THUNDER

D1.1 Macro Market Factor Analysis

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D1.1 – Macro market factor analysis

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1. Executive summary

Deliverable 1.1 Macro market factor analysis includes the results of PESTLE analysis conducted within the THUNDER project to identify key macro-level factors influencing the implementation and replication of the THUNDER solution in Bulgaria. The analysis focuses on assessing political, economic, social, technological, legal, and environmental conditions that may act as enablers or barriers for the deployment of the solution.

The THUNDER solution combines data centre waste heat recovery with seasonal thermal energy storage using thermochemical materials, delivering the stored heat to district heating networks during the heating season. This approach aims to support the decarbonisation of heating systems and contribute to increased energy efficiency in urban areas.

The assessment was carried out using the PESTLE framework and draws on EU-level directives (e.g., RED III, EED III), national legislation, stakeholder interviews, and desk research, including academic and grey literature. The analysis is specific to the Bulgarian context and reflects the situation as of June 2025.

Although the focus of the PESTLE analysis is on data centre waste heat recovery and its utilization, this topic is not explicitly reflected in national-level policies in Bulgaria. Waste heat recovery is generally considered in connection with district energy systems, which led the research to place more emphasis on the district heating sector, as it currently forms the main context through which waste heat is understood and addressed.

The PESTLE analysis indicates that, at present, there are more barriers than opportunities for replicating the solution. However, changes in EU directives are expected to drive national regulatory adjustments and improved incentive structures over time. In parallel, the gradual renovation of the building stock and advancements in thermal storage technologies are likely to create a more supportive environment for the implementation of the solution.

Key Findings

Political Factors

Bulgaria’s National Energy and Climate Plan (NECP) is aligned with EU targets and supports the integration of renewable and recovered heat. However, the absence of clearly defined national incentives and the temporary suspension of energy taxes reduce financial drivers for decarbonisation.

Economic Factors

While several EU funding schemes, such as the Modernisation Fund, LIFE CET, Innovation Fund, and Horizon Europe, can support projects like THUNDER, the national context remains challenging. Fossil-based systems continue to dominate due to cost advantages, the district heating market is monopolistic, and infrastructure is underfunded and inefficient with high heat losses.

Social Factors

Local interest in low-cost or free heating from waste heat is high, which supports potential acceptance. However, district heating is often perceived as outdated, and general awareness of modern waste heat technologies remains limited.

Technological Factors

Data centre waste heat recovery is commercially mature and replicable, but the aging state of Bulgaria’s district heating systems poses technical integration challenges. Thermochemical seasonal storage remains at a low TRL (TRL 4) and is not yet commercially available, introducing technical uncertainty.

Legal Factors

Bulgaria’s legal framework permits recovered heat integration and promotes renewables. However, there are no explicit regulations for data centre heat or seasonal storage, resulting in ambiguity. Licensing and permitting processes for third-party heat are unclear and inconsistently applied across regions.

Environmental Factors

The THUNDER solution supports emissions reduction and air quality improvement by displacing fossil-based heat. Still, Bulgaria lacks structured tools for mapping waste heat sources and measuring avoided emissions, which limits strategic planning and visibility of environmental benefits.

The THUNDER solution aligns well with EU climate goals and benefits from the maturity of data centre heat recovery and available EU funding support. However, successful implementation and replication in Bulgaria face significant barriers: outdated infrastructure, regulatory uncertainty, limited public awareness, and the absence of national incentives or data systems for managing low-temperature waste heat. Addressing these gaps through targeted investments, regulatory clarification, and stakeholder engagement will be essential to unlock the full potential of the THUNDER approach.

2. Introduction

This deliverable (D1.1) presents the findings of the PESTLE analysis conducted for the THUNDER project as part of WP1, and it is an output of the subtask 1.1.1. Macro market factor analysis. The primary aim of this analysis is to systematically identify and assess macro-level factors that could serve as barriers or enablers for the successful implementation and replication of the THUNDER solution in Bulgaria.

The THUNDER solution itself is innovative, focusing on recovering waste heat from a data centre, subsequently storing it in a seasonal thermal energy storage system using thermochemical materials, and finally supplying this stored heat to the local district heating network during the winter months. Following the structured PESTLE framework, the analysis is categorized across Political, Economic, Social, Technological, Legal, and Environmental dimensions. Each dimension has been thoroughly investigated to determine its potential impact on Bulgaria, which serves as the demonstrator country, and to assess the solution's broader replicability across the European Union.

3. Methodology

3.1. PESTLE Analysis

The PESTLE analysis conducted for the THUNDER project aims to systematically identify and assess macro-level factors that may act as barriers or enablers for the implementation and replication of the THUNDER solution in Bulgaria. The solution involves recovering waste heat from a data centre, storing it in a seasonal thermal energy storage system using thermochemical materials, and supplying it to the local district heating network during the winter months.

