries engaged in DH production.

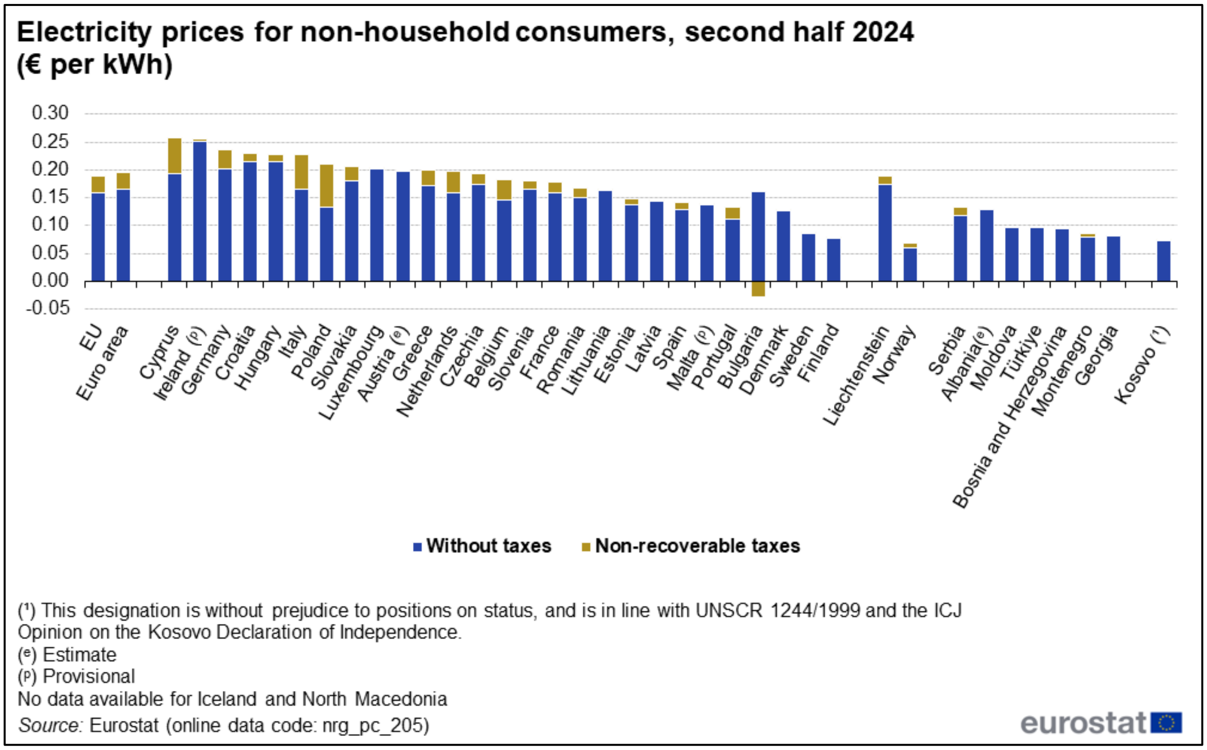

Fig. 10. Electricity prices for non-household consumers, Euro area countries, 2nd half 2024 [56]

Employing high-performance heat pumps and electric boilers is a suitable choice for electrifying heating and replacing natural gas-based systems. In this context, it is also important to consider the proportion of electricity generated from renewable sources. Electricity is generally considered a clean option, and hopefully, renewable sourced electricity is rising in Europe.

In Denmark, electricity used for heating is subject to a reduced tax rate compared to other electricity consumption; however, the remaining tax burden remains considerable, limiting the economic competitiveness and wider adoption of electric heat pumps [15]. Østergaard et al. (2021) [22] showed variable electricity taxes linked to spot prices encourage thermal energy storage and price-responsive operation but have little impact on heat pump capacity. Additional incentives are needed to drive significant heat pump investment.

[Fig. 11] illustrates how the preferred unit for dispatch (PUD) is determined by the marginal heat production cost relative to electricity price. Power-to-heat (P2H) units become the PUD during low electricity prices. While electricity spot prices set the general cost trend, factors like grid tariffs, taxes, and subsidies influence cost differences between units [25]. For instance, high levies increase the marginal heat production cost of P2H, making it competitive only at very low electricity prices compared to P2H without levies.

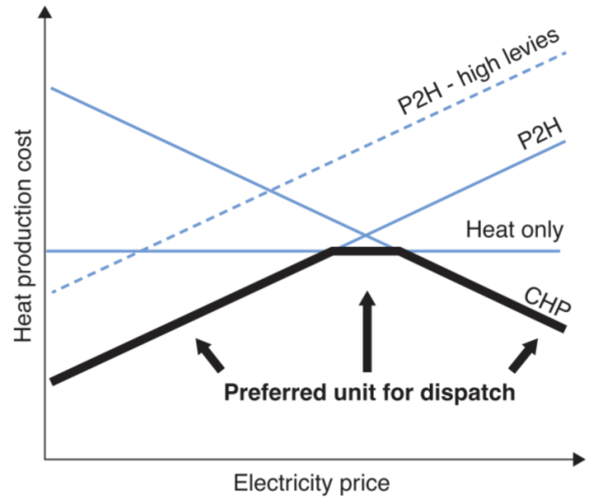

Fig. 11. Preferred unit for dispatch (PUD) and marginal heat production costs in a district heating plant [25] ("Heat-only" refers to a plant that produces only heat, not electricity.)

B. Natural Gas

Natural gas taxation is crucial for the competitiveness of DH systems, as gas is widely used in boilers and CHP plants. Favorable tax policies can make DH more financially and environmentally sustainable.

Visualization in [Fig. 12] highlights the significant impact of fiscal policy on households natural gas bills, showing that government levies can make up a substantial portion of the total cost. Natural gas taxation varies across countries, impacting energy affordability, social policy, and the energy transition.

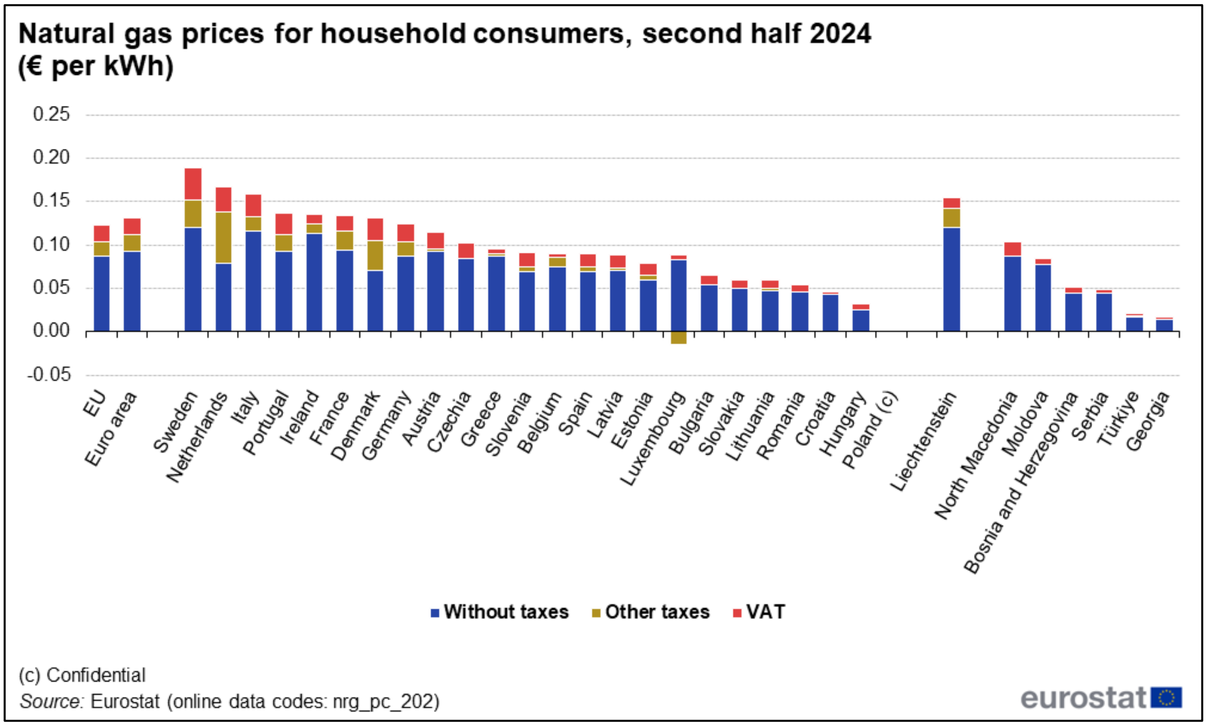

Fig. 12. Natural gas prices for household consumers, Euro area countries, 2nd half 2024 [57]

High taxes on natural gas for households may encourage fewer people to adopt gas boilers [58]. There is a surprising point in comparing three countries of Austria, Germany, and Denmark; Austria exhibited the highest price before taxation, followed by Germany and Denmark [57]. However, post-taxation, the trend reverses, with Denmark attaining the highest final price and Austria ranking last. Notably, the Netherlands imposes one of the most substantial taxes on natural gas for households.

[Fig. 13] presents natural gas prices for non-household consumers across Euro area countries in the second half of 2024, illustrating the energy costs faced by industries and DH operators that depend on gas-fired CHP or boiler plants. These prices represent end-user contract prices including wholesale market components, network charges, and national taxes or levies and thus reveal how fiscal and regulatory frameworks shape overall gas expenditure. Variations among countries highlight how taxation and levy structures significantly influence the competitiveness of gas-based heat production and the economic attractiveness of switching to renewable heat sources. For DH operators, these cost differences affect both short-term operational strategies and long-term investment decisions toward decarbonization.

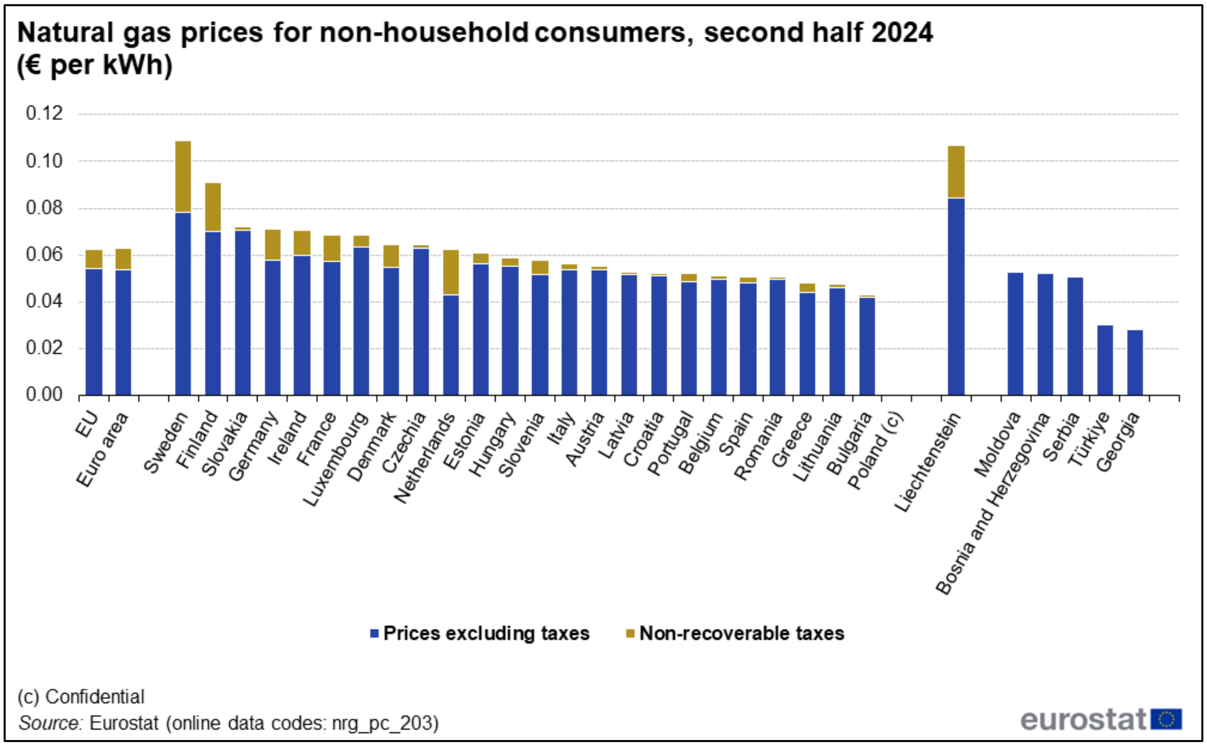

Fig. 13. Natural gas prices for non-household consumers, Euro area countries, 2nd half 2024 [57]

C. Biomass

Biomass, the most widely used renewable source in European DH systems, faces uneven taxation. The pricing of heat supplied by biomass is significantly influenced by the geographical location of the heating plant, as a substantial portion of market activity remains confined to a regional scale within a country [59]. Some member states, like Denmark, fully exempt biomass for heating from energy taxes, aiding national decarbonization and the rapid expansion of biomass-fired CHP and boiler units in DH networks [15]. Conversely, some countries impose VAT and transport costs on biomass, increasing its final price for end-users. Regional variations in biomass supply and taxation significantly impact heat costs, as seen in the Austrian case. This study of Austrian biomass heating plants based on 20 case studies shows LCOH of 69 to 106 €/MWh with an average of 84 €/MWh (before tax) [60]. Depending on the tax treatment of biomass, these costs may either remain competitive or become less attractive relative to natural gas.

D. Waste Heat

Waste heat recovery offers a great pathway for renewable or low-carbon DH, often sourced from industrial processes or data centers. Despite its potential, waste heat recovery faces adoption barriers, including limited awareness of its benefits and legal opportunities, high electricity costs relative to gas, operational inefficiencies in practice, and a shortage of skilled personnel for installation and maintenance [61].

Denmark has eliminated taxes on industrial excess heat and facilitated its integration into DH networks [62]. However, the lack of a clear taxation framework in some countries limits waste heat's uptake. Waste heat isn't usually taxed directly, but fiscal uncertainty, like reduced VAT or energy tax exemptions, can deter investment. Clearer and more favorable tax policies could encourage industrial actors to supply excess heat to DH networks, turning waste into a low-cost renewable resource.

E. Solar Thermal

Solar thermal plants face initial investment costs as their primary barrier. However, fiscal policy can indirectly affect competitiveness by reducing VAT rates on equipment, installation, and energy service contracts. Targeted tax credits for solar thermal integration could significantly improve its economic viability, especially when combined with seasonal thermal energy storage.

Taxing energy (fuel) sources of DH presents opportunities and challenges for policy design. Taxation of renewable energy sources for DH, such as biomass and solar thermal, impacts their competitiveness compared to fossil fuels. While fossil fuels face excise duties and carbon pricing, renewable fuels often benefit from exemptions or reduced tax rates, affecting investment incentives and operational costs. Some countries align fiscal incentives with decarbonization goals, while others unintentionally favor conventional fuels, resulting in a fragmented policy landscape. A coherent tax framework that consistently rewards low-carbon and renewable sources, reflecting their environmental benefits, is crucial for aligning DH markets with broader energy transition targets.

3.2.2.2 Carbon Tax Schemes and ETS

Despite advancements in renewable technologies, they currently lack full economic competitiveness with fossil-fueled technologies in terms of cost. Therefore, it is important to put taxes on carbon dioxide (CO_2) emissions from traditional technologies to address externalities [63].

At the European level, carbon taxation is highly heterogeneous, reflecting differences in national policy priorities and energy mixes. As of April 1, 2025, carbon taxes vary substantially across member states, as illustrated in [Fig. 14]. Nordic countries such as Sweden, Finland, and Denmark apply some of the highest carbon taxes globally, exceeding €100 per ton of CO_2 in some sectors, which has accelerated the transition away from coal and oil in district heating [64]. In contrast, several Eastern and Southern European countries have either minimal or no carbon taxation, relying instead on the EU Emissions Trading System (ETS) as the primary instrument. This difference creates uneven incentives for decarbonization across Europe.

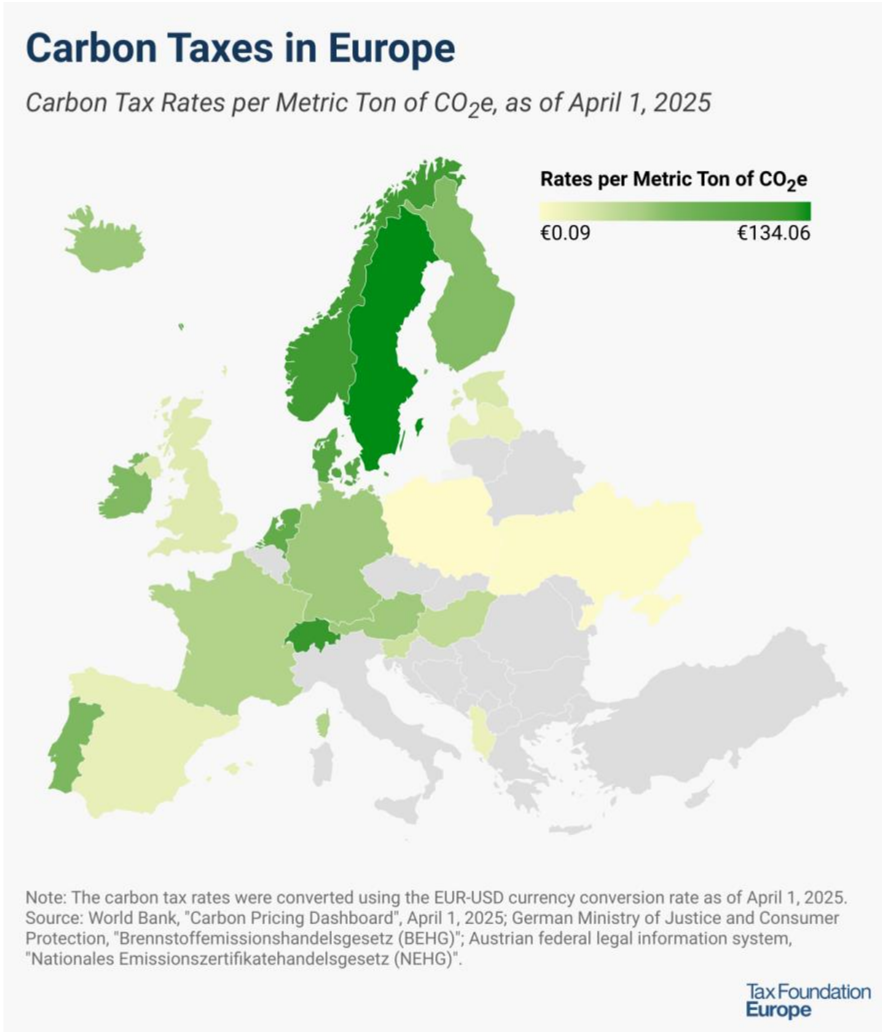

Fig. 14. Carbon taxes in Europe as of April 1, 2025. [64]

The European Union Emissions Trading System (EU ETS), launched in 2005, is the world's first and one of the largest carbon markets. It operates on a cap-and-trade principle, requiring emitters to pay for their greenhouse gas (GHG) emissions, thus incentivizing reductions. The system covers electricity and heat generation, industrial manufacturing, and aviation sector which contributes to about 40% of total EU emissions and started covering maritime transport in 2024. It contributes to lowering overall EU emissions while generating revenues to support the green transition. The EU ETS operates in all EU Member States, Iceland, Liechtenstein, and Norway, and has been linked to the Swiss ETS since 2020 [65]. Building on this success, the EU ETS 2, starting in 2027, will extend carbon pricing to buildings, road transport, and other sectors, promoting deeper decarbonization across the EU economy.

The EU ETS aims to encourage energy efficiency and fuel switching to renewable energy by imposing a carbon price on energy-intensive industries. However, its effectiveness has been hindered by a low carbon price, necessitating additional measures [15]. Which means carbon price is lower than the cost of investing in cleaner technologies, so companies often just pay it instead of reducing emissions.

A bi-level optimization method applied by Martelli et al. (2020) [63] determines optimal renewable subsidies and carbon taxes for multi-energy systems (MES). By testing four real-world cases, the study shows that significant CO_2 reductions can be achieved with only marginal increases in total system costs for both MES owners and governments. These findings highlight how carefully designed carbon tax schemes can outperform existing energy policies in terms of cost-effectiveness and emission savings.

In conclusion, carbon taxation represents a powerful tool for steering DH systems towards renewable sources and energy efficiency. However, its effectiveness depends on coherent implementation, coordination with other policy instruments (e.g., subsidies and ETS), and careful consideration of socioeconomic impacts.

3.2.3 Subsidies and Loans

A. Subsidies

Subsidies and financial support mechanisms are pivotal for advancing renewable energy integration in DH systems. Despite technological progress, renewable heating remains less competitive than fossil-based systems, making financial aid essential to enhance DH competitiveness, stabilize prices, and reduce emissions [63][46]. In existing DH areas, subsidies can strengthen and expand networks, while in regions without DH, incentives promote individual heat pumps, balancing collective and decentralized options [63]. Well-designed schemes encourage investments in low-emission technologies such as CHP, electric boilers, and biofuels [25][60], while also supporting waste heat recovery and solar thermal systems to increase the renewable share in DH networks [66].