As the analysis follows the PESTLE framework, the research results are categorized under Political, Economic, Social, Technological, Legal, and Environmental dimensions. Each dimension has been investigated with the objective of determining its potential impact on the demonstrator country and its broader replicability across the EU. The methodology includes the following steps:

Identification of key factors and classification

For each PESTLE dimension, relevant factors were selected based on a review of previous EU funded projects (e.g., the most relevant identified projects; REWARDHeat (REWARDHeat, 2024), ReUseHeat (Lygnerud, n.d.), guidance from European Commission publications (e.g., EED and RED III). Each factor was evaluated after research as a barrier and opportunity for the implementation and replication of the THUNDER solution in Bulgaria.

Desk-based research and policy review

Data were collected through legislation and regulatory documents, technical reports and scientific articles, and grey literature and stakeholder interviews conducted in WP1. The focus of the analysis was Bulgaria.

3.1.1. Limitations

The findings of this PESTLE analysis are based on data available as of June 2025 and reflect the policy, regulatory, and economic landscape at that time. Political and legal factors, including national targets and funding options, are sensitive to changes and may be affected by new legislation or shifts in EU level priorities. While Bulgaria’s National Energy and Climate Plan (Rebuplic of Bulgaria Ministry of Energy & Ministry of the Environment and Water, 2024) sets a strong strategic direction, its implementation at the local level remains uncertain and subject to future administrative and policy developments. Technological, social, and environmental insights are based on literature review and stakeholder interviews conducted with partners directly involved in the THUNDER demonstration site. These interviews provided useful input on how the solution is being developed, but they mainly reflect the experience of involved partners and may not fully represent the views of other local stakeholders or the public.

3.2. Political factors

The political factors were assessed based on relevant EU and national policies. At the EU level, the Renewable Energy Directive (EC, 2023) and the Energy Efficiency Directive (EC, 2023) set binding targets that Bulgaria is required to follow. At the national level, the analysis focused on the National Energy and Climate Plan and the Energy from Renewable

Sources Act (ZEVI), which outline targets and support measures for the integration of renewable energy and waste heat in the heating and cooling sector. The evaluation focused on the consistency between EU and national policies, the extent to which the legal framework supports waste heat recovery from data centres, district heating decarbonisation, and the implications of Bulgaria's current taxation regime for the implementation and replication of the solution.

Factors selected for the analysis:

- Alignment with EU-level policy developments
- National energy and climate targets (e.g., RED, EED compliance)
- Availability and type of state-level incentives or subsidies
- National taxation schemes (e.g., energy/environmental taxes)

3.3. Economic factors

For the economic factors, the assessment focused on the availability of funding schemes, heat market structure, tariff regulation, the cost conditions in Bulgaria's district heating sector and data centre waste heat potential. EU-level funding instruments such as the Modernisation Fund, LIFE CET, Horizon Europe, and the Innovation Fund were reviewed to evaluate support for projects involving waste heat recovery and thermal energy storage. National-level data and reports from the Ministry of Energy, Energy and Water Regulatory Commission (EWRC), and National Statistical Institute were used to analyse the structure and ownership of DH systems, the pricing framework, infrastructure conditions, and fuel mix.

Factors selected for the analysis:

- Incentives for waste heat recovery
- Market structure for district heating
- Maturity and regulation of the district heating market
- Cost structure of heat in district energy systems
- Age and depreciation of existing infrastructure/district heating assets
- Data centre waste heat potential

3.4. Social factors

For the social factors, the analysis is informed by academic literature on public acceptance of green technologies, reports on district heating perception in Bulgaria, and findings from the stakeholder workshop held in Varna in January 2025. Sources include studies on behavioural attitudes, cultural perceptions, and trust in institutions, complemented by project-specific insights into public engagement and communication strategies. The review focused on understanding public awareness, social acceptance, and user perceptions relevant to waste heat recovery and seasonal thermal storage solutions.

Selected factors for the analysis:

- Public awareness and acceptance of waste heat recovery and district energy technologies
- Perception of old district heating systems (outdated vs innovative)
- Cultural and behavioural factors influencing adoption of waste heat recovery and innovative technologies
- Customer cost expectancy

3.5. Technological factors

For the technological factors, the assessment was based on findings from the Key Exploitable Results workshop held in WP6 (Task 6.3) in May 2025, supported by project internal discussions and academic literature. The analysis focused on the maturity level of technologies, system integration requirements, and the potential for replication within Bulgaria.