In Finland, Norway, and Sweden, generous subsidies incentivize investment in combined heat and power plants with electric boilers, whereas in Denmark, lower subsidies favor investment in wood chip boilers [67]. Denmark has also introduced subsidies to replace individual oil and gas boilers with heat pumps, while eliminating taxes on excess industrial heat. These measures promoted widespread adoption of heat pumps, enabled integration of industrial excess heat into DH networks, and raised competition between subsidized heat pumps and conventional DH systems [62].

In Germany, subsidies encourage early adoption of low-carbon technologies such as heat pumps, although benefits and costs vary by building type. Aligning these incentives with municipal heat planning is important, as DH can complement decentralized solutions [67].

In the Baltic countries, Møller Sneum et al. [24] highlight that taxes and subsidies currently play only a limited role in shaping DH plant operations, as system flexibility and technologies like heat storage have a stronger impact on cost efficiency.

In summary, subsidies in DH mainly influence investment decisions, not operational behavior [25]. The introduction of subsidies for the adoption of individual HPs in regions with potential for promoting RDH may pose a risk to the overall uptake of DH. Well-designed financial support promotes low-emission technologies and sustainable heat production, while removing subsidies increases reliance on fossil boilers and limits renewable technology adoption. Careful policy design is essential to avoid market distortions and ensure long-term efficiency in RDH.

B. Loans

Loans are a key financial instrument for addressing the high upfront costs and long payback periods typical of DH infrastructure. Well-designed loan schemes also stabilize consumer prices and attract private capital, advancing both local and national energy transition goals. Consumer payments like down payments or connection fees often supplement loans, partially guaranteeing repayment. This strengthens DH companies' financial security and improves their ability to obtain financing for new projects [14].

Sweden and Denmark have led DH development through favorable loan arrangements. Sweden uses low-interest loans from national programs and institutions such as the European Investment Bank (EIB) and the Nordic Investment Bank to expand DH, particularly among private operators [25]. These loans supported large-scale DH projects, attracted private investment, and modernized networks. Cooperative investments between DH companies facilitated network interconnections and broader system growth.

Denmark's DH sector particularly benefits from municipally guaranteed credit schemes offering low-interest, non-profit loans through a municipal credit institution established in 1899. With repayment periods of 20-50 years and rates of 2-3% below commercial levels, this system has maintained affordability and stability for over a century [14][25]. Temporary privatization to transnational energy firms introduced high-interest internal loans that increased consumer prices, but municipal ownership restored affordability after 2014-2015 [14]. However, access to such financing is limited to municipal and cooperative utilities, restricting market-based participation and slowing sector diversification.

A Danish experience showed lower market prices for natural gas and extended periods for DH loan repayments, temporarily made natural gas heating cheaper. This increased the share of DH consumers paying more for heating compared to individual gas boilers from 5.2% in 2012 to 27.4% in 2013 [14]. Favorable financing has also enabled Denmark's large-scale deployment of solar-assisted DH, supported by municipalities' loan guarantees, standardized system designs, and widespread technical expertise [68].

In Germany, low-interest loans are part of national subsidy frameworks. The federal BEG EM program allows households to access KfW bank loans for renewable heating and energy-efficient upgrades. These loans complement one-time investment subsidies, reducing upfront costs and speeding up the transition from fossil fuels, especially in smaller buildings with shorter payback times [67].

In the Netherlands, DH projects are generally financed by large utilities and financial institutions such as the EIB. However, low-interest, tax-deductible loans of up to

€25,000 often exclude older apartment buildings with outdated systems. Moreover, Dutch banks' limited DH financing experience can lead to higher interest rates, reducing project feasibility [25].

In the United Kingdom, DH loans mainly come from commercial banks and corporate investors. Yet, the sector's relative immaturity and limited institutional experience result in higher borrowing costs, creating a significant financial barrier to wider DH adoption [25].

Favorable loan schemes have been fundamental to the expansion and stabilization of district heating systems across Europe. Denmark and Sweden illustrate how long-term, low-interest financing can maintain affordability, attract investment, and accelerate renewable integration. Nonetheless, restricted access for private operators and uneven institutional experience among countries continue to influence the pace and inclusiveness of DH sector growth.

3.3 Non-financial Strategies

In this thesis, non-financial strategies are categorized into two primary types: (1) regulatory and policy instruments, and (2) behavioral and informational instruments. Regulatory and policy instruments are mechanisms through which governments steer markets and actors toward desired outcomes such as environmental protection, energy efficiency, and sustainable economic growth. They include laws, standards, and strategic frameworks that define obligations, rights, and incentives within the energy system. Meanwhile, behavioral and informational instruments influence decisions through awareness, feedback, and social norms rather than direct economic incentives. Although strategies within this section do not mainly target financial outcomes, they can indirectly influence monetary decisions.

3.3.1 Regulatory and Policy Instruments

Governmental and international policies play a crucial role in shaping research, development, and deployment of DH systems. Regulation should protect consumers from monopolistic practices, promote fair competition, encourage innovation, and ensure sustainable energy use while fostering technological advancement. Policies also serve as instruments to transition of DH toward renewable-sourced and other sustainable solutions [7][14].

The research reveals that saving energy is often ignored because countries focus more on competing economically [62]. Large technology corporations (Big Tech) play a major role in emissions reduction through renewable energy investments and digital solutions. However, this raises questions about whether current policy frameworks genuinely advance climate goals or primarily reinforce corporate interests.

In the following sections, several key regulatory and policy frameworks in the European Union are presented which address the energy sector and DH. Initially, an EU-wide framework is presented, followed by several country-specific frameworks.

3.3.1.1 The EU's Clean Energy Package [69]

The EU Clean Energy Package (CEP), finalized in June 2019 following negotiations between the European Commission, Council, and Parliament. It includes eight legislative texts: four directives and four regulations.

The EU CEP has four key directives that significantly impact DH systems by addressing different aspects of the EU's energy transition:

1) Renewable Energy Directive (EU) 2018/2001 (RED II):

   RED II sets a binding EU-wide target of at least 32% renewable energy in consumption by 2030. It strengthens consumer rights by recognizing prosumers and encourages renewable energy development in the electricity sector, but not in heating.

2) Energy Efficiency Directive (EU) 2018/2002 (EED):

   Establishes a target of 32.5% more efficient energy use by 2030 compared to the projected 2030 energy use under a business-as-usual scenario. It also introduces new measures for metering, billing, and consumer information. The Energy Efficiency Directive (2012/27/EU) has been revised by Directive (EU) 2023/1791, which introduces more ambitious targets for DHC systems. Under the new directive, an "efficient DHC" system is defined as one that meets the following criteria, outlined in [Table 1]:

Table 1. Deadlines of transposing requirements of Directive (EU) 2023/1791 [70]

Year	Renewable Energy (%)	Waste Heat (%)	High-Efficiency Cogenerated Heat (%)	Combined or Additional Conditions
By 31 Dec 2027	≥ 50	≥ 50	≥ 75	Mix of three ≥ 50%
From 1 Jan 2028	≥ 50	≥ 50	≥ 80	Mix of three ≥ 50% (with at least 5% renewable energy)
From 1 Jan 2035	≥ 50	≥ 50	—	Mix of renewable and waste heat ≥ 50% or mix of three ≥ 80% (with ≥ 35% renewable or waste heat)
From 1 Jan 2040	≥ 75	≥ 75	—	Mix of renewable and waste heat ≥ 75% or mix of three ≥ 95% (with ≥ 35% renewable or waste heat)
From 1 Jan 2045	≥ 75	≥ 75	—	Mix of renewable and waste heat ≥ 75%
From 1 Jan 2050	100	100	—	Only renewable energy, waste heat, or their combination.

3) Energy Performance of Buildings Directive (EU) 2018/844 (EPBD)

   focuses on improving the energy performance of buildings across the EU. It promotes the transition toward nearly zero-energy buildings (NZEBs), the deployment of smart technologies, and large-scale renovation of existing building stock to reduce energy consumption and increase renewable integration.

4) Electricity Directive (EU) 2019/944

   Modernizes EU electricity markets to make them more flexible, competitive, and consumer centered. It enhances consumer rights, supports demand response and prosumer participation, and strengthens the role of national regulators.

The EU CEP includes four directly binding regulations across all EU Member States. These regulations focus on market operation, system security, governance, and agency coordination:

1) Regulation (EU) 2019/943 on the Internal Market for Electricity

   Updates the rules governing how electricity markets operate across the EU. It promotes competition, flexibility, and cross-border trade, supports renewable integration, and strengthens rules for balancing and capacity mechanisms.

2) Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action

   Establishes a framework to ensure that Member States meet the EU's 2030 energy and climate targets. It requires each country to prepare integrated National Energy and Climate Plans (NECPs) and progress reports, ensuring coherence and transparency across the EU.

3) Regulation (EU) 2019/941 on Risk-Preparedness in the Electricity Sector

   Improves cooperation among Member States to prevent and manage electricity crises. It sets common principles for identifying risks, preparing national risk-preparedness plans, and ensuring coordinated responses during emergencies.

4) Regulation (EU) 2019/942 establishing the European Union Agency for the Cooperation of Energy Regulators (ACER)

   This regulation strengthens ACER's powers to oversee cross-border energy markets, enhance cooperation between national regulatory authorities, and ensure the consistent application of EU energy rules.

Together, these measures aim to increase renewable integration, improve energy efficiency, strengthen consumer participation, and create a more resilient and flexible energy system.

3.3.1.2 National Policies and Legislative Frameworks

In this section, the key national policies and legislative frameworks of Denmark, the Netherlands, and Germany are introduced and discussed.

A. Danish Climate Agreement (Denmark)

   Adopted with broad parliamentary support, the Danish Climate Agreement (2020) strengthened Denmark's leadership in renewable heating. A key provision was the removal of the excess heat tax, which facilitated the integration of surplus industrial heat, particularly from data centers, into DH systems. The agreement also introduced subsidies to accelerate the replacement of oil and gas boilers with low-carbon alternatives, such as DH and HPs, supporting their integration into the national energy infrastructure. [62]

B. Heat Supply Act (Denmark)

The Heat Supply Act, enacted in 1979, is the cornerstone of Denmark's heating regulation, governing public heating installations with outputs above 250 kW and CHP units up to 25 MW. It assigns municipalities the responsibility for planning and approving local heating projects, including socio-economic analyses to ensure cost-effectiveness and environmental benefits compared to alternative options. The Act enforces a non-profit principle, whereby DH companies set consumer prices based solely on actual production, distribution, and administrative costs. Danish utilities, often municipally supported and non-profit, prioritize consumer interests by investing in capital-intensive technologies such as solar thermal plants, supported by standardized designs and experienced suppliers that reduce investment risks. Zoning regulations prevent overlapping heat networks, while regulatory supervision maintains transparency and efficiency. This coordinated planning and regulation have enabled Denmark to develop one of the world's most efficient and flexible DH systems, effectively integrating renewable and excess heat sources. [71]

C. Dutch Climate Agreement (the Netherlands)

The Dutch Climate Agreement (2019) is a national strategy to cut Greenhouse Gas (GHG) emissions by 49% by 2030 and achieve climate neutrality by 2050 with respect to 1990 levels. Developed through cooperation among government, industries, and municipalities, it covers five sectors: electricity, industry, buildings, transport, and agriculture. It sets a clear pathway to phase out natural gas in buildings by 2050, with intermediate targets for 2030. Municipalities lead local heat decarbonization plans, supported by thermal energy communities (TECs) that engage citizens and promote participation in the energy transition. [72]

D. Heat Act 2.0 and Gas Ban (the Netherlands)

The Heat Act 2.0 (expected 2026) requires public or semi-public ownership of DH systems, ensures cost-based tariffs, and safeguards consumers, while promoting transparency, efficiency, and fair competition. It also obliges municipalities to develop local heat transition strategies, guiding the phase-out of natural gas. Complementing this, the municipal gas ban (from 2024) empowers local authorities to enforce these strategies, facilitating the integration of thermal energy communities (TECs), increasing connection rates, and providing frameworks for citizen participation and support measures. Together, these measures advance the Netherlands' heating transition and the broader goals of the Dutch Climate Agreement. [72]

E. Renewable Energy Sources Act (Germany)

The Renewable Energy Sources Act (EEG, 2000) introduced feed-in tariffs that supported renewable electricity generation from technologies such as biomass and biogas. Although primarily an electricity law, the EEG indirectly benefited district heating by encouraging the deployment of CHP plants that supply residual heat to DH networks. This indirect contribution complements Germany's broader policy efforts to integrate renewable heat, though comprehensive heat-planning frameworks have since been developed through more recent legislation. [72]

F. Municipal Heat Planning Act (Germany)

The Municipal Heat Planning Act (2024) requires municipalities to develop heat transition strategies, recognize energy communities as stakeholders, and set renewable energy targets for DHN. Targets for existing networks include 30% renewable or unavoidable waste heat by 2030, 80% by 2040, and 100% by 2045, while new networks from 2024 must reach at least 65% renewable or unavoidable waste heat. Older projects must adapt as feed-in tariff support ends, emphasizing the need for flexible business models. [72]

G. Cooperative Act (Germany)

The Cooperatives Act (2006) facilitates the formation and operation of energy cooperatives, enabling communities to collectively develop and manage small-scale renewable energy projects. By promoting democratic participation, local ownership, and reinvestment of profits, the Act supports community involvement in energy production and indirectly encourages the use of residual heat from biomass and biogas in DHN. [72]

[Table 2] compares Denmark, Germany, and the Netherlands on their building decarbonization goals, existing fossil fuel heating bans, and upcoming restrictions. It highlights each country's target years for full or partial decarbonization, current prohibitions on oil and gas heating in new or existing buildings and planned measures to expand renewable heat use and phase out natural gas systems.

Table 2. Fossil fuel heating phase-out and building decarbonization targets of Denmark, Germany and the Netherlands [72]

Country	Decarbonization Targets	Existing Fossil Fuel Heating Bans	Planned Fossil Fuel Heating Bans
Denmark	Carbon-neutral DH and electricity by 2030;	Oil and natural gas heating prohibited in new buildings since 2013; oil banned in areas with gas/DH since 2016; gas no longer mandatory in DH plants since 2018	No natural gas heating in any building by 2035
Germany	Fully decarbonized buildings by 2045; 50% renewable heat by 2030	New buildings must have at least 15% renewable heat since 2009	From 2026-2028, new heating systems in existing buildings must have ≥ 65% renewable heat; rule applies to new buildings from 2024
The Netherlands	Complete building decarbonization by 2050;	Natural gas heating prohibited in new buildings since 2018	From 2026, all new heating systems in existing buildings must largely rely on sustainable sources; no new

	20% of buildings decarbonized by 2030		gas boilers; from 2024, municipalities may terminate natural gas supply in districts

Overall, policymakers should implement stable, flexible policies promoting heat decarbonization and TECs, strengthen community skills, and engage local stakeholders in planning and implementing heat strategies. Economic incentives and high DH connection rates are also recommended [72].

3.3.2 Behavioral and Informational Instruments

This section examines the instruments that directly influence the behavior of consumers of DH. It is mainly focused on the tools that educate and raise the awareness of consumers which leads them towards more energy efficient and sustainable solutions. The key point is that the majority of financial (e.g., pricing and economic incentives) and nonfinancial strategies presented in preceding sections can also have a secondary impact on consumer behavior. Several mentionable tools and strategies in this area are presented below:

A. Individual Metering and Charging

Introducing individual heat metering and charging (billing) is often seen as a way to reduce energy use by aligning consumer costs more closely with their own consumption. However, outcomes depend heavily on both building quality and user behavior. In poorly insulated dwellings or in social housing, metering can shift financial burdens onto residents without necessarily reducing consumption. A case from a council block in London in 2010 demonstrated these challenges, as plans to install meters were suspended over concerns about thermal performance and affordability [73]. This highlights the complexity of ensuring fairness in cost allocation and the need to link behavior-based measures with broader upgrades to building efficiency. In the Netherlands, legislation also requires the upgrade of DH distribution systems to enable individual metering and billing [42]. This improves transparency, allows consumers greater control over heating levels, and helps utilities to reduce heat losses.

B. Informative Billing and Digitalization (Smart Metering)

Complementary approaches such as informative billing, and feedback mechanisms encourage more sustainable user choices. Informative billing transforms conventional bills into a feedback tool by showing consumers their energy use over time, comparisons with past periods, and, in some cases, with similar households. Studies from Norway show that replacing infrequent estimated bills with accurate, bimonthly informative bills can reduce consumption by 8-12%, with lasting effects [74]. Frequent, clear billing enhances consumer understanding and satisfaction.

Overall, informative billing and feedback tools strengthen demand-side management, promotes energy conservation, and prepares the ground for smart metering and automated systems (discussed in section 2.2). Smart meters and digital tools provide real-time energy use feedback, raising consumer awareness and promoting efficient behavior. IoT devices, smart thermostats, and advanced control systems optimize temperatures automatically, reduce costs, and improve system efficiency [20].

C. Hearing Positive Experiences

Public understanding of advanced heating technologies remains limited. Studies indicate that people are more likely to adopt new systems when they see them in use locally or hear positive experiences from trusted sources such as neighbors or local authorities. Community initiatives, open-home programs, and regulated installation with follow-up support can build trust, encourage correct use of controls and tariffs, and ultimately increase social acceptance [75].

D. Energy Labeling

Awareness strategies can also focus on energy labeling, helping consumers recognize lifetime operating costs alongside upfront purchase prices. By improving understanding, households are better positioned to prioritize efficient technologies. Research by Du et al. (2024) [76] shown that appliances with a moderate energy efficiency label are the most adopted. To address this, energy label standards should be raised to ensure that appliances with a moderate label are also energy efficient.

E. Engaging Sales Agencies

Policy simulations suggest that engaging sales agencies can be more effective than traditional information campaigns in promoting energy-efficient appliances [76]. However, the largest barrier to widespread DH adoption is still the availability of infrastructure, underlining the importance of coordinated planning.

Households choose heating systems based on total cost of ownership, balancing comfort and long-term expenses. In households, changes in energy prices usually lead to only small and slow adjustments in heating use. Most consumers cannot quickly change their heating habits or switch systems, so their demand reacts only weakly to price signals. Price changes may only affect demand in the long run, and decisions are also influenced by subsidies, regulations, and alternatives. While behavioral responses matter, policy measures and infrastructure development are crucial in steering households toward low-carbon heating options. [77]

4 Synthesis of Market Strategies for Prosumers and Demand Response

Market strategies directly influence the extent to which consumers can act as prosumers and how effectively demand response mechanisms operate to enhance system flexibility and efficiency. By shaping pricing models, incentives, and participation frameworks, these strategies determine how actively consumers engage with energy production and consumption. Strong, well-structured market approaches can empower individuals to contribute to network stability, optimize resource usage, and ultimately support a more resilient and sustainable energy system.

4.1 Comparative Assessment

To compare the influence of strategies presented in the literature review (chapter 3) on prosumers and DR, each strategy group is qualitatively assessed in [Table 3]. A simple qualitative scale ranging from 1 (low) to 3 (high) is employed for both indicators. The assessment draws upon insights from the reviewed studies as well as the author's evaluation of the practical performance of each mechanism.

The rating scale is defined as follows:

Prosumer engagement:

- **1 (Low):** Minimal consumer involvement; participation is mostly passive.
- **2 (Moderate):** Some active involvement in planning or operation; limited influence on decisions.
- **3 (High):** Strong active involvement; consumers participate in governance, decision-making, or own part of the system.

Demand Response (DR) Enhancement:

- **1 (Low):** Few incentives for flexible demand; system largely rigid.
- **2 (Moderate):** Partial DR incentives; some opportunities for demand shifting.
- **3 (High):** Strong DR incentives; consumers can actively adjust demand.

[Table 3] serves as a pivotal contribution to the literature review by quantifying the effects of presented strategies on prosumer engagement and DR enhancement. By summarizing impacts, the table provides a structured overview of the key insights derived from the reviewed studies.

Table 3. Market mechanisms / strategies and their impact on prosumer integration and demand response enhancement

Strategy / Mechanism	Effect on Prosumer Engagement	Rate (1-3)	Effect on DR Enhancement	Rate (1-3)

Public (Municipal) Ownership	Ensures stability, trust, and consumer protection; however, innovation and third-party participation develop more slowly.	2	Provides high reliability and predictable tariffs, but rigid annual pricing limits flexibility.	2
Private Ownership	Promotes efficiency and innovation but prioritizes profit and reduces consumer influence.	2	Enhances operational efficiency but provides limited DR incentives without supportive regulation.	2
Consumer / Community Ownership	Encourages strong consumer involvement, local acceptance, and shared investment.	3	Facilitates cross-sector integration (e.g., power-to-heat, waste heat), supporting high system flexibility.	3
Public-Private Partnership (PPP)	Combines public oversight with private expertise, balancing accountability, innovation, and prosumer trust.	2	Offers moderate flexibility; effectiveness depends on contract design and alignment of incentives.	2
Regulated Market	Builds prosumer trust through transparency, fairness, and consumer protection.	2	Provides stable conditions for long-term DR planning but weak price-based signals.	2
Deregulated Market	Encourages competition and innovation but increases uncertainty for small actors.	2	Variable price signals can promote DR but increase volatility and consumer risk.	2
True-Cost / Cost-Plus Pricing	Ensures fairness and cost recovery but weakens incentives for efficiency and innovation.	1	Stable but provides minimal behavioral or flexibility impact.	1
Marginal Cost Pricing	Supports efficient resource allocation and clearer investment signals.	2	Provides strong economic incentives for DR and load shifting; requires digital metering and forecasting.	2
Time-of-Use (ToU) Pricing	Enables active participation through predictable time-based tariffs.	2	Strong DR potential; consumers shift heating load to off-peak periods.	3
Real-Time Pricing (RTP)	Maximizes transparency and encourages highly active prosumer participation.	3	Most effective DR instrument; aligns demand with renewable availability.	3
Seasonal Pricing	Simple and intuitive; moderate influence on consumer behavior.	2	Supports seasonal load shifting but limited flexibility during extreme weather.	2
Carbon Tax	Encourages low-carbon investment and raises awareness of emissions.	2	Strong incentive for DR in long-term and renewable heat, provided policy stability.	2

Energy & Fuel Taxes	Influence prosumer choices and competitiveness of technologies.	2	High fossil taxes enhance DR and renewable switching; high electricity levies hinder power-to-heat.	2
Subsidies & Loans	Reduce entry barriers; support prosumers, local investors, and cooperatives.	3	Drive renewable capacity and flexibility investments; support for advanced control systems and digitalization for DR.	2
Policy & Regulatory Instruments	Provide consumer rights, prosumer empowerment, and institutional stability.	3	Enable long-term DR integration through predictable market rules.	3
Smart Metering & Digitalization	Transform consumers into active participants using real-time data and automation.	3	Enable dynamic pricing, automated DR, and system-level flexibility.	3
Individual Metering & Charging	Links consumption to cost, causing better knowledge of prosumers.	2	Allows individualized DR reaction; dependent on building efficiency.	2
Informative Billing & Feedback	Improves energy awareness and motivates conservation.	2	Enhances DR when combined with smart meters; impact alone is moderate.	2
Awareness & Communication Campaigns	Strengthen local trust and acceptance of DH systems.	2	Encourage gradual behavioral change but have limited measurable DR effect.	1

The comparative assessment reveals distinct influences of ownership, market, pricing, fiscal, and behavioral mechanisms on prosumer engagement and DH system flexibility. While the table summarizes these relationships, a deeper understanding emerges from examining their interactions and reinforcing or limiting effects. The following section delves into these dynamics, interpreting significant patterns and implications.

4.2 Discussion and Interpretation

The comparative analysis reveals clear patterns in how different categories of market mechanisms affect prosumer participation and DR performance.

1. Ownership and governance structures create the foundation for participation.

   Community or cooperative (consumer) owned systems achieve the highest prosumer integration because financial and decision-making involvement fosters trust, accountability, and a sense of collective purpose. Public (municipal) ownership ensures stability and consumer protection but often limits innovation and responsiveness. Fully private ownership promotes efficiency and investment but can reduce transparency and weaken long-term consumer engagement unless supported by strong regulation. Hybrid or public-private partnership models tend to balance efficiency with accountability, making them particularly suitable for modern DH expansion.

2. Dynamic and transparent pricing mechanisms are the strongest enablers of demand response.

   Real-time and time-of-use tariffs score highest for DR because they provide clear price signals that reflect system conditions and enable prosumers to adjust their heat consumption manually or automatically. When combined with smart metering and digital control tools, these schemes translate directly into flexible load management. In contrast, static cost-plus or true-cost pricing models ensure predictability but offer little motivation for behavioral change or efficiency improvements. Seasonal pricing, while easier for consumers to understand, provides only moderate flexibility.

3. Fiscal and policy instruments shape the economic environment in which flexibility can thrive.

   Carbon and fuel taxation, subsidies, and low-interest financing effectively steer investments toward cleaner heat sources, but their impact on day-to-day DR behavior depends on policy stability and market transparency. Coherent fiscal frameworks that tax fossil fuels while exempting or supporting renewables deliver the best results for prosumer engagement. Fragmented or inconsistent taxation across energy carriers, on the other hand, creates uncertainty and weakens incentives to participate in collective heating schemes.

4. Behavioral tools act as essential enablers.

   Smart metering, informative billing, and digital feedback systems amplify the effect of financial incentives by making energy use visible and actionable. These measures strengthen consumer awareness and provide the real-time data required for flexible operation. Likewise, awareness campaigns, cooperative training, and community engagement programs build trust and normalize prosumer behavior, which is critical for sustaining participation over time.

Key insights:

Overall, the comparative evaluation highlights that no single market strategy or mechanism is universally optimal for both prosumer engagement and demand response enhancement. Ownership models such as cooperatives, regulatory frameworks like the Heat Supply Act and the EU Clean Energy Package, and digital solutions such as smart metering consistently achieve higher scores, as they combine strong consumer involvement with clear DR incentives. In contrast, mechanisms centered on rigid pricing (e.g., cost-plus or true-cost models) or limited competition tend to restrict both prosumer participation and system flexibility. Fiscal measures and subsidies show mixed effects, depending on policy consistency and design. Ultimately, the analysis confirms that the most effective approaches are those that balance financial transparency, consumer empowerment, and technological innovation, creating conditions in which prosumers are motivated to engage, and DH systems can operate more flexibly.

No single strategy performs best across all contexts. The evidence indicates that the highest effectiveness arises from hybrid frameworks that combine economic transparency, participatory governance, and technological innovation.

I. Cooperative or municipally regulated ownership provides the institutional trust and fairness necessary for consumer engagement.
II. Dynamic pricing and digital control systems supply the operational flexibility to respond to market or network signals.
III. Stable fiscal and regulatory environments ensure that prosumers and investors view renewable DH as a low-risk, long-term commitment.

Together, these elements form the basis of a modern, participatory market design capable of integrating renewable heat sources, enabling demand response, and accelerating the transition toward low-carbon DH systems.

These findings directly affect the strategic recommendations presented in Chapter 6, where Italy's potential for large-scale RDH is examined through the combined lens of market design, prosumer participation, and system-level flexibility.

5 Methodology

This research adopts a mixed qualitative-quantitative approach to explore how market strategies and policy mechanisms can enhance prosumer participation and demand response in RDH systems, with Italy as the case study. The methodology consists of two main stages:

1) Comprehensive literature review and comparative analysis of market strategies for RDH expansion with focus on prosumers and DR enhancement.
2) Scenario-based modeling and analysis of the Italian DH sector and strategic recommendations based on the preeminent findings in stage 1.

Research Design and Approach

The study follows a sequential logic. First, it identifies and classifies market strategies for RDH that influence prosumer integration and system flexibility through a detailed review of high quality scientific, institutional, and policy literature mostly. These strategies are categorized into financial (e.g., pricing, taxes, subsidies, loans) and non-financial (e.g., regulation, behavioral tools). It is followed by a comparative assessment of strategies influence on prosumers and DR using comparative evidence from leading European countries.

Second, the findings are translated into a scenario modeling framework that evaluates how RDH could evolve within Italy's energy system. The framework uses national statistics and realistic assumptions to quantify the potential environmental and economic outcomes of scaling up RDH. This is followed by strategic and policy recommendations based on the studied materials to achieve scenario targets.

This dual structure allows both a qualitative understanding of market behavior and a quantitative estimation of its effects.

Data Sources

This research relies on high-quality, peer-reviewed literature from leading journals, supported by EU directives, national legislation, and authoritative statistical databases including Eurostat, the International Energy Agency (IEA), ARERA (Italy's Regulatory Authority for Energy, Networks and the Environment), Euroheat & Power, and the Italian District Heating Association (AIRU). Policy analysis is further informed by key national and EU documents, particularly the Clean Energy Package, the Energy Efficiency Directive (2018/2002/EU and 2023/1791/EU), and Italy's National Recovery and Resilience Plan (PNRR).

Scenario Framework

Two scenarios were defined to explore alternative development pathways for Italy's DH sector:

1) Base Scenario: represents the continuation of current stagnant trends with same share of renewable penetration as 2023 levels and limited growth of DH supply.
2) RDH 60 Scenario: models an ambitious transition where renewable sources reach 60 percent of the total DH fuel mix by 2035, expanding DH coverage to about 13 percent of total building-sector heat demand.

The RDH 60 scenario, which serves as the main scenario, evaluates the system-level impacts on fuel substitution, the reduction in the national natural gas consumption, CO_2 emissions, and cost savings in comparison to the Base scenario. The evaluations are conducted using a spreadsheet-based model developed within Microsoft Excel, selected for its transparency and reproducibility. The modeling approach employs straightforward arithmetic and ratio-based relationships rather than sophisticated optimization techniques, prioritizing clarity and traceability over computational complexity.

Key Assumptions and Indicators

Major assumptions include:

- The baseline year of the most recent data available, selected for analysis, is 2023.
- linear efficiency improvements raising DH system efficiency from 81% in 2023 to 90% in 2035.
- Linear evolution of total heat demand reduction due to building retrofits (approximately 20% by 2035).
- Fuel-mix shifts following national renewable potentials identified in section 6.1.3 (bioenergy, geothermal, solar thermal, heat pumps, waste heat).
- CO_2 emission factor for natural gas: 15.583 tCO_2/GWh.
- Average gas import price: 40 €/MWh (post-crisis mid-term estimate).

The main output indicators are:

1. Total heat supplied to the DH network (TWh_t)
2. Renewable share in the DH fuel mix (%)
3. Avoided natural gas use (TWh and Mtoe)
4. Avoided CO_2 emissions (kt CO_2)
5. Monetary value of avoided gas imports (million €)

These metrics enable consistent comparison between the Base and RDH 60 scenarios in terms of environmental, economic, and energy security performance. Further details of the modelling process is described in section 6.3.

6 District Heating in Italy: Scenario and Strategy Design

This chapter includes a scenario-based modeling and analysis of the Italian DH sector and strategic and policy recommendations based on the preeminent findings in Chapter 3 and 4. Through this analysis, it becomes possible to test how different market, and technological choices influence the future trajectory of DH in Italy. This approach does not aim to predict exact outcomes but rather to illustrate plausible pathways, highlight trade-offs, and provide insights for policymakers and stakeholders considering the expansion of RDH in Italy.

6.1 Energy System and District Heating Context

To understand the role that RDH could play in Italy, it is first necessary to examine the broader national energy context. This includes analyzing the structure of Italy's energy supply, the composition of final energy consumption, and the status of DHN. These elements provide the baseline against which the scenarios in this chapter are developed and evaluated.

6.1.1 National Energy Supply and Consumption

[Fig. 15] shows the evolution of Italy's total energy supply from 2000 to 2023. The data indicate a declining trend after the peak in 2005 while confirming the country's continued dependence on fossil fuels, with natural gas and oil representing the dominant shares throughout the period. Coal use has steadily declined, while renewables, particularly wind, solar, biofuels, and waste (renewable and non-renewable), have had an increasing trend over this period, though their contribution remains comparatively small. The overall trend indicates a gradual diversification of the energy mix, but the reliance on natural gas and oil leaves Italy exposed to price volatility and energy insecurity.

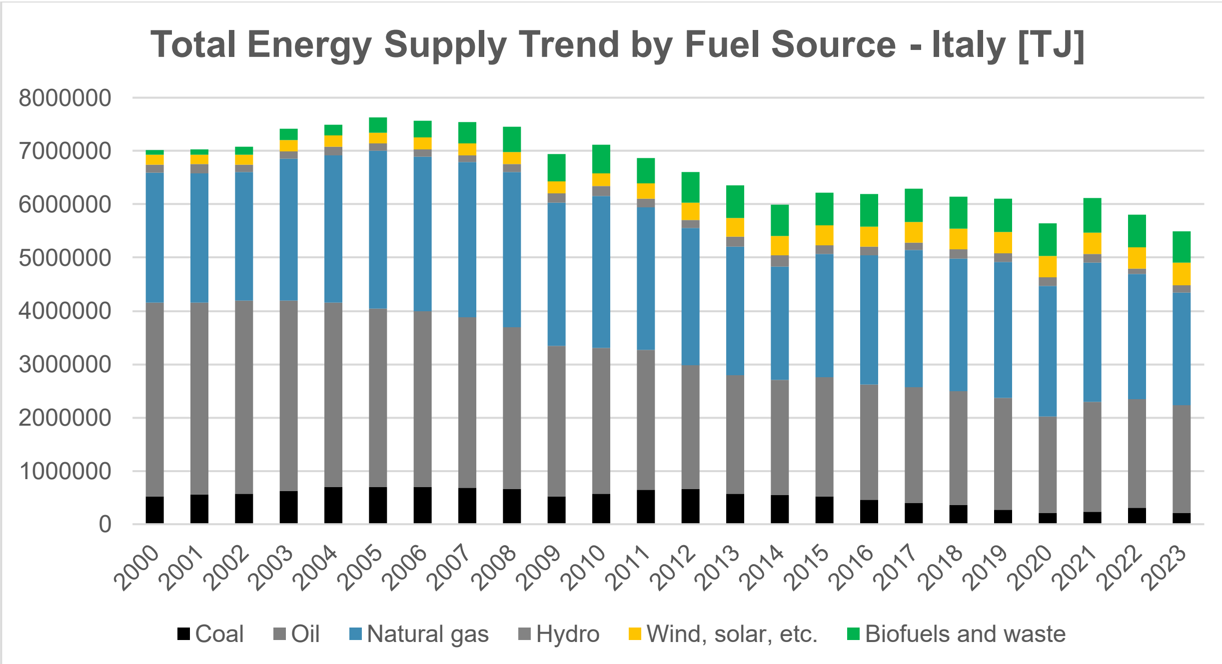

Fig. 15. Total energy supply trend by fuel source in Italy [78]

Total final consumption (TFC) of energy in Italy has shown a decreasing trend after its peak in 2005, as depicted in [Fig. 16]. Likewise, the final consumption of the residential sector, which contributes to the largest share of heating demand, has been decreasing since its peak in 2012. These declines can be largely attributed to the increased adoption of more energy-efficient technologies across different sectors, although other factors like climate change and shift in population may also have contributed. [Fig. 16] illustrates how final energy consumption has changed across different sectors. The transport sector consistently leads all others, with a noticeable increase in consumption following the pandemic in 2020.

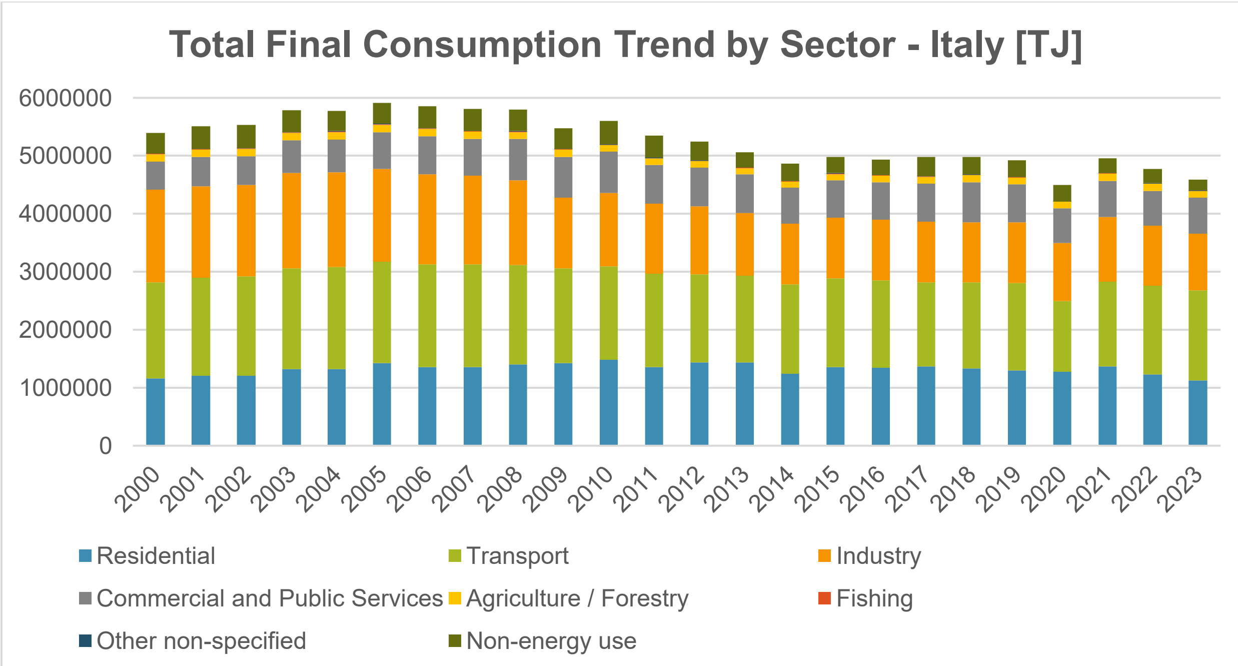

Fig. 16. Total final consumption trend by sector in Italy [78]

Since both energy supply and consumption have a decreasing trend, we need a criterion to show how the whole energy system is performing. It is evident that not all the energy supply reaches its final consumption, resulting in a portion being lost (wasted) during transformation and transfer to the final use. [Fig. 17] illustrates what percentage of the energy supply in Italy is consumed (TFC) and what percentage of it is lost. It is a positive development that the trend of wasted energy has been decreasing over the period, which signifies an increase in the overall efficiency of the Italian energy system.

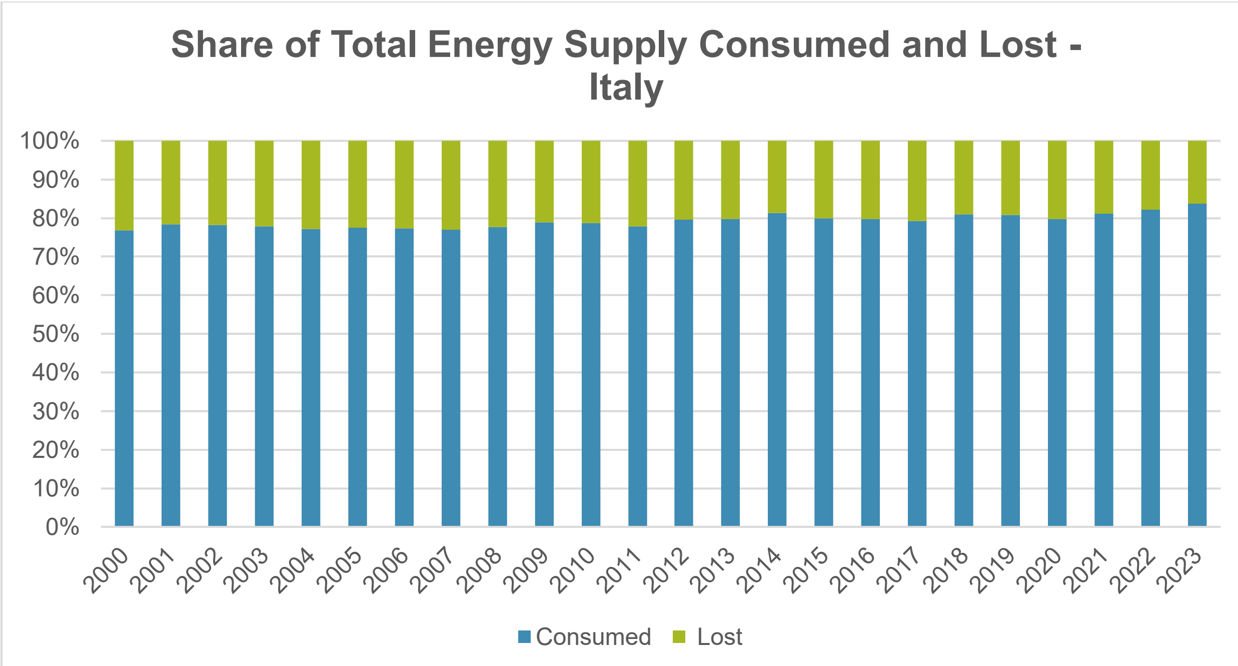

Fig. 17. Share of total energy supply that reaches final consumption and being wasted, Italy [78]

Furthermore, one might wonder about the relationship between TFC and population. [Fig. 18] shows that there's no strong correlation between the two. While population and TFC both had a decreasing overall trend after 2014, the data don't show a consistent or proportional relation in TFC with population changes. This suggests other factors, like improved energy efficiency, economic structural changes, and energy-saving technologies, may influence TFC more than population alone.