Factors:

- Thermochemical seasonal storage readiness
- Replicability of waste heat recovery solutions across sites or sectors
- Existing technical risks or uncertainties around waste heat recovery and seasonal heat storage

3.6. Legal factors

For the legal and regulatory factors, the assessment is based on a review of Bulgaria's national legislation, including the Energy Sector Act, the Energy from Renewable Sources Act (ZEVI), and the Energy Efficiency Act. Licensing rules issued by the Energy and Water Regulatory Commission (EWRC) were also examined to understand the procedures governing heat production and distribution. The analysis considered the alignment of these frameworks with EU directives and the extent to which they address the integration of recovered heat and seasonal thermal energy storage. Supporting information was drawn from official legislative texts and regulatory documents.

Factors that were selected for the analysis:

- Permission processes
- National or regional legislation related to waste heat recovery from data centres and district energy systems
- Specific regulations for data centre heat recovery or the reuse of waste heat

3.7. Environmental factors

For the environmental factors, the analysis draws on national legislation such as the Clean Ambient Air Act and the Environmental Protection Act, as well as Bulgaria's National Energy and Climate Plan. Additional insights were obtained from EU-funded projects like ReUseHeat and supported by academic literature. The assessment focused on regulatory frameworks, reporting obligations, and the availability of tools for environmental monitoring and planning.

Selected factors for the analysis:

- Emissions reduction potential of waste heat recovery from data centres and impact on local air quality
- Availability of low temperature waste heat sources (e.g., data centre, sewage water, food retail)
- Mapping and quantification of waste heat recovery potential
- Role of environmental monitoring and reporting

4. PESTLE Analysis

4.1. Political

The political landscape plays an important role in supporting or discouraging the implementation of the integration of innovative solutions. Therefore, EU and national level polices were reviewed to understand if they are supporting the implementation of the solution or not. As a member state, Bulgaria is obliged to comply with EU Directives.

Renewable Energy Directive (EC, 2023), emphasizes the integration of renewable energy and waste heat and cold into the heating and cooling sector, setting specific targets to increase their share. These targets are outlined in detail in Appendix I.

In the Energy Efficiency Directive (EC, 2023), waste heat recovery is identified as a key source to improve the efficiency of heating and cooling systems, with explicit mention of data centre waste heat. The directive also provides an updated definition of efficient district heating and cooling, which can be met through one of two criteria: either a minimum share of renewable and waste heat in the energy mix or compliance with specific greenhouse gas (GHG) emission thresholds. These definitions are further detailed in Appendix I.

Both directives are legally binding for Bulgaria as a member state, thus the national policies, including National Energy and Climate Plan (NCEP) (Rebuplic of Bulgaria Ministry of Energy & Ministry of the Environment and Water, 2024) must align with these directives. The NCEP of Bulgaria reflects this alignment with highlighting targets for efficient district heating and cooling as well as the integration of waste heat. Although seasonal thermal energy storage (STES) is not explicitly mentioned, its relevance is implied through broader objectives such as demand-side flexibility and increased energy efficiency.

According to the NECP, the heating and cooling sector in Bulgaria is projected to achieve a 44.01% share of renewable energy in gross final consumption by 2030. Under the energy efficiency dimension, the country is committed to reducing final energy consumption through enhanced building performance and the implementation of efficiency measures across energy generation, transmission, and distribution. This includes the modernisation and expansion of energy infrastructure.

The heating and cooling sector remains a central pillar of Bulgaria's decarbonisation strategy. The decarbonisation potential of district heating lies in improving energy efficiency and increasing the share of renewable and recovered waste heat. Energy from Renewable Sources Act (ZEVI) (Rebublic of Bulgaira, 2023) establishes binding targets to raise the share of renewable energy in the heating and cooling sector by an average of 1.3 percentage points per year over two periods, 2021 to 2025 and 2026 to 2030, based on 2020 levels (Rebuplic of Bulgaria Ministry of Energy & Ministry of the Environment and Water, 2024). For district heating and cooling systems, this corresponds to an annual average increase of at least 1 percentage point in the share of energy derived from renewable sources and waste heat and cold.

In addition, a target of increasing the share of renewable energy and waste heat in district heating and cooling by 2.2 percentage points per year is set during the period 2021 to 2030, based on 2020 levels. To support the achievement of these targets, heat generation and distribution companies are encouraged to develop and implement strategic plans aimed at transforming their systems into efficient district heating and cooling networks, in line with EU definitions. Despite this policy direction, no direct incentives or national level policies specifically supporting the modernization of the heat sector are in place. Existing support has primarily focused on improving energy efficiency in buildings through building sector upgrades.

To ensure progress toward the identified targets, NECP emphasises the need for adequate incentives supported by national policies, as well as the active involvement of local authorities and stakeholders, which includes support for new investments through both direct and indirect funding mechanisms. However, amendments to relevant legislative acts are still required, and the structure and scope of incentives must be clearly defined to provide regulatory certainty.

Before 2022, Bulgaria followed standard EU practice by applying excise duties on energy products used for heating (gas, oil, natural gas, heavy fuel oil, kerosene, and electricity) (Republic of Bulgaria Natioanl Statistical Insitute, 2019).