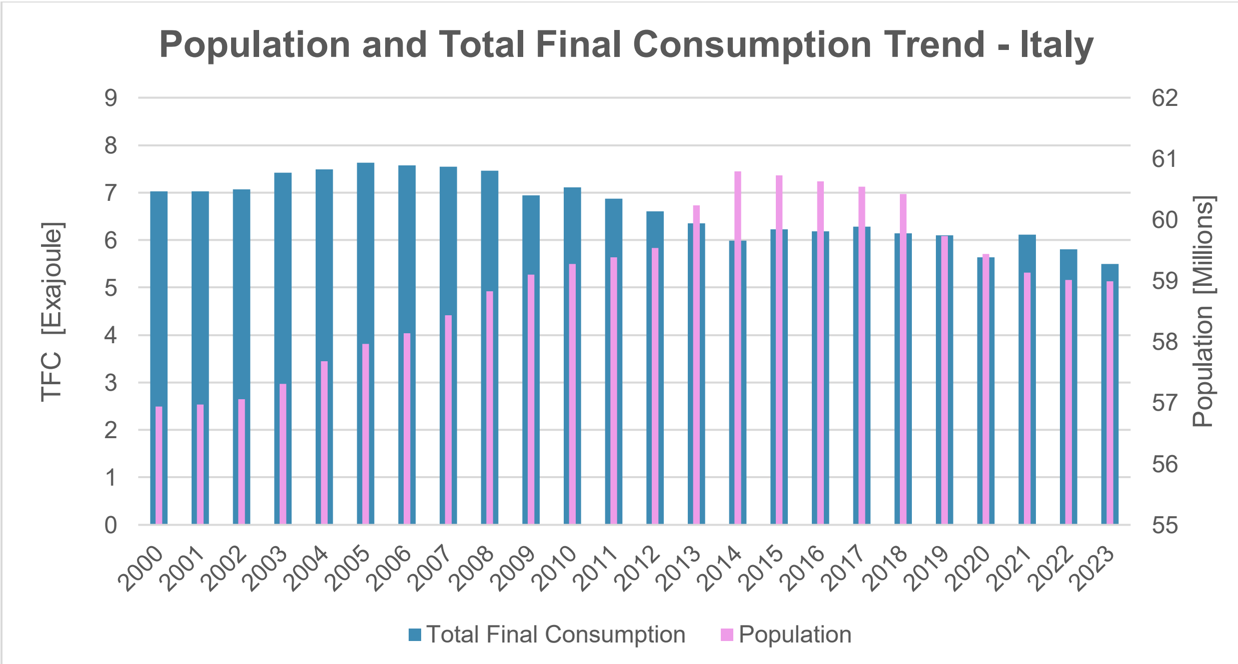

Fig. 18. Population and total final consumption trend of Italy ([78] & [79])

It is worthy to analyze the existing data for a specific year as it provides us with more information regarding the performance of the energy sector. Based on the last year available data in [Fig. 19], 2023, Italy's energy supply remained predominantly fossil-based, with natural gas and oil together providing more than three-quarters of total supply. Natural gas held the largest share, followed closely by oil, while coal contributed only a small portion. Renewables mainly biofuels, solar, wind, and hydro accounted for just about 21% of the fuel mix. This mix shows Italy's continued reliance on fossil fuels while gradually incorporating renewable alternatives.

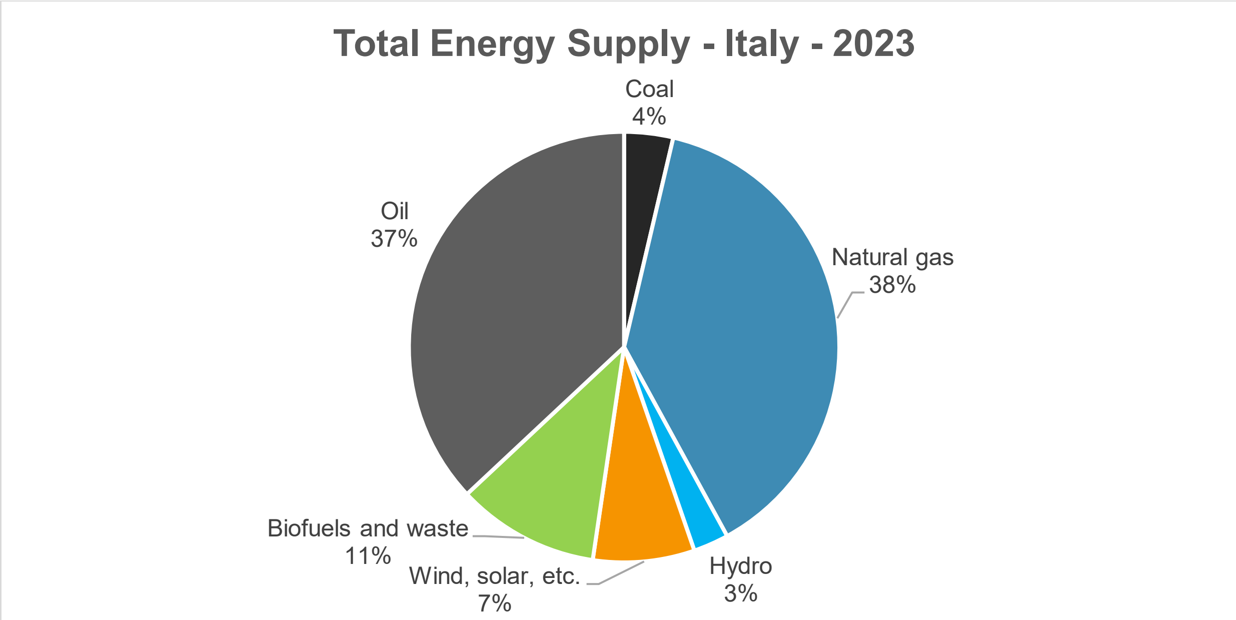

Fig. 19. Total primary energy supply in Italy, 2023

In 2023, Italy's final energy consumption was mainly driven by transport and residential sectors, together accounting for over half of total demand [Fig. 20]. Industry followed as a significant user, while commercial and public services consumed comparatively smaller shares. This distribution reflects Italy's energy demand being closely linked to mobility and household and Industry needs.

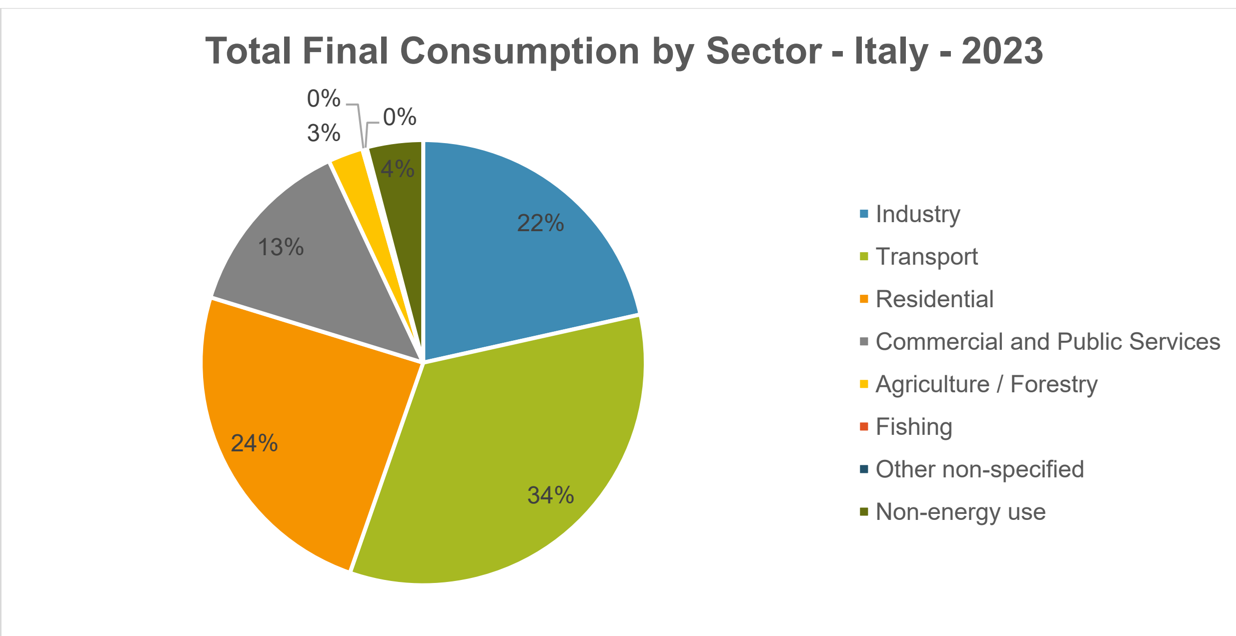

Fig. 20. Total final consumption in Italy, 2023 [78]

According to [Fig. 21], in 2023, space heating was the largest share (66%) of residential energy consumption. Together with water heating (11%), both accounted for approximately 77% of the total energy usage. Electrical appliances, cooking, and space cooling accounted for smaller shares of the energy demand. This pattern reflects Italy's high heating demand due to its climate and the significance of thermal comfort in households.

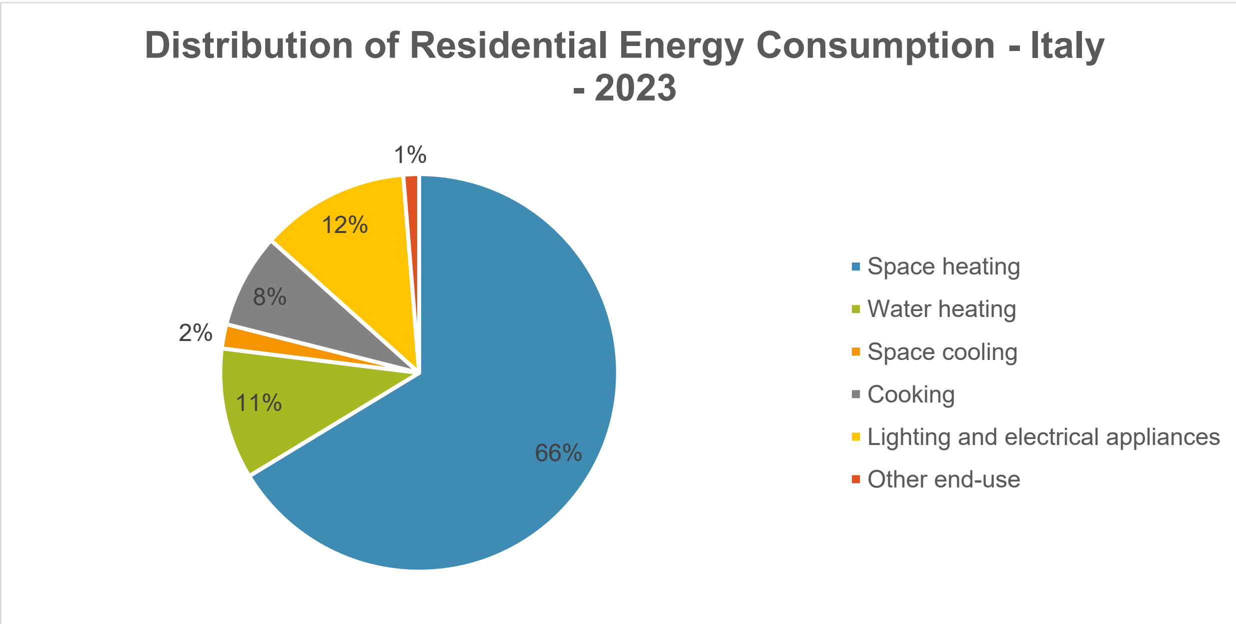

Fig. 21. Distribution of residential energy consumption in Italy, 2023 [80]

In addition to the residential sector, the services and industry sectors also contribute to noticeable shares of heating demand.

[Fig. 22] shows technological mix of the heating in the building sector (residential and services) in Itay. Natural gas boilers hold a substantial market share of 63%, followed by biomass boilers at 19%. Notably, DH accounts for only 3% of the total heat demand of the building sector, which is a relatively low share, even less than half of the oil boilers. The figure represents data from 2019, but it has remained relatively stable since then.

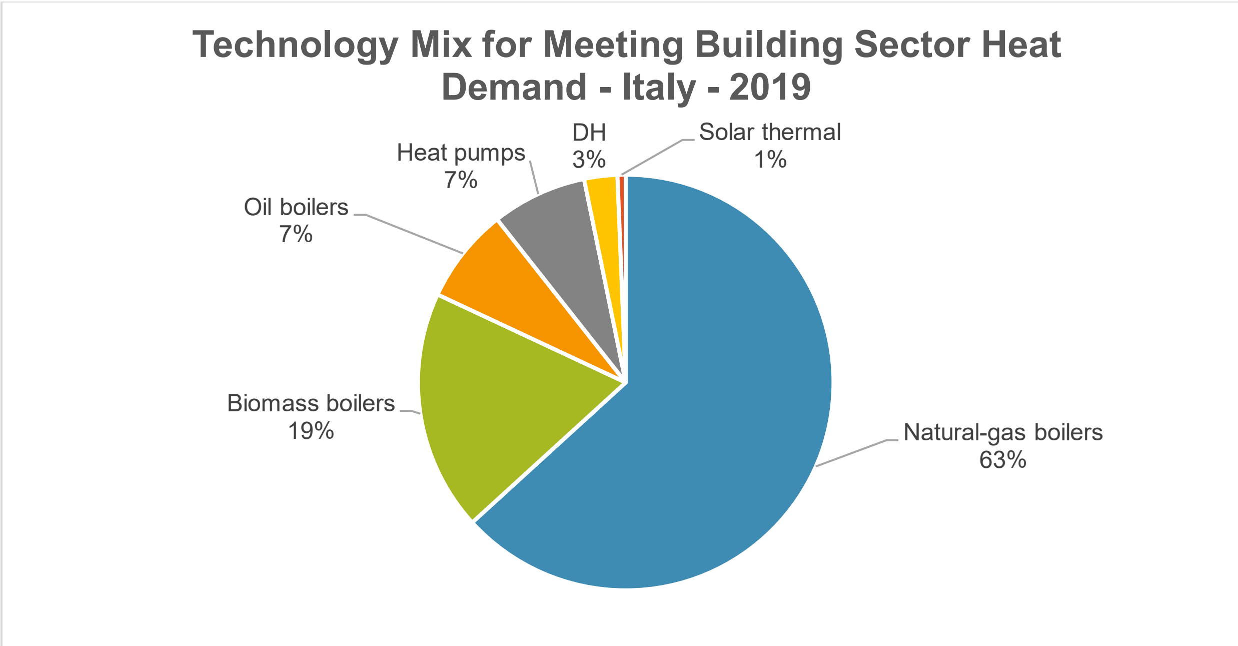

Fig. 22. Share of residential and services sector (building sector) heat demand by technology in Italy, 2019 [81]

The following section explains how heating demand in Italy is associated with DH.

6.1.2 District Heating Status

DH serves about 4.44 million citizens and 92,700 consumers in Italy. In 2023, there were 434 networks (4 more than in 2022), extending to 5,000 km. Turin and Milan were the only DH systems to add new pipelines, accounting for 69% of the new installations. In 2023, DHC networks in Italy achieved primary energy savings of approximately 0.5 Mtoe and avoided the emission of almost 1.7 $MtCO_2$. [82]

[Fig. 23] illustrates the evolution of heat delivered to DHN in Italy from 2000 to 2023, distinguishing between renewable and non-renewable sources. Overall, it shows a steady growth until around 2015 and a moderate fluctuation thereafter. While non-renewable sources remain dominant, the contribution of renewables has gradually increased, particularly after 2010, reflecting Italy's progressive integration of sustainable sources (mostly bioenergy) into DH systems.

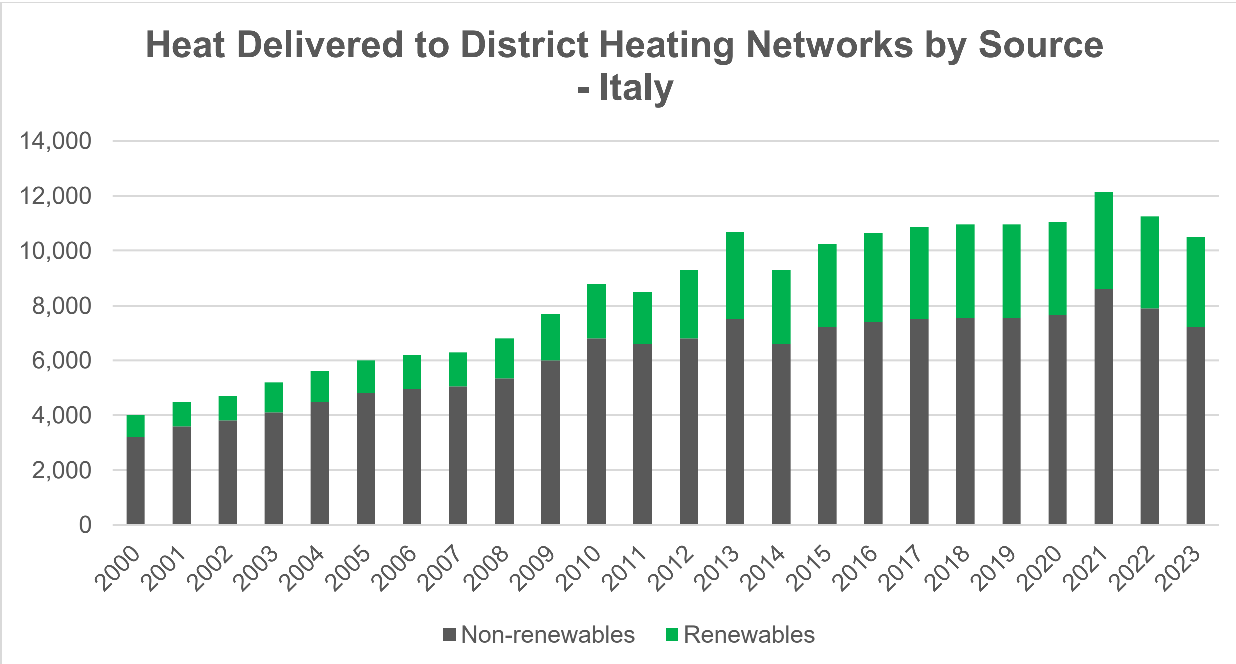

Fig. 23. Heat delivered to district heating network by renewable and non-renewable sources in Italy (estimated from [83])

The heating volume supplied through existing networks increased by about 6.4 million m³ in 2023. However, the growth trend has been declining since 2015. Turin's network dominates the growth trend, with 1.32 Mm³ of growth, accounting for 20.6% of the total. [82]. [Fig. 24] illustrates the gradual increase in the volume of heat supplied by DH from 2000 to 2023.

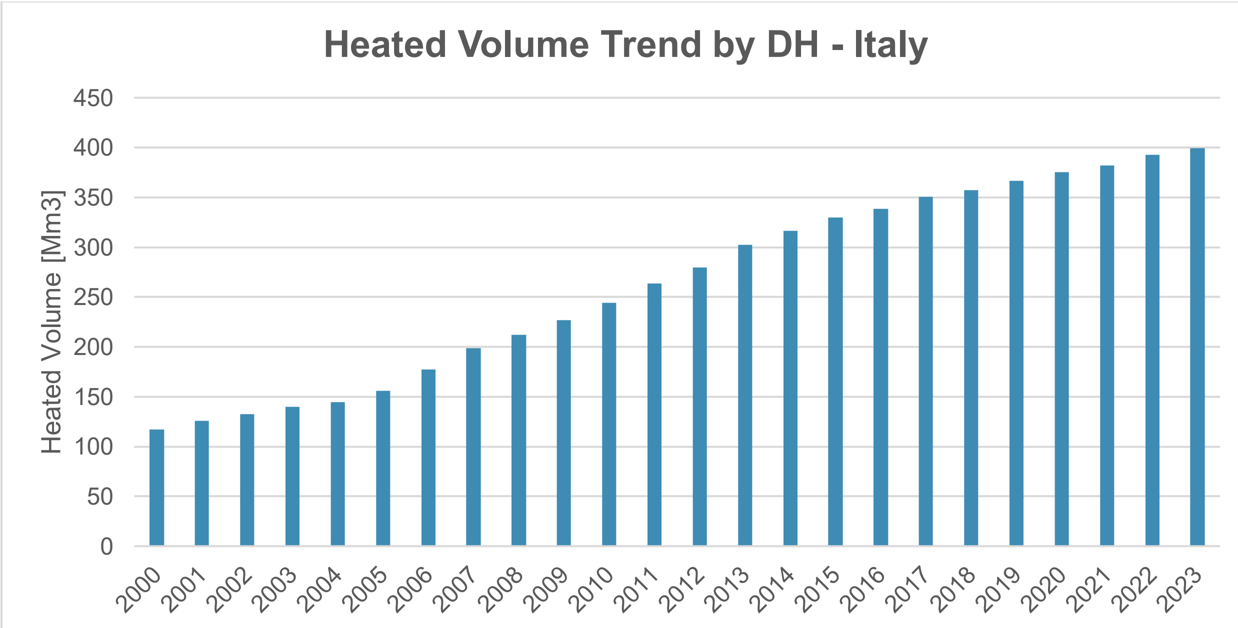

Fig. 24. Heated volume by district heating in Italy [83]

Comparing this trend with the stable DH network heat delivery since 2016 [Fig. 23], a positive development is evident. The increasing heated volume despite stable supply suggests improved system efficiency, likely due to thermal storages, reduced supply temperature, building retrofits, and other measures minimizing heat loss. However, global warming raises concerns about whether the building sector needs less heat due to warmer weather. According to Euroheat & Power [82] decrease in heating demand is largely due to the rising temperature and climate change. By observing [Fig. 25], it is evident that the average mean surface temperature of Italy has upward trend during the depicted period.

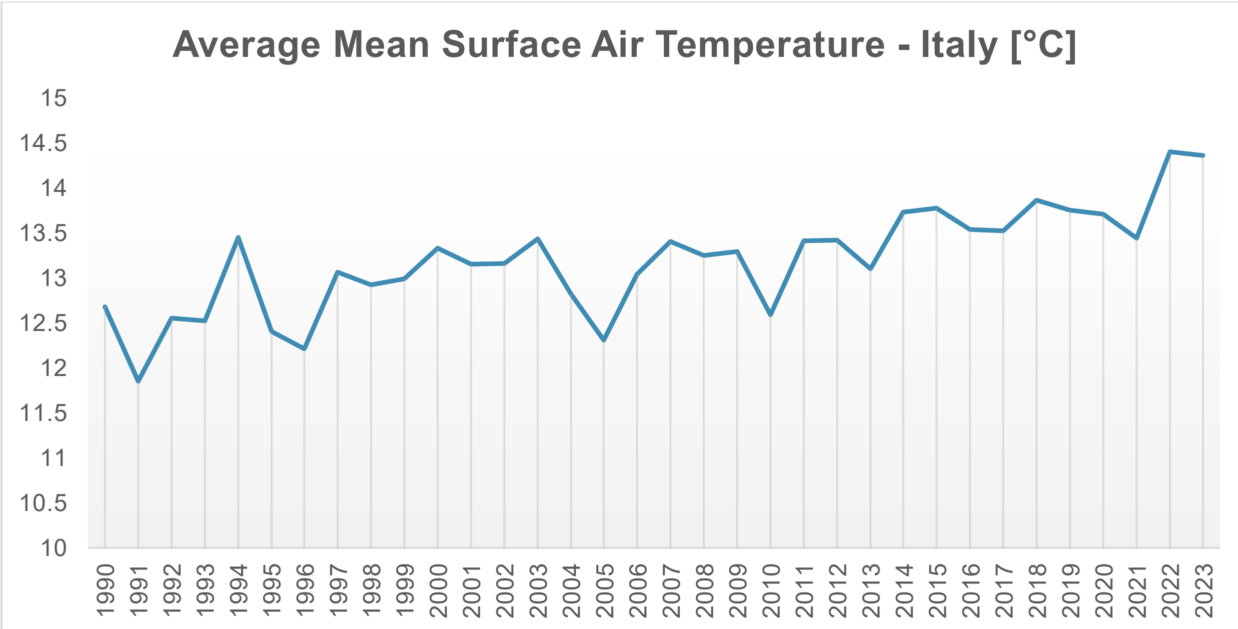

Fig. 25. Average mean surface air temperature of Italy (1990-2023) [84]

[Fig. 26] depicts the distribution of heated volume supplied by DH across Italian regions. As illustrated, the majority of the supply is concentrated in northern Italy, with several cases present in central regions.

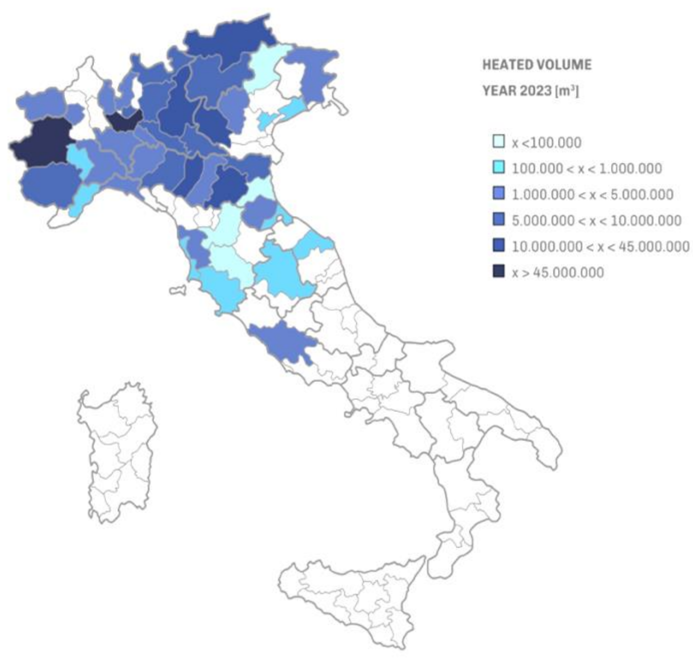

Fig. 26. Heated volume [m^3] of Italian provinces by district heating in 2023 [83]

[Fig. 27] presents the regional distribution map of Italy's population. Northern Italy, with a population density of about 27.5 million residents, comprises eight regions. These regions collectively account for approximately half of the nation's total population of 59 million in 2025 [79].

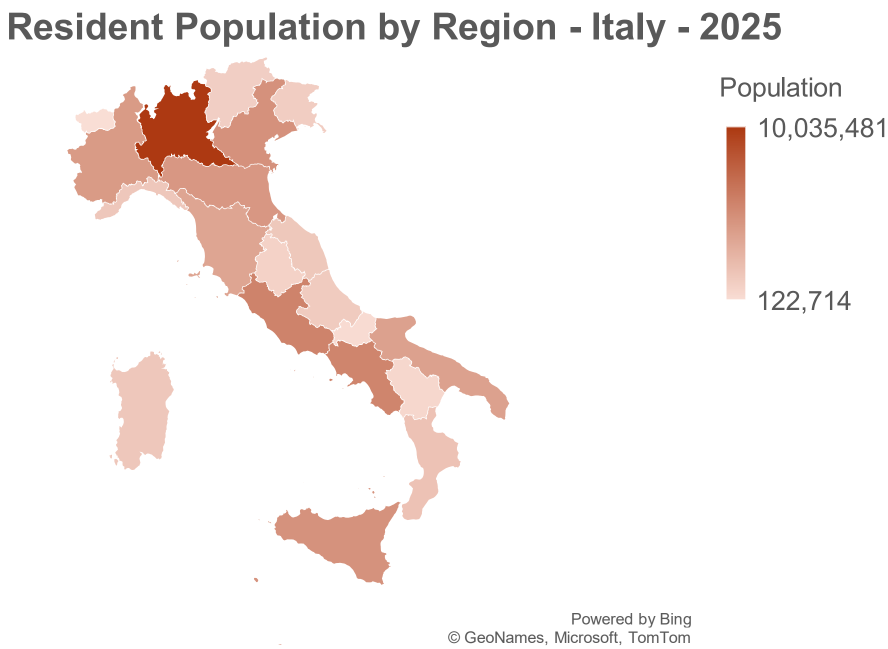

Fig. 27. Resident population of Italian regions, 2025 [79]

According to Italy's climatic map, the north has colder winters and lower temperatures, leading to higher heating demand [85]. This highlights the importance of considering regional differences when analyzing heating demand and the potential role of DH systems.

To go deeper into the details of the Italian DH system, it is worthy to analyze a single year specifically, where this is done for the last available year's data, 2023.

In Italy, heating demand is predominantly concentrated in the residential sector. According to the latest 2023 data on final heat consumption supplied by DH, 64% of DH is consumed by the residential sector, 33% by the services and others, and only 3% by the industrial sector [Fig. 28].

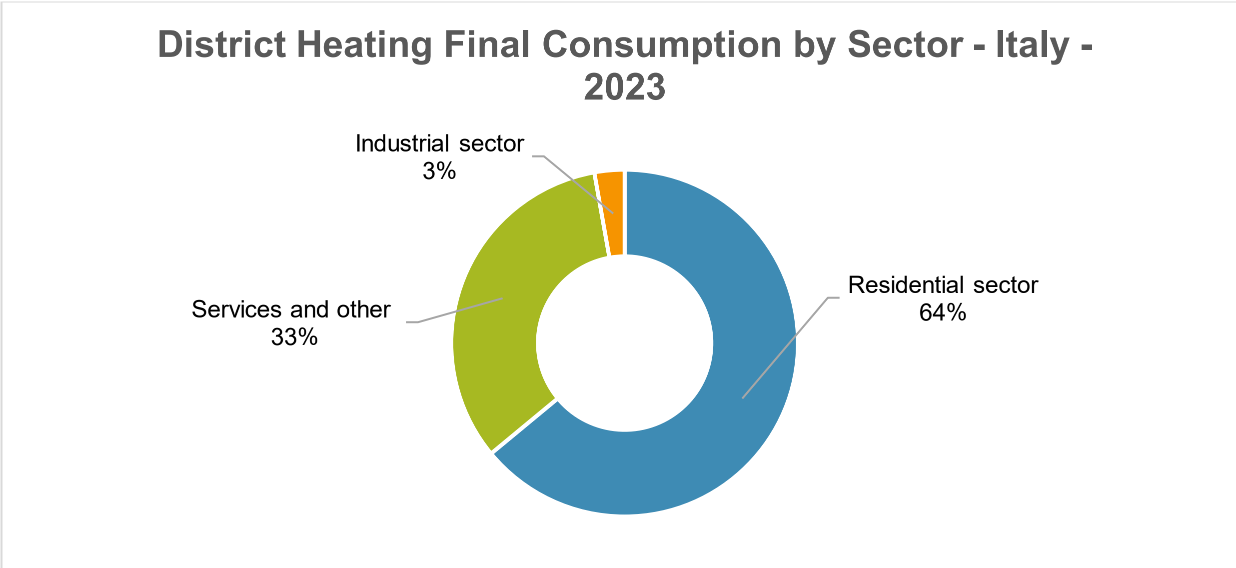

Fig. 28. District heating final consumption by sector in Italy, 2023 [83]

In 2023, DH accounts for 3% of the total heat demand [82] and only about 2.3% (5,436 GWh [83]) of total residential heating demand in Italy was supplied by DH [86]. This share is notably low compared to other countries, highlighting the limited penetration of DH in the Italian residential sector; as shown in [Fig. 4].

The fuel mix supplying DH in 2023, consisted of approximately 28% renewable and 72% non-renewable sources. Among the renewable share, the majority comes from biofuels (≈82% of total renewables), while the remainder is supplied by geothermal energy, heat pumps, industrial waste heat, and solar thermal systems. As expected, natural gas dominates the non-renewable share, accounting for 63% of the total DH fuel mix [Fig. 29].

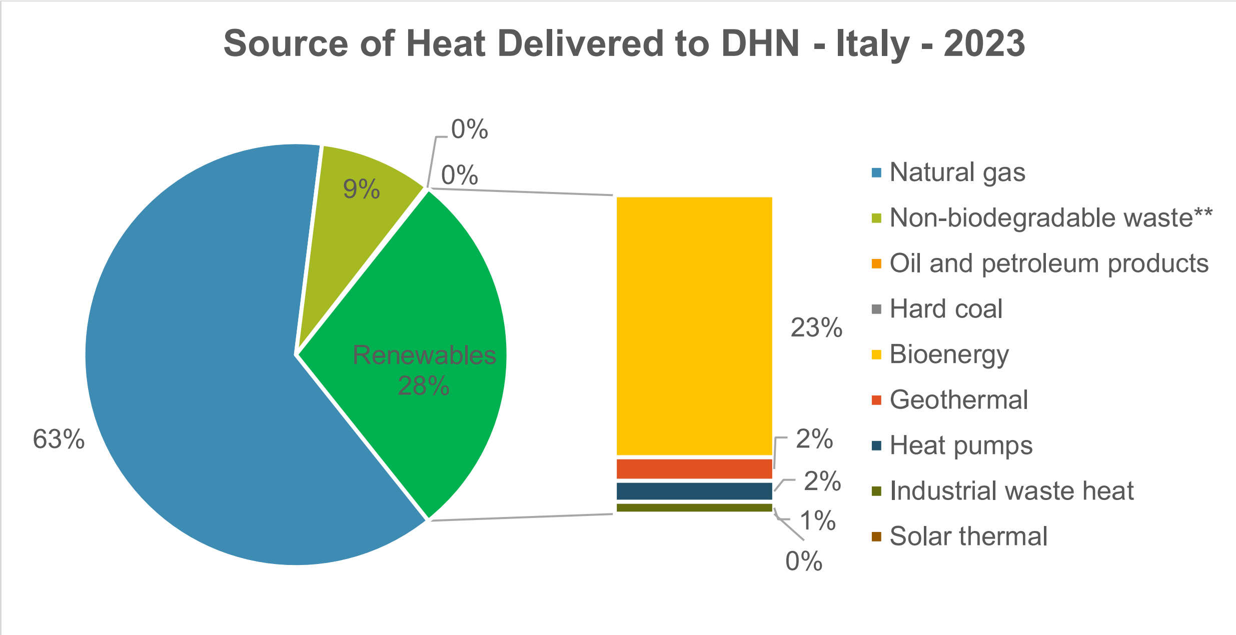

Fig. 29. Source of heat delivered to district heating network in Italy, 2023 [83]

The main heat producers in Italian DH system are combined heat and power (CHP) plants, heat-only boilers (HOBs), geothermal plants, solar thermal systems, heat pumps, and industrial waste heat. The fuels used to power CHPs and HOBs are natural gas, oil, coal and peat, non-renewable waste, and bioenergy. Out of these, only the last category represents renewable energy sources. [Fig. 30] illustrates the distribution of heat delivered to DHN in Italy in 2023 by plant type and energy source. CHP plants provided the largest share, with fossil-based generation still dominating but a notable share from renewable sources. Boilers contributed to a smaller yet significant portion, also largely fossil-fueled. Direct renewable plants, HPs, and waste heat recovery represented minor shares.

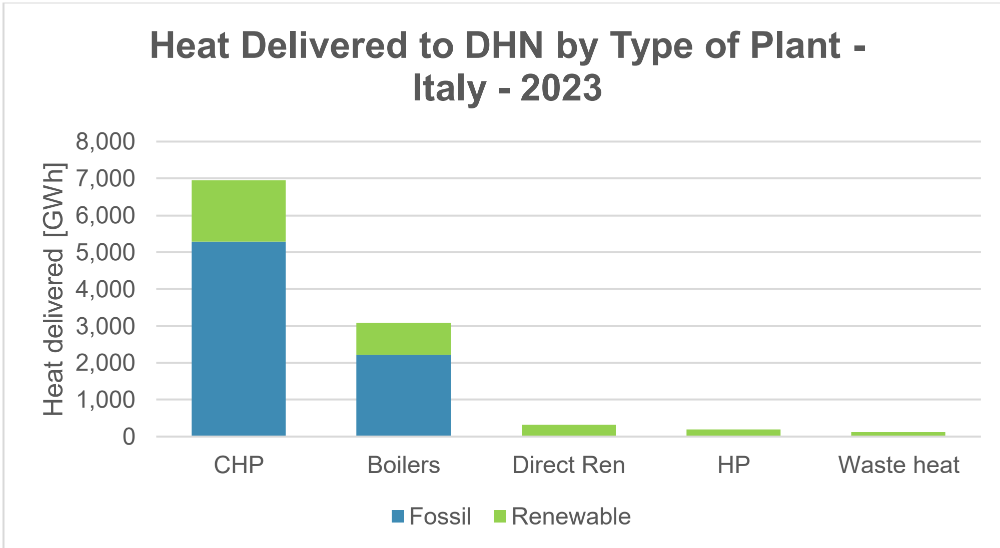

Fig. 30. Heat delivered to district heating network by type of plant in Italy with attention to the fossil and renewable fuels, 2023 [83]

Not all the heat delivered to the DHN reaches the final consumer, and a portion of it is lost during transfer and distribution. [Fig. 31] illustrates the energy losses occurring from production to final consumption in plants feeding the DHN in Italy. As shown, heat experiences greater losses compared to electricity, with approximately 21% of heat and 6% of power being lost, respectively.

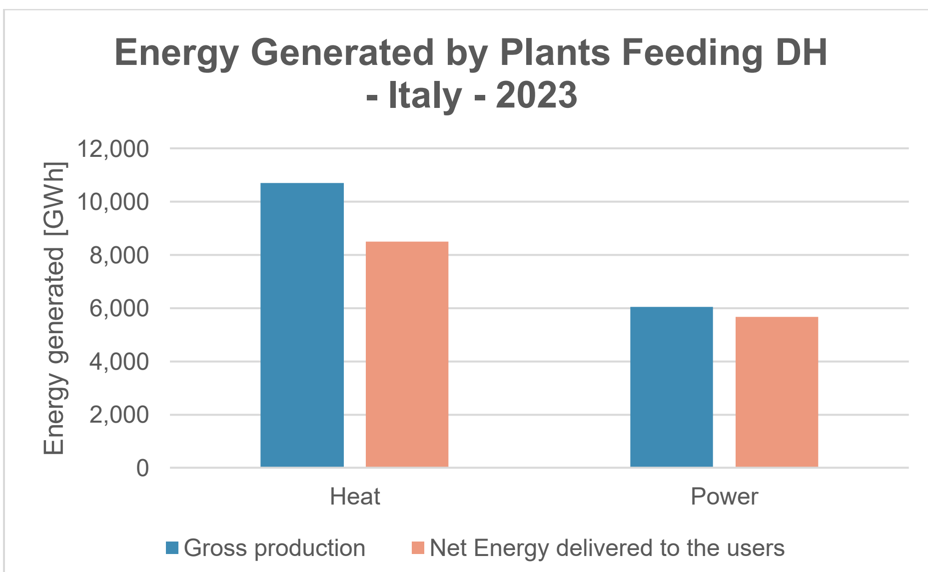

Fig. 31. Heat and electricity generated by plants feeding DH in Italy, with focus on gross production and net energy delivered to the users, 2023

6.1.3 Renewables and Waste Heat Potential

The limited DH penetration, combined with Italy's high dependence on natural gas import, underlines the need to explore how renewable-based DH could strengthen both energy security and decarbonization. Assessments of Italy's energy system by Dénarié et al. (2021) [87] reveal significant potential for integrating renewable (Bioenergy, Geothermal, Solar thermal) and waste heat into DHN. Accordingly, mapping and quantification estimate that 156 TWh of the total 329 TWh of civil (building) sector heat demand could be integrated in DH by the mentioned sources. This potential exceeds the 114 TWh of building sector heating demand technically suitable for DH connection, highlighting the vast underutilized opportunity for heat recovery.

However, Regional imbalances persist, with northern regions facing higher heat demand than available renewable and waste heat and southern regions exhibiting surplus potential, suggesting scope for complementary applications like district cooling [Fig. 32].

Fig. 32. Geographical national distribution in NUTS3 region of suitable DH heat demand and available waste heat and renewables for DH integration, Italy [87]

A. Waste heat

Although the renewability of waste heat is reliant upon its origin, it serves as a low-emission surplus source of heat. Waste heat generated from industrial processes, power plants, and wastewater treatment facilities presents a significant resource for DH in Italy. By integrating these sources, the country can mitigate fossil fuel consumption, enhance energy efficiency, and reduce emissions. Currently, there are no government initiatives or incentives specifically designed to promote waste heat recovery in DH networks in Italy [82]. The concept of "waste heat" was only introduced with the RED II program.

Dénarié et al. (2021) [87] reveal 112 TWh/year recoverable excess heat from industrial sites, power plants, and wastewater treatment facilities are available to be integrated into DH in Italy. [Fig. 33] illustrates the distribution of waste heat sources in Italy.

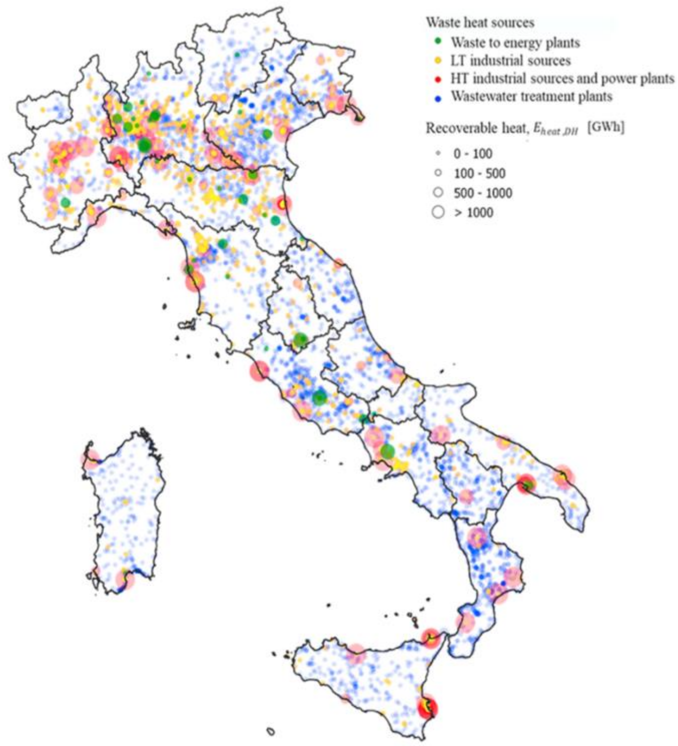

Fig. 33. Waste heat sources map of Italy [87]

Low- and High-temperature industrial waste heat sources and waste-to-energy plants are fewer in number but provide the largest energy output per site. Most of these types are located in northern Italy, though several major plants operate in the south. Wastewater treatment plants (blue), despite their lower individual heat potential, are widely distributed across the country and closely aligned with population density, ensuring their presence near most heat demand areas.