However, as of July 9, 2022, as a results of the energy crises, Bulgaria temporarily lifts energy taxes on heat energy used in heating, fuels used in combined heat and power (CHP) generation, and certain types of electricity, including renewable sources. This tax relief is planned to remain in effect until June 30, 2025 (Delchev & Partners Law Firm, 2022).

Bulgaria does not apply a direct carbon tax on heating. There is no dedicated tax that charges a fixed amount per tonne of CO_2 emitted from fuel use in buildings or district heating systems. Instead, carbon emissions from heating are only priced indirectly through taxes on energy carriers, which include an implicit carbon cost estimated at around €22 per tonne CO_2eq. When combined with broader EU-level pricing mechanisms, the total effective carbon price reaches approximately €43 per tonne CO_2eq (OECD, 2024).

Alignment with EU-level policy developments – Opportunity

EU Directives such as RED III and EED explicitly support waste heat recovery (including from data centres) and efficient district heating, setting binding targets that Bulgaria must follow, creating a favourable political environment for the THUNDER solution.

National energy and climate targets (e.g., RED, EED compliance) – Opportunity

Bulgaria's National Energy and Climate Plan is aligned with RED and EED, explicitly supporting the integration of waste heat and renewable sources in district heating, making it a strong enabler for implementing and replicating the THUNDER solution.

Availability and type of state-level incentives or subsidies – Barrier

While the NECP acknowledges the importance of incentives and the need for amendments and clear definitions, the lack of currently defined and implemented incentive schemes creates uncertainty and slows down deployment.

National taxation schemes (e.g., energy/environmental taxes) – Barrier

The absence of a direct carbon tax on heating and the temporary suspension of energy taxes, ending at the time of writing this deliverable, reduce the financial incentive to shift from fossil fuels to low-carbon alternatives like waste heat recovery and seasonal thermal energy storage. What will follow remains uncertain.

4.2. Economic

Economic factors that can affect the implementation and replication of the THUNDER solution include the availability of funding schemes. These are crucial to assess, as they can have a direct impact on replication by providing support for the high upfront costs typically associated with heating and cooling solutions.

Several EU funding schemes can support district heating and cooling projects involving data centre heat recovery and seasonal thermal energy storage (EC, n.d.) as these align with EU goals on energy efficiency, renewable integration, and decarbonisation.

Key funding instruments include:

- Cohesion Fund supports sustainable development and environmental improvements, including low-carbon heat networks.
- European Investment Bank provides loans for clean energy projects; no longer funds fossil-based systems.
- European Fund for Strategic Investments / InvestEU (Bennet, 2025)mobilises private investment in areas like energy efficiency and renewable energy.
- Horizon Europe includes funding for energy efficiency, heating and cooling innovation, and thermal storage under Cluster 5 Climate, energy and mobility.
- Just Transition Mechanism supports regions transitioning from coal; district heating with recovered heat may qualify.

- LIFE: Clean Energy Transition funds coordination and policy support actions for energy efficiency and renewable heating.
- Modernisation Fund targets investments in 13 lower-income Member States for energy efficiency, storage, and modern grid infrastructure.
- Innovation Fund supports large-scale demonstration of innovative low-carbon and energy storage technologies.

Despite these developments, country level incentives are not specifically targeting heat sector decarbonisation or supporting waste heat recovery. However, as outlined in the NECP, it is expected that such support measures will become more explicit over time. One of the existing national schemes, the Energy Efficiency and Renewable Sources Fund, supports investments related to energy efficiency measures (EERSF, 2023), including improvements in industrial processes, which may potentially cover waste heat recovery from data centres.

The current situation of the district heating market is crucial to identify the opportunities and barriers for the replication of the solution, as the waste heat recovery is mentioned in combination with district energy systems in Bulgaria. As a result, a detailed search was conducted to understand the current situation in Bulgaria.

4.2.1. District heating sector in Bulgaria

The district heating (DH) sector in Bulgaria serves as the primary source of heating and hot water in densely populated cities, providing services to approximately 30% of urban households, primarily utilizing natural gas. Sofia operates the largest DH system in the country, contributing around 65% of the national heat supply and serving over 440,000 consumers, largely through combined heat and power (CHP) plants. This system in Sofia is notably the only one owned by the municipality (ReHeatEast, 2022), while all other systems across the country are privately owned. Each city typically has a single district heating company, resulting in a natural monopoly. According to a 2018 World Bank report, the DH sector in Bulgaria is recognized as the most economical and environmentally sustainable option for heat supply (World Bank Group, 2018).

The sector is regulated by the Energy and Water Regulatory Commission (EWRC), which is responsible for licensing, setting tariffs, and ensuring compliance, thereby protecting consumers through fair pricing, reliable service, and transparent