B. Solar Thermal

Solar thermal could play a meaningful role in Italy's future heating mix, particularly within DH systems. Technical assessments suggest a potential of around 8-24 TWh/year, equivalent to 2-10% of total heat production by 2050, depending on system configuration and solar penetration [88]. [Fig. 34] presents the direct normal irradiance map of Italy, providing a visual representation of the distribution of solar power across the country.

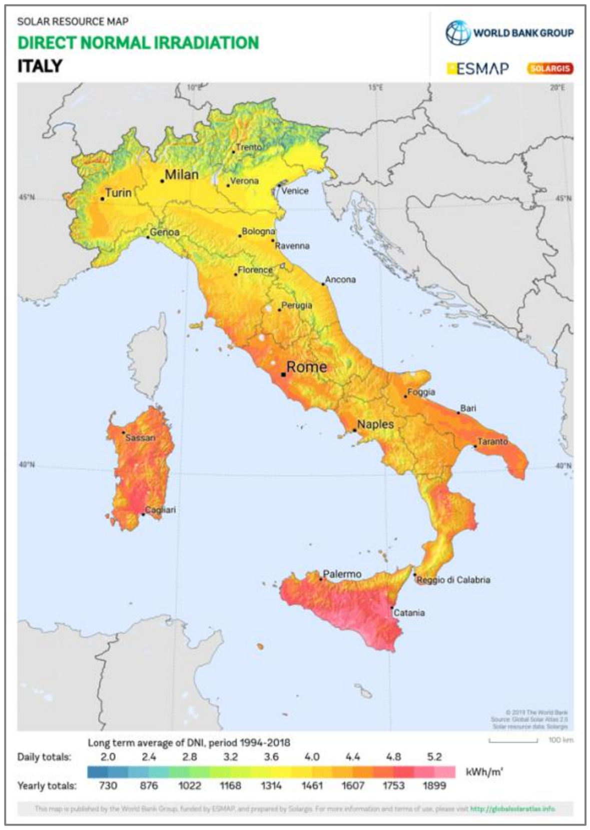

Fig. 34. Direct normal irradiation map of Italy [89]

While solar thermal may slightly increase overall system costs, it can relieve pressure on scarce renewable resources such as biomass and contribute to decarbonizing heat supply where other renewable options are limited [88]. Fortunately, the investment cost for the installation of the solar field can be partially recovered due to the Italian incentive known as “Conto Termico” [90].

Solar thermal heat integration is most effective when combined with seasonal storage and low-temperature DH networks. However, it is usually less attractive in the presence of waste heat [10].

- Bioenergy

Biomass-based DH systems (BDHS) in Italy meet less than 1% of national space-heating demand despite large availability of woods from forest [91]. Although Italy has significant theoretical biomass resources, empirical assessments of real DH contexts indicate that only around 1-2 GW of additional biomass-fueled DH capacity could be sustainably deployed, corresponding to roughly 1.5-2.5 TWh/year [92]. This suggests that biomass can provide an important local complementary contribution but cannot alone drive large-scale national DH decarbonization. BDHS offer advantages like renewable, dispatchable local resources that support decarbonization and strengthen local economies. However, their expansion is limited by high initial investment costs, regulatory instability, and concerns over environment (forest destruction) and emissions (biomass emits less fossil CO_2 than gas or oil, but combustion still releases emissions) [91]. Integrating thermal energy storage and optimizing CHP operation can improve system efficiency by up to 20%, enhancing flexibility and resource utilization. Small and medium-scale BDHS in regions with available biomass basins offer a promising pathway to sustainable development and enhanced implementation of circular economy paradigms in Italy [91].

- Geothermal

Geothermal energy presents a promising yet under-exploited avenue for district heating in Italy. Current estimates suggest that geothermal could deliver around 18 TWh/year of thermal energy for DH networks up to 2050 [93]. While Italy has substantial and exploitable geothermal resources, with deep geothermal reserves estimated between 6 and 116 TWh [94]. Some regions, such as Tuscany, already exploit geothermal for heat and power, but city-wide geothermal DH deployment remains marginal [94]. Barriers include high upfront drilling and network costs, regulatory and licensing complexity, and competition from other renewable or waste heat sources. Nevertheless, with supportive policies and investment in infrastructure (e.g., low-temperature networks and thermal storage), geothermal offers a stable, local, low-carbon heat supply suited to urban DH expansion in colder Italian regions where heat demand is greatest.

- Heat Pumps

Electric heat pump systems integrated into DHN represent a promising path for Italy's low-carbon heating transition. Large heat pumps act as a core enabling technology that upgrades low-temperature renewable and waste heat sources for DH use. Their contribution is therefore not a standalone resource potential, but a conversion pathway that activates a portion of the above potentials. Furthermore, the renewability of heat pumps is contingent upon the renewable content of its electricity input.

If the waste heat is already at a usable temperature (around 60-90 °C), it can be directly supplied to the DH network, requiring only small amounts of electricity for pumps [62]. However, if the waste heat is low temperature (e.g., 25-40 °C), electricity is needed to run large heat pumps that raise the temperature to usable levels for heating.

Large heat pumps take low-temperature heat from ambient air, water bodies (e.g. rivers, seawater), wastewater treatment plants, geothermal sources, datacenters, power transformers, supermarkets, and metro stations, and upgrade it to useful district heating temperatures using electricity, turning otherwise wasted heat into usable energy [87]. Research indicates that the integration of DH systems with HP and CHP units has the potential to significantly reduce both costs and emissions associated with the heat-electricity sector up to 50% [95]. Regrettably, there is no tax relief available for the electricity consumed by heat pumps [82].

Although Italy currently lacks detailed national figures for heat pump-inclusive DH capacity, European technology reports highlight that heat pump-based DH is becoming competitive in dense urban areas and that large heat pump units (tens of

MW_t) are already deployed in comparable settings [96]. Key enablers include low temperature supply networks, integration of heat source, and regulatory/financial frameworks that support electrification of heat.

In Italy's northern regions where heating demand is highest, the deployment of DH networks with heat pumps could leverage these dynamics to deliver renewable heat at scale. Large HPs in DH systems can efficiently use stable, renewable, and locally available heat sources like wastewater, industrial waste heat, surface water, and geothermal. Heat pumps are crucial to decarbonization strategies, but their widespread use can challenge grid stability unless complemented by CHP or targeted grid reinforcements [97].

[Table 4] summarizes the estimated annual renewable and excess heat potential for DH in Italy from this section.

Table 4. Estimated annual renewable and excess heat potential for district heating in Italy

Renewable Source	**Estimated Potential (TWh/year)**
Waste Heat	~112 TWh/year
Solar Thermal	~8-24 TWh/year
Bioenergy	~1.5-2.5 TWh/year
Geothermal	~18 TWh/year

6.2 Market and Policy Environment

Overview of the Current Market

The Italian DH sector remains relatively small and slow-growing despite its significant potential to contribute to national decarbonization objectives. Expansion has been hindered by regulatory uncertainty, fragmented governance, and the absence of a coherent long-term support framework. While incentives such as Conto Termico and the Superbonus have strongly supported individual heating technologies, especially electric HPs and building-level retrofits, dedicated support for DH networks has historically been limited, slowing network expansion and renewable integration [82].

To accelerate growth, market strategies must integrate prosumer participation and DR mechanisms, supported by regulatory and fiscal instruments that reduce connection costs and reward renewable and waste-heat feed-in.

Ownership Structure of DH Networks

The ownership of DH networks in Italy is predominantly public or mixed ownership, with municipalities holding significant stakes either directly or through multi-utility companies. Major DH operators such as IREN, A2A, HERA, ENGIE, and Gruppo EGEA are structured as publicly controlled or public-private utilities, reflecting Italy's broader tradition of municipal involvement in local energy services. Fully private DH operators exist but represent a minority and are typically active in smaller or industrial networks. The dominance of municipal and mixed-ownership utilities has ensured long-term stability and consumer protection but has also limited competitive pressure compared to countries with stronger governance frameworks and more mature DH markets, such as Denmark and Sweden. Ownership arrangements thus play a central role in shaping investment decisions, pricing strategies, prosumer participation, and the capacity of DH operators to integrate renewable heat sources and DR actions.

Incentive Schemes

Italy's two main national heating incentives, Conto Termico and the Superbonus, have shaped investment in renewable heat but have not created a stable, long-term framework for DH development.

Conto Termico 2.0 provides grants for renewable heat and energy efficiency, but its structure primarily supports small-scale interventions such as household HPs and solar thermal systems. Consequently, most disbursements have gone to these distributed technologies. Large renewable plants connected to DHN rarely access the scheme, as the size caps and administrative procedures are not well aligned with utility-scale projects. This limits the mechanism's ability to directly support renewable expansion within DH systems.

The Superbonus 110% (2020-2022) was primarily designed to support building-level energy-efficiency upgrades and the replacement of individual heating systems. The legislation formally included the possibility to incentivize connections to "efficient district heating systems" as defined by Legislative Decree 102/2014, and subsequent guidance from ENEA clarified that biomass-fueled DH could in principle benefit from the scheme. In practice, however, available evidence indicates that the vast majority of Superbonus resources were absorbed by insulation measures, HPs and other on-site technologies, with very limited or poorly documented uptake of DH connections. Combined with its temporary and highly unstable design, the Superbonus therefore had only an indirect and marginal effect on the expansion of DHN and large-scale renewable heat deployment in Italy.

A notable shift came with the National Recovery and Resilience Plan (PNRR) Mission 2 (2021), which allocated €200 million specifically for efficient DH systems. The program funds network extensions, waste-heat integration, and decarbonization upgrades, marking the first major national investment in DH infrastructure in over a decade. Although modest in size, it signals growing recognition of DH's strategic role in Italy's clean-heat transition.

Regulatory Framework and Policy Instruments

The legal foundation for DH regulation is Legislative Decree 102/2014, which transposed the EU Energy Efficiency Directive into national law. Article 10 assigns ARERA (Italian Regulatory Authority for Energy, Networks and Environment) the responsibility for defining network-connection rules and ensuring transparent, non-discriminatory access [98].

However, for nearly a decade, several implementing decrees remained pending or only partially implemented, leaving third-party access (TPA), pricing transparency, and service quality standards dependent on local agreements.

Following the 2021-2022 gas price crisis, the government strengthened ARERA's mandate. Since 2023, ARERA has introduced transitional DH tariff regulation (applicable for 2024-2025), using cost-reflective criteria and enhanced consumer protection. A comprehensive tariff methodology is expected in the coming years, marking a shift toward nationally regulated DH, reducing historical regional disparities.

Italy has introduced various national and EU-backed instruments aimed at modernizing DH systems and supporting renewable integration, though many remain partial or under implementation. [Table 5] summarizes the key policy instruments currently shaping Italy's DH market environment.

Table 5. Key EU and national policy instruments and support measures for DH in Italy

Instrument / Measure	Description
Directive (EU) 2022/542 - VAT Reform	Enables Member States to apply reduced VAT rates to heating services; supports lower VAT for renewable/CHP-based DH. Implementation in Italy applies primarily to household DH supplied by renewables or high-efficiency CHP.
Legislative Decree 102/2014	Core legal framework for energy efficiency and DH; assigns ARERA responsibility for connection rules, transparency, and promotion of renewable and waste-heat integration.
Law 172/2017 (Art. 19-decies)	Supports high-efficiency CHP connected to DH networks; implementing decree remains pending as of 2025.
Legislative Decree 73/2020	Updates Conto Termico 2.0; permits inclusion of DH connection fees as eligible expenses, pending ministerial implementation.
PNRR Mission 2 - Efficient District Heating (Investment 3.1)	Allocates €200 million for modern, efficient DH networks; funds waste-heat recovery and renewable-based expansion. 29 projects approved across 9 regions.
PNRR Efficient DH Call (2022-23)	Competitive tenders for DH projects; initial DNSH (Do-No-Significant-Harm) compliance issues later clarified; funding supports network extensions and renewable integration.
White Certificates (TEE)	Revised in 2022; recent legal decisions have broadened eligibility; applicability to DH-related renewable systems is under evaluation.

Price Regulation and Taxation

Since 2023, Italy has progressively introduced regulated DH tariffs under ARERA oversight, beginning with a provisional tariff methodology for 2024-2025 based on transparency, consumer protection, and alignment with decarbonization targets. As shown in [Table 6] Italy applies differentiated VAT rates to heat supply:

Table 6. VAT rates applied to different types of heat supply in Italy

Type of Thermal Energy Supply	VAT Rate	Taxpayer
DH from renewables or high-efficiency CHP	**10%**	Households
DH from fossil or non-qualifying sources	**22%**	Households
All heat sources	**22%**	Industrial and commercial users

Note: A temporary 5% VAT was applied during 2021-2023 as an emergency measure but is no longer in effect.

Italy does not apply a national CO_2 tax to natural gas or heating fuels. Large DH plants participate in the EU Emissions Trading System (ETS), while individual gas boilers remain outside ETS, creating a structural cost imbalance that disadvantages DH relative to standalone gas heating [82].

Structural Barriers

Several structural challenges continue to limit Italy's DH expansion:

- **Policy focus on individual systems:** Incentives favor stand-alone heat pumps and gas boilers over network-based solutions, limiting DH competitiveness.
- **Electricity-centric Renewable Energy Communities:** RECs support electricity sharing but currently lack a framework for shared thermal energy, excluding DH from community-energy schemes.
- **Gas infrastructure lock-in:** Italy's extensive natural-gas network and historical pricing structures create strong inertia against switching to DH.
- **Fragmented regulation:** Until recently, Italy's district heating sector operated under fragmented regulation, with tariff transparency, waste-heat feed-in rules, and service standards varying significantly across regions despite limited national oversight.

Together, these factors explain Italy's slow DH expansion and highlight the strategic need to scale RDH. Strengthening RDH reduces reliance on imported natural gas, particularly relevant after the 2022 crisis, and supports Italy's commitment to achieving net-zero emissions by 2050.

The analysis presented in this section is supported by ARERA (2020; 2023), the Ministry of Ecological Transition (2022), GSE (2023), EU VAT reform (Directive 2022/542), IEA (2023), OECD (2023), and AIRU/HERA (2023).

6.3 Scenario Design and Modeling

The scenario analysis in this section examines how coordinated decarbonization efforts, represented through exploratory renewable-penetration targets and assumed fuel switching, could reshape Italy's DH sector by 2035. The analysis is not a prediction but a comparison of two plausible pathways that bracket a realistic range of outcomes. The scenarios focus on expanding RDH by strengthening prosumer participation. Environmental and economic implications are then assessed accordingly.

6.3.1 Purpose and Rationale

As discussed in the section 6.1, the heating sector in Italy is highly dependent on natural gas. This scenario modeling explores how coordinated decarbonization efforts and renewable integration can help Italy reduce the use of natural gas and move towards its decarbonization targets.

Two scenarios are developed: a continuation of current stationary trends (Base) and accelerated renewable transition (RDH 60). The analysis explores two plausible trajectories between limited reform and strong renewable energy deployment.

The aim of the scenario analysis is to explore how scaling up RDH can reshape the Italian energy system. Specifically, the modeling seeks to:

- Quantify the impact of RDH expansion on fossil fuel dependence and greenhouse gas emissions.
- Compare the outcomes of a status quo baseline with an ambitious renewable transition scenario.

6.3.2 Modeling Approach and Scenario Definition

The scenario modeling conducted is a spreadsheet-based analysis performed using Microsoft Excel. The baseline year for the modeling was set to 2023, as it represents the most recent year with comprehensive and reliable data availability.

Two scenarios were developed as follow:

<u>SCENARIO BASE:</u>

This scenario examines the future of Italy's DH system under limited expansion (stagnation) and presents a business as usual (BAU) case for its development up to 2035.

Technical and fuel-mix constraints:

I. Keeping 2023 levels of fuel mix unchanged up to 2035 according to [Table 7]

Table 7. Scenario Base: DH fuel mix and heat supplied to DHN

	Heat supplied to DHN (TWh_t)		% of the fuel mix
Fuel	**2023**	**2035**	**2023 & 2035**
NG	6.59	7.52	62.7
Non-bio waste heat	0.90	1.02	8.6
Oil	0.02	0.02	0.2
Bioenergy	2.47	2.82	23.5
Solar Thermal	0.00	0.00	0.0
HP	0.20	0.23	1.9
Geothermal	0.22	0.25	2.1
Ind. Waste heat	0.11	0.13	1.1
SUM	**10.52**	**12**	**100**

II. Slight increase in heat supplied to DHN from 10.5 TWh_t in 2023 level to 12 TWh_t in 2035 (14% increase)

SCENARIO RDH 60:

This scenario serves as the main scenario, with the objective of expanding the RDH in the Italian heating system and mitigating the reliance on natural gas.

According to *Heat Roadmap Italy* (Aalborg University, 2018) [99], a large-scale expansion of DH could technically and economically supply around 71% of Italy's total heating demand by 2050. The study identifies an economically feasible range between 51% and 81%, depending on local conditions and investment costs. This scenario is not an official policy target but a modelled potential within a cost-effective, deeply decarbonized energy system. By assuming the lower limit of the research for our scenario definition in this thesis, Italy has the target to satisfy about 50% of its total heat demand by DH in 2050. Based on a second-order polynomial growth, the RDH 60 scenario aims to satisfy around 13.6% of the total heat demand by 2035 [Fig. 35]. The second-order polynomial projection has been selected due to the simultaneous expansion of the DH system and the reduction in heating demand.

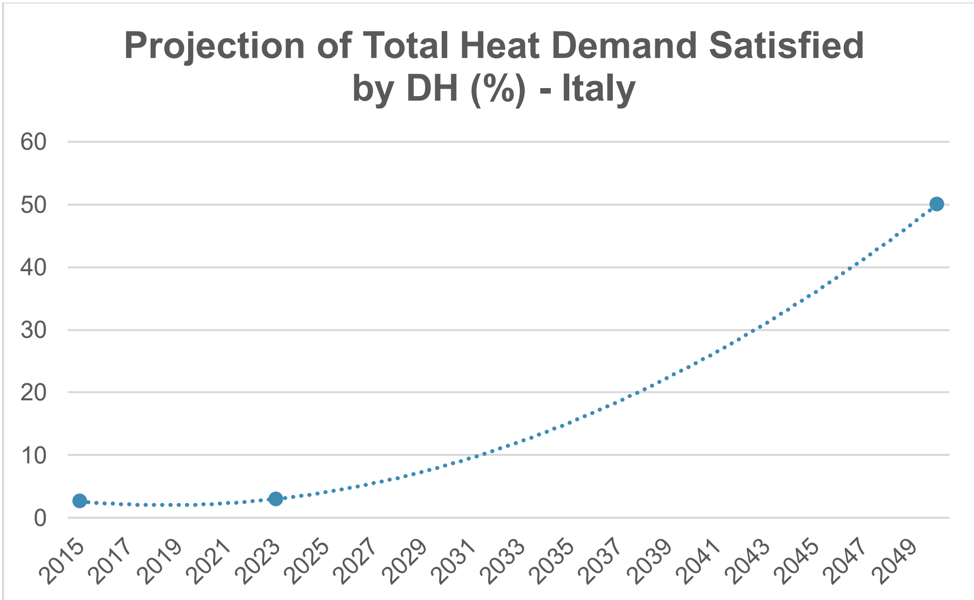

Fig. 35. Projection of total heat demand satisfied by DH (%), Italy

Italy's building (residential + services) sector heating demand in 2023 was approximately 350 TWh [82]. Improving building envelopes and retrofits are expected to reduce this value by around 20% by 2035 [100], resulting in a future demand of approximately 280 TWh/year. If DH supplies around 13% (a bit lower than 13.6%) of this value, it corresponds to about 36 TWh/year of final useful heat delivered to the buildings. In 2023, heat delivered to end users via DH was roughly 8.5 TWh, so this implies a more than fourfold scaling. To supply 36 TWh of useful heat to end users in 2035, 40 TWh of heat must be produced and fed into DHN. This value is achieved with assuming DHN efficiency will reach to 90% in 2035 with linear increase from ~80% level in 2023. Achieving this requires deployment of 4th and 5th generation low-temperature DH systems in parallel with upgrading the networks with better overall efficiency and, in result, less heat loss.

Technical and fuel-mix constraints:

I. Reaching 60% share of renewables in the DH fuel mix by 2035 by adopting the following minimum targets of each fuel as shown in [Table 8] (targets are defined in TWh and are set based on renewable potentials in [Table 4]).

Table 8. Scenario RDH 60: DH fuel mix and heat supplied to DHN

	Heat supplied to DHN (TWh_t)		**% of the fuel mix**	
Fuel	**2023**	**2035**	**2023**	**2035**
NG	6.59	5.0	62.7	12.5
Non-bio waste heat	0.90	1.0	8.6	2.5

Oil	0.02	0.0	0.2	0.0
Bioenergy	2.47	3.0	23.5	7.5
Solar Thermal	0.00	5.0	0.0	12.5
HP	0.20	10.0	1.9	25.0
Geothermal	0.22	6.0	2.1	15.0
Ind. Waste heat	0.11	10.0	1.1	25.0
SUM	**10.52**	**40**	**100.0**	**100.0**

Note: Industrial waste heat is considered out of 60% renewable target. In total, 60% of renewables and 25% of waste heat source is assumed, resulting in an overall utilization of 85% of renewables and waste heat.

II. Increase in heat delivered to DHN from 10.5 to 40 GWh_t in 2035 (280%)

III. Extended DH is replaced by individual gas boilers (as a result, the use of natural gas is reduced and replaced by RDH).

Further Assumptions and Considerations for the Modeling:

I. Residential and Services share of total final heat consumption are 66% and 34% respectively; levels of 2023 are kept unchanged for all the simulation years up to 2035.

II. Industrial sector is not involved in the modeling since it consists negligible share of DH final use in Italy.

III. Linear increase in DHN efficiency (production to consumption ratio) reaching to 90% in 2035 with linear increase from 81% level in 2023.

IV. Linear decrease of heat demand in building sector by 20% by 2035 compared to 2023 level.

V. Simulation runs on a linear basis; increments and reductions are applied annually in a linear manner. This implies that the same amount is consistently added or reduced each year.

6.3.3 Methodological Steps

1) Establishing the 2023 baseline

The analysis begins by defining 2023 as the reference year. National statistics on energy supply, final heat consumption, DH heat production, fuel mix composition, and system efficiency are extracted from authoritative datasets to form a consistent baseline against which all projections are compared.

2) Defining key variables and assumptions

Central system parameters, total heat demand evolution, DH efficiency improvements, renewable and waste-heat potentials, are set according to the assumptions and data sources presented in Section 6.3.2. Also, natural gas emission factor and mid-term gas import price are introduced in step 5 and 6 of this section. These parameters govern the evolution of the system to 2035 and ensure comparability across scenarios.

3) Constructing the two scenarios

Two development pathways are formulated:

1) Base Scenario, representing a continuation of current trends with limited DH expansion and stagnant renewable penetration.

2) RDH 60 Scenario, modeling the achievement of a 60% renewable share in the DH fuel mix by 2035 and an expansion of DH coverage to 13% of building-sector heat demand.

4) Projecting heat supply and renewable penetration

For each scenario, future DH heat supply is calculated using linear interpolation of total heat demand and system-efficiency trends. The renewable fuel mix is allocated according to the national potentials and resource availability identified in Section 6.1.3.

5) Calculating avoided natural gas use and CO_2 emissions

Scenario differences in fossil-fuel requirements are quantified to estimate avoided natural gas consumption (TWh and Mtoe). Avoided emissions are then computed using the adopted emission factor for natural gas (15.583 tCO_2/GWh).

6) Monetizing natural gas import savings

The economic benefit of reduced fossil-fuel dependence is assessed by multiplying avoided gas consumption by the assumed average gas import price (40 €/MWh). This indicator reflects the systemic economic value of the RDH 60 transition relative to the Base Scenario.

7) Connecting results to market strategy insights

Finally, the quantitative outcomes are interpreted using the market strategy framework developed in Chapters 3 and 4. This step identifies which financial, regulatory, and behavioral mechanisms are necessary for achieving the RDH 60 pathway and ensuring that the modeled outcomes are realistically attainable.

6.4 Results and Analysis of the Scenario Modeling

In this section, the results and outputs of each scenario are presented, followed by a comparative analysis at the end.

SCENARIO BASE:

The base scenario reflects Italy's current stagnant DH system, characterized by a strong reliance on natural gas and limited DH coverage. Emissions remain high, with only small improvements driven by efficiency gains and small-scale renewable projects.

[Fig. 36] illustrates a weak increase in heat supplied to the DHN. By the end of 2035, the heat delivered is projected to reach 12,000 GWh_t, reflecting a limited annual increase over the period.

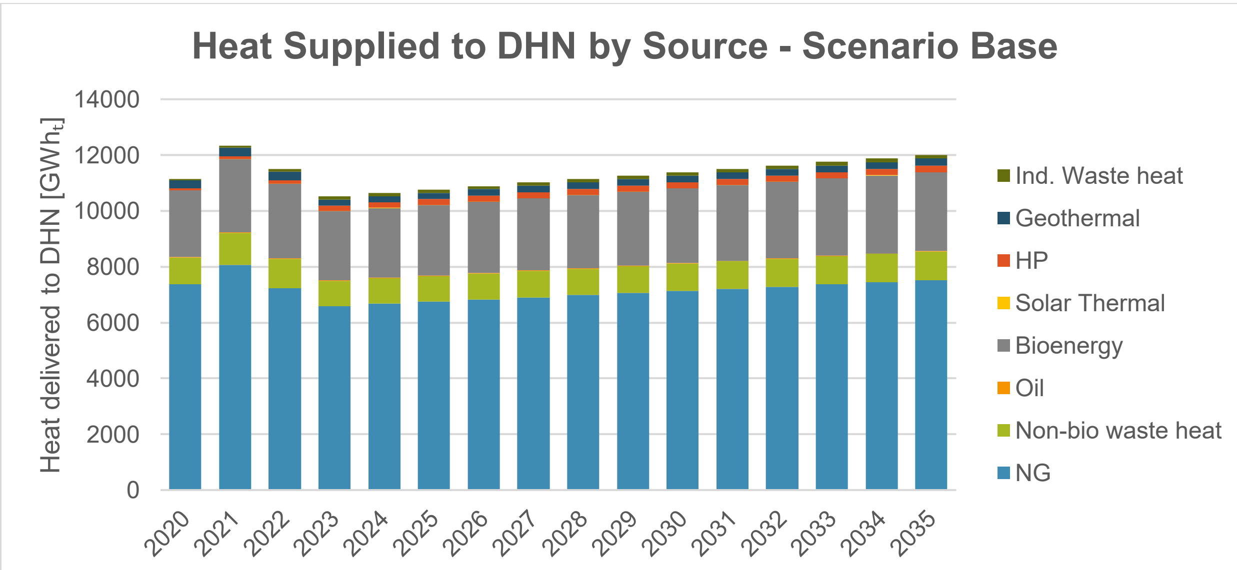

Fig. 36. Heat supplied to district heating network by source in scenario Base

For the Base scenario, the supply mix in the years following 2023 is assumed to remain unchanged, with most of the heat primarily supplied by natural gas as illustrated in [Fig. 37].

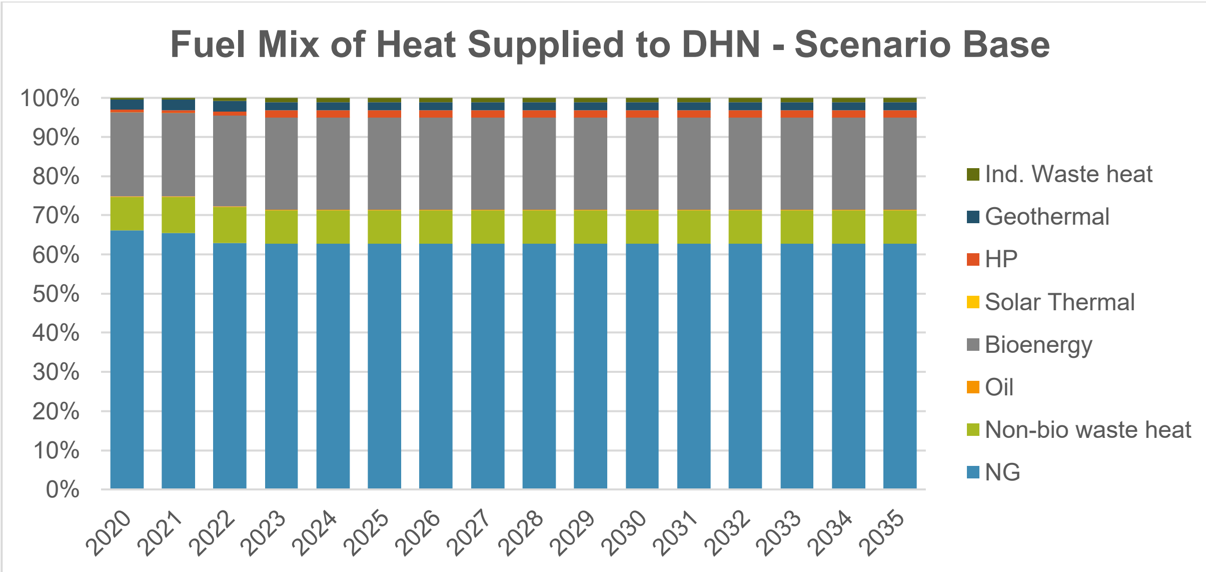

Fig. 37. Fuel mix of heat supplied to district heating network by source in scenario Base

In this scenario, the heat demand met by DH in the building sector reaches from 2.5% to 4% throughout the period, mainly due to reduction in heat demand and not the network expansion.

SCENARIO RDH 60:

[Fig. 38] illustrates the robust increase in the heat supplied to the DHN under the RDH 60 scenario mainly by renewable sources. By 2035, the supplied heat to DHN is projected to reach 40,000 GWh_t, representing a 280% increase compared to the base year 2023. While natural gas and non-biodegradable waste heat follow a relatively decreasing trend throughout the period, a substantial growth in renewable sources is observed. Waste heat and HPs play a dominant role in this scenario. Additionally, significant contributions emerge from solar thermal and geothermal energy, which gain increasing importance relative to the 2023 baseline. Bioenergy experiences a minor increase due to low availability and environmental issues.

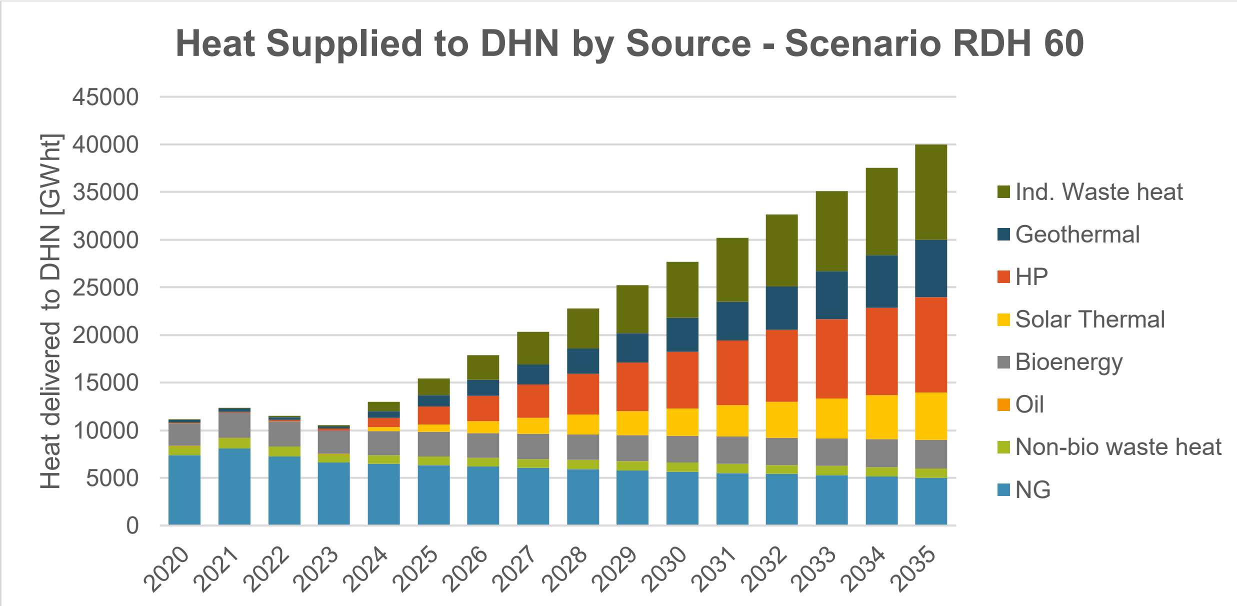

Fig. 38. Heat supplied to district heating network by source in scenario RDH 60

[Fig. 39] presents the projected fuel supply mix of the DHN under the RDH 60 scenario. A clear reduction in the share of non-renewable fuels is observed, progressively replaced by renewable sources. By 2035, low-carbon sources will replace most of the fossil fuel supply in the fuel mix, allowing the system to reach a 60% renewable share in DH.

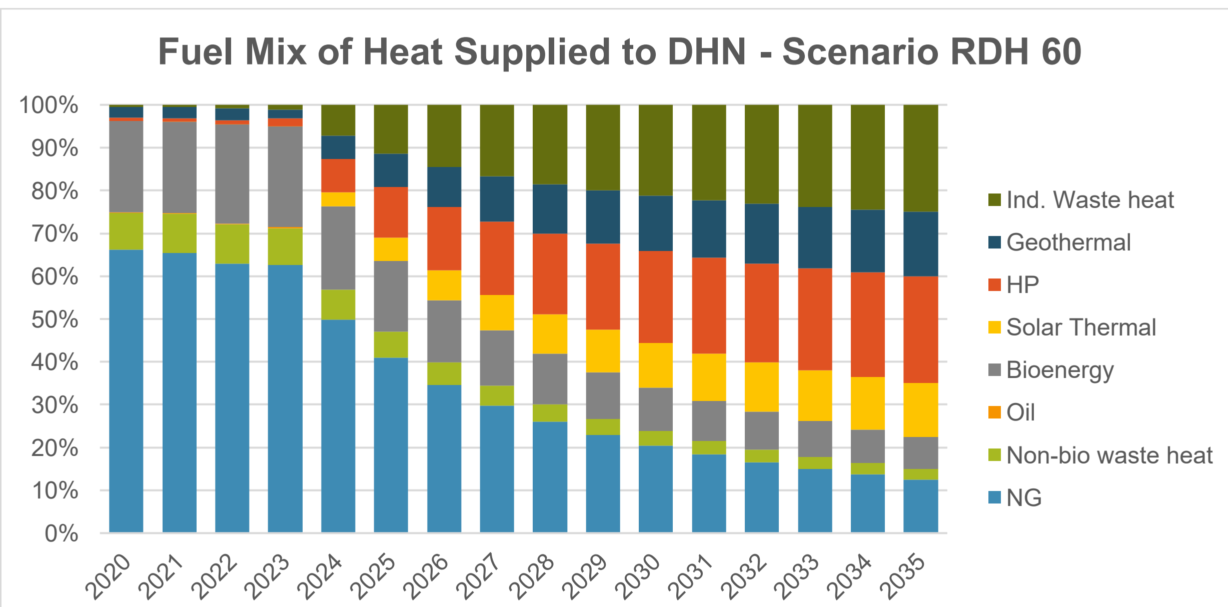

Fig. 39. Fuel mix of heat supplied to district heating network by source in scenario RDH 60

In this scenario, the gradual expansion of DH results in an increase in the share of buildings heat demand covered by DH, rising from 2.5% in 2023 to 13% by 2035 illustrated in [Fig. 40].

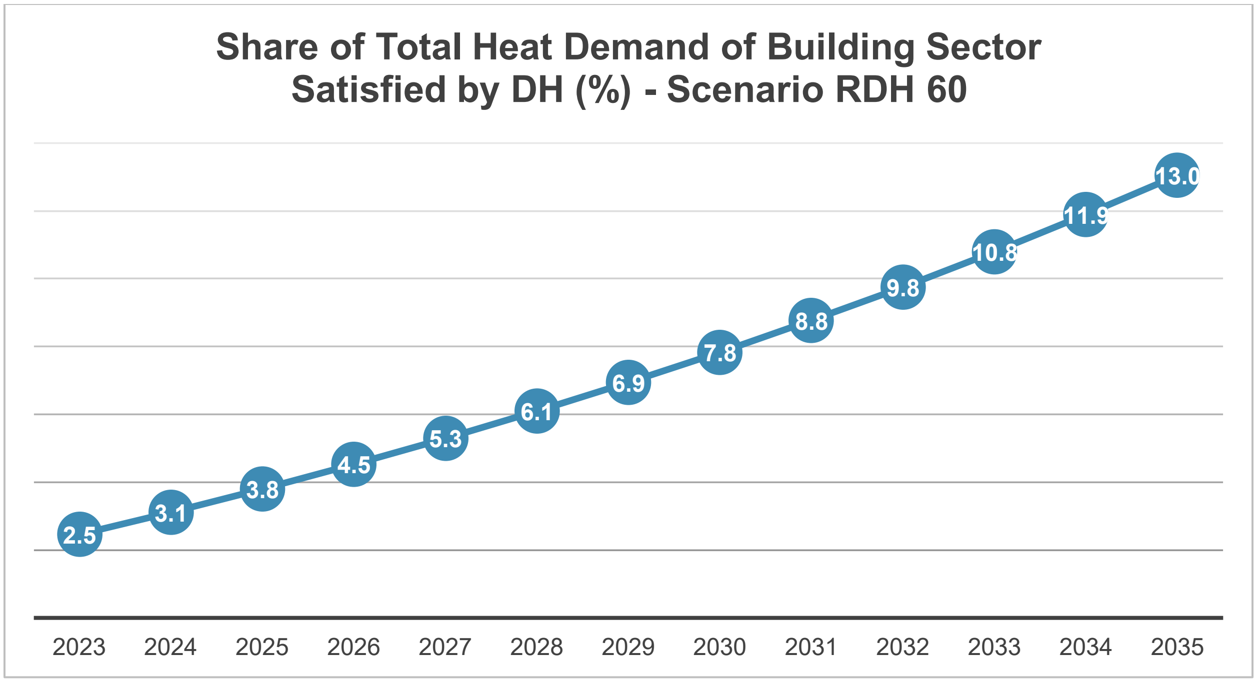

Fig. 40. Share of total heat demand of building sector in Italy satisfied by DH in scenario RDH 60 compared to Base scenario (%)

Expanding RDH to cover 60% of total heating demand demonstrates significant potential for decarbonization. Fossil fuel consumption outside DH network decreases substantially, and system-level efficiency improves through economies of scale and the integration of waste heat, heat pumps, geothermal, and solar thermal. By adopting proper strategies, prosumers become active contributors, supported by dynamic tariffs and cooperative ownership schemes. Demand response is enhanced through digital tools and thermal storage, reducing peak demand and improving flexibility.

SCENARIO COMPARISON:

[Fig. 41] present the DH supply mix at the end of the period for both the Base and RDH 60 scenarios. The comparison highlights the significant transformation in the fuel mix, clearly illustrating the scale of change between two scenarios.

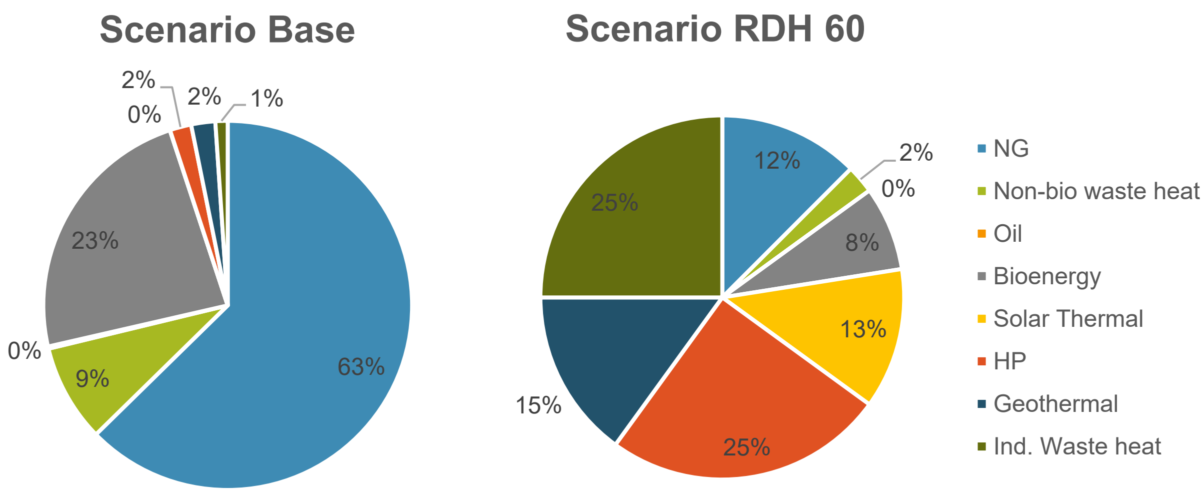

Fig. 41. District heating fuel mix in 2035 for scenario base (left) and scenario RDH 60 (right)

[Fig. 42] Illustrates the progressive decline of natural gas-based heat supply and massive increase industrial waste heat, heat pumps, geothermal and solar thermal sources under the RDH 60 scenario compared to the Base scenario. This signifies a structural shift towards renewable energy sources and excess heat over time.

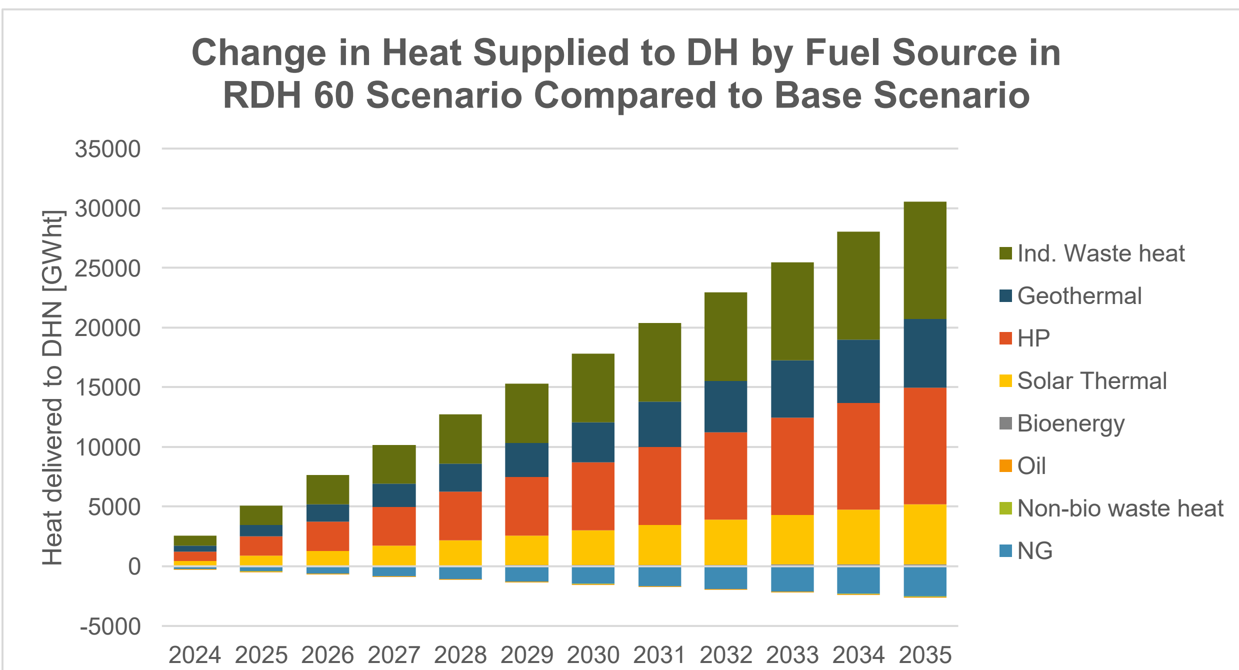

Fig. 42. Change in heat supplied to district heating by fuel source in RDH 60 scenario compared to Base scenario

TECHNO-ECONOMIC AND ENVIRONMENTAL ANALYSIS:

As one of the key objectives of this analysis, it is important to evaluate the extent of natural gas-based heat production that can be avoided. The results in [Fig. 43] indicate that the vast majority of reductions stem from decommissioning of individual gas boilers, which are replaced by RDH solutions. Only a negligible share of avoided natural gas is attributed to the reduction in DH networks' gas use.

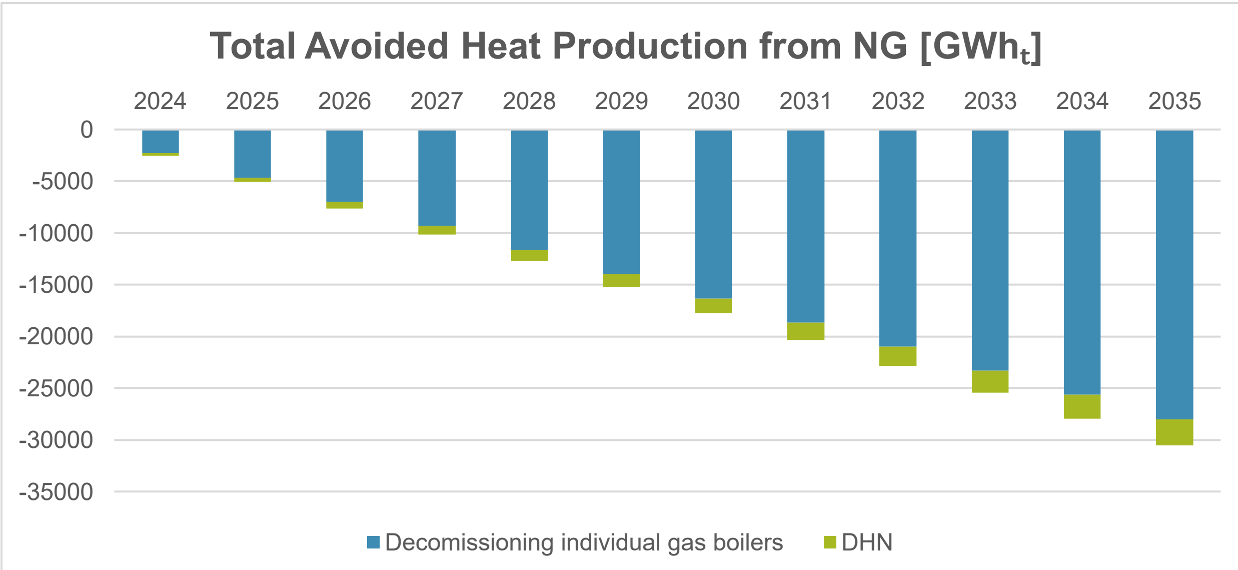

Fig. 43. Total avoided heat production sourced in natural gas in RDH 60 scenario compared to Base scenario

[Fig. 44] illustrates the yearly natural gas savings in the RDH 60 scenario compared to the Base case. Avoided gas consumption increases progressively from 2024 to 2035, reaching over 3 Mtoe (≈ 35 TWh) of annual savings by 2035. Since approximately 43% of national natural gas consumption is attributed to building heating (Odyssee-MURE, 2024), this scale of avoided gas becomes highly significant. The annual gas savings achieved is approximately 6% of the total national primary gas source (referenced to 2023). Despite the scenario seemed ambitious, the measure only reduced the primary gas use in building heating by about 14%. In Italy, gas boilers meet a substantial portion of the nation's heat demand, accounting for approximately 247 TWh in 2019 [81].

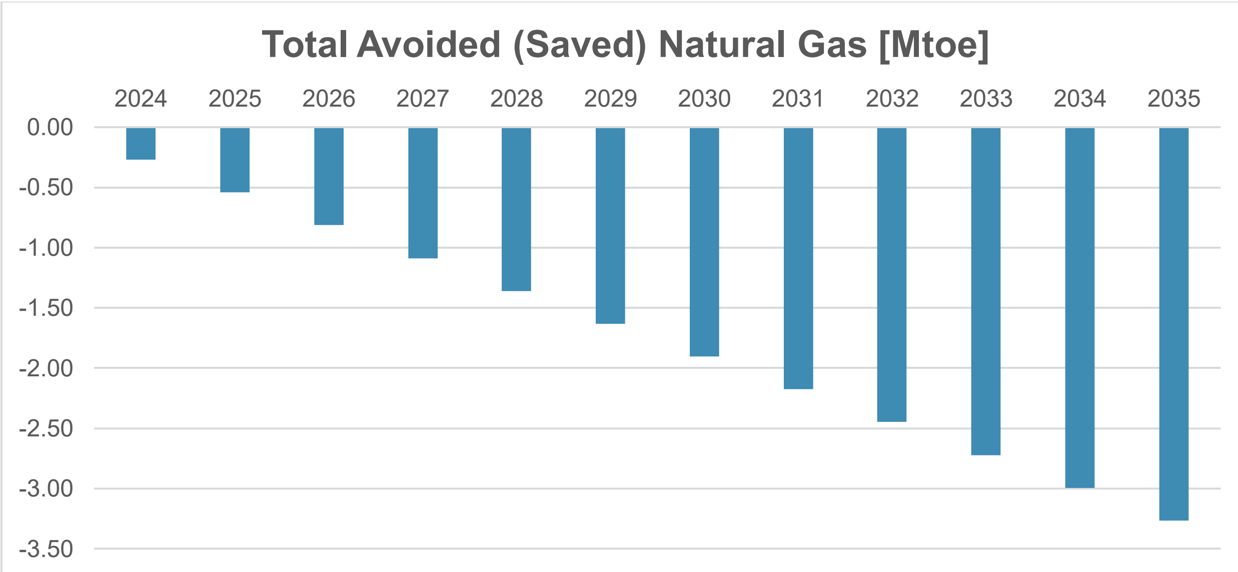

Fig. 44. Total avoided (saved) natural gas from being burned in RDH 60 scenario compared to Base scenario (Mtoe)

[Fig. 45] shows the estimated monetary value of avoided natural gas imports in the RDH 60 scenario. The calculation is obtained by applying an average reference natural gas price of ~40 €/MWh, based on the post-crisis Dutch TTF benchmark, which is slightly above the expected 2024 average to reflect a conservative mid-term price level. The results demonstrate that reducing natural gas imports leads to increasing annual savings over time, reaching around € 1.5 billion/year by 2035. This economic perspective highlights the relevance of RDH deployment not only for decarbonization, but also for improving national energy security and reducing exposure to imported fossil fuels.

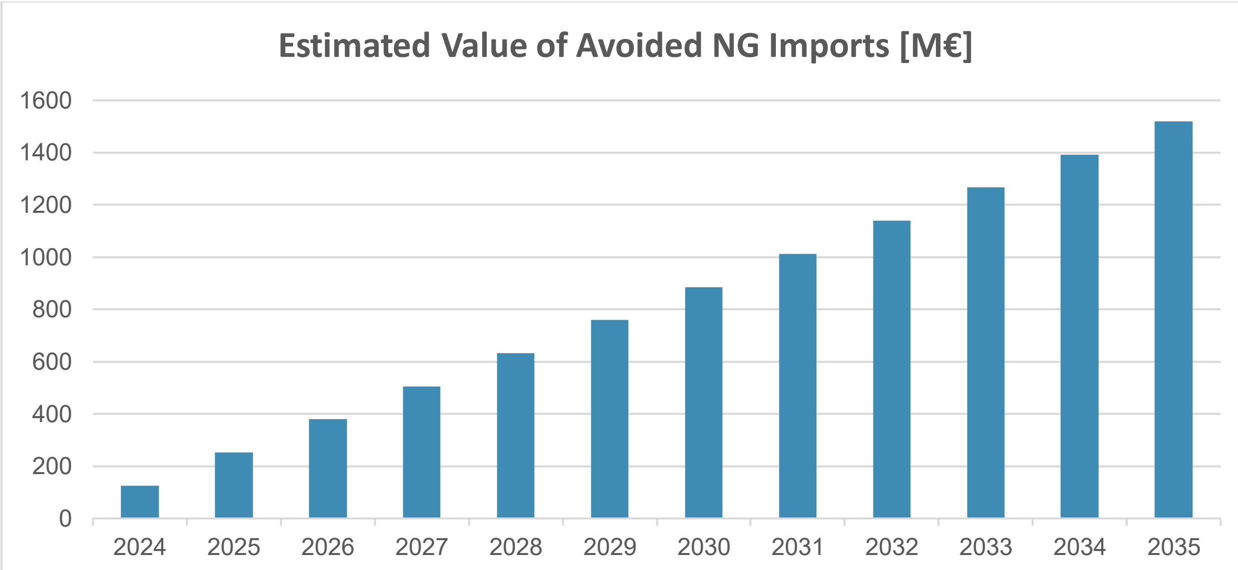

Fig. 45. Estimated value of avoided natural gas imports in RDH 60 scenario compared to Base scenario (M€)

At the end of this section, the annual avoided CO_2 emissions related to the reduction in natural gas combustion are presented in [Fig. 46]. This indicator quantifies the direct climate benefit of replacing fossil gas consumption with RDH. Across the entire 2024-2035 period, the scenario results in approximately 3.8 $MtCO_2$ of avoided emissions. To contextualize this value, the cumulative savings represent roughly 1.1% of Italy's energy-related national CO_2 emissions in 2022 (IEA CO_2 Emissions Statistics, 2024). By 2035, assuming annual heating-related emissions in the Italian building sector of approximately 30-45 $MtCO_2$ (Climate Transparency, 2022), a reduction of 600 $ktCO_2$ corresponds to roughly 1.7% of the sector's total emissions. While not transformative on their own, these reductions illustrate that RDH acts as a complementary and structural decarbonization lever when combined with efficiency measures and broader renewable pathways.

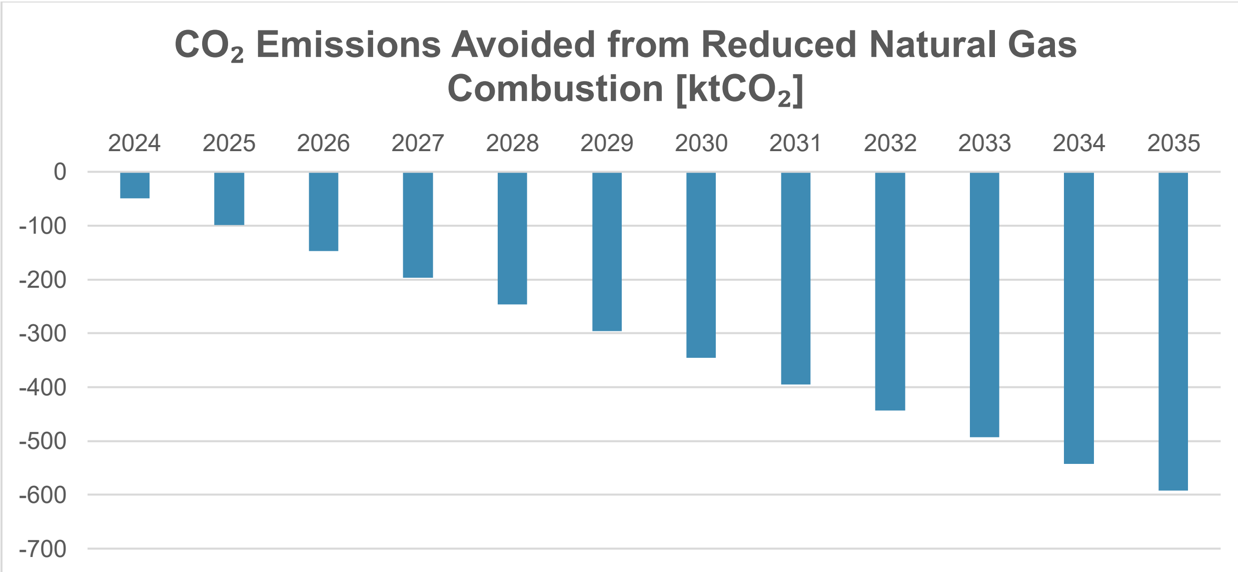

Fig. 46. CO_2 emissions avoided from reduced natural gas combustion in RDH 60 scenario compared to Base scenario (ktCO_2)

The comparison reveals that the RDH 60 scenario delivers clear benefits in terms of emissions reduction, energy security, and renewable integration. However, unlocking these benefits requires targeted market strategies, long-term investment frameworks, and regulatory credibility that can guide both investors and consumers. In this context, the next section translates the scenario insights into concrete strategic directions and policy recommendations needed to enable the RDH transition.

6.5 Strategic, Market and Policy Recommendations

Expanding RDH in Italy requires coordinated action across governance, markets, and infrastructure planning. The RDH 60 scenario demonstrates clear environmental and economic benefits, but these gains can only be realized if they are supported by stable, flexible, and inclusive institutions. The following recommend measures most effective strategies identified throughout this thesis.

Integrated and Stable Policy Frameworks

Italy needs a coherent national framework that provides long-term direction while remaining adaptable to technological and socio-economic changes. International experience shows that stable regulation, clear rules for cost allocation, and predictable financial support create the confidence necessary for investment and help DH evolve as systems become more digitalized, low-temperature, and renewable. Flexible regulatory structures should guide tariff design, renewable integration, fossil-fuel phase-down, and prosumer access, ensuring continuity in support as markets develop.

Strengthening Institutional Capacity and Community Participation

The development of RDH depends heavily on capable local institutions. Uneven municipal expertise and fragmented governance can slow or even block expansion. Capacity-building programs for municipalities, cooperatives, and local operators would address these weaknesses by improving technical, organizational, and financial skills. Supportive mechanisms may include technical assistance, advisory platforms, and training programs, especially for emerging projects. Community-based initiatives, cooperatives, and intermediary actors can also play a crucial role in early stages by sharing experience, guiding project development, and helping smaller systems reach economies of scale.

Embedding Prosumers and Energy Communities in Local Heat Planning

Municipal heat planning will be central to Italy's heating transition. Involving prosumers, energy communities, industrial waste heat suppliers, and building managers in these processes can strengthen social acceptance, reveal accurate local needs, and unlock additional renewable or waste heat sources. Municipalities can offer coordination, local knowledge, and access to information, but many require targeted support to perform this role effectively. National guidelines, standardized data tools, and training for local authorities can help ensure that heat planning taps into the full potential of prosumers and local energy communities.

Financial and Fiscal Measures to Reduce Investment Barriers

High upfront investment costs remain one of the primary obstacles to RDH. Long-term low-interest loans, green bonds, and targeted subsidies can reduce capital risk and support technologies such as large heat pumps, geothermal sources, bioenergy, solar thermal, and thermal storage. Reduced VAT rates for renewable heat and connection fees would improve affordability for households and businesses. Introducing performance-based remuneration for excess heat injection would provide predictable income streams for industrial waste heat suppliers and commercial prosumers. The annual savings of roughly 1.5 billion euros from avoided natural gas imports offer policymakers an opportunity to redirect part of these resources toward DH expansion.

Market Design, Pricing Structures, and Consumer Integration

Static tariffs limit both flexibility and consumer participation. Dynamic pricing supported by smart meters and digital control systems can encourage load shifting, reduce peak demand, and support the integration of variable renewable heat. The introduction of transparent feed-in pricing for prosumers would remove uncertainty and support investments in heat recovery, renewable heat production, and flexibility services. In areas where DH is the most socio-economically competitive solution, high connection rates are essential for cost efficiency. Rather than relying on mandatory connection policies, financial incentives such as reduced connection fees, tax reductions, and targeted subsidies can make DH more attractive than individual systems. Clear communication about cost savings, comfort, and environmental benefits can further influence consumer decisions.

Strategic Planning and Long-Term Coordination

RDH requires coordinated development across electricity systems, building renovation programs, and local heat strategies. Large heat pumps, thermal storage, and waste heat recovery depend on integrated planning and access to unified data. National guidance on heat planning should include standard methodologies and criteria to help municipalities identify high-value areas for DH, considering demand density, renewable resource availability, and the presence of recoverable waste heat. Prioritizing dense urban areas, renewable clusters, and industrial zones can significantly improve the economic performance of network expansion.

Together, these measures provide a coherent path for accelerating RDH in Italy. Strengthening institutions, enabling prosumers, improving tariff structures, expanding financial support, and coordinating long-term planning will allow DH systems to evolve into flexible, resilient, and low-carbon components of Italy’s future energy system.

7 Conclusion

This thesis explored how market design, policy mechanisms, and governance structures can support the expansion of Renewable District Heating and strengthen prosumer participation and demand response. The analysis shows that technological improvements alone are insufficient. The heating transition requires effective institutions, stable financial frameworks, transparent pricing systems, and the active involvement of consumers, communities, and local authorities.

The results highlight several strategies that consistently enhance flexibility, consumer engagement, and renewable integration. These include participatory and cooperative governance structures that build trust and transparency, dynamic pricing supported by digital technologies, clear and predictable rules for renewable and waste heat feed-in, well-designed fiscal measures, and coordinated local heat planning. Together, these elements form the backbone of a modern district heating market capable of integrating renewable heat and enabling active prosumer roles.

Applying these insights to Italy through the RDH 60 scenario demonstrates that scaling renewable district heating provides measurable environmental and economic benefits. By 2035, this pathway reduces natural gas use by around 3 Mtoe per year, avoids approximately 600 ktCO_2 emissions annually, and generates roughly €1.5 billion in savings from reduced natural gas imports. These improvements show that renewable district heating can act as a structural decarbonization lever when combined with efficiency measures and broader renewable energy deployment.

The Italian context also reveals persistent challenges. Fragmented governance limited municipal capacity, uneven tariff transparency, and a lack of coordinated national planning slow the adoption of high-impact strategies. Strengthening institutional capacity, improving regulatory consistency, and integrating prosumers and local energy communities into planning processes are essential steps to overcome these barriers. Financial mechanisms, including long-term low-interest loans, targeted subsidies, reduced VAT rates, and performance-based remuneration for renewable and waste heat, can further accelerate the deployment of district heating infrastructure.

The modeling approach in this thesis is intentionally simplified and exploratory. It relies on annual averages and ratio-based relationships rather than hourly dispatch or spatially detailed simulations. Future research should incorporate finer temporal and spatial resolution, network optimization, and behavioral modeling to further refine district heating's potential within an integrated energy system.

In summary, the transition to Renewable District Heating is a coordination challenge across institutions, markets, and communities. When supported by stable governance, transparent pricing, financial incentives, digital technologies, and inclusive planning, renewable district heating can become a flexible, cost-effective, and environmentally sustainable pillar of Europe and Italy's heating transition.

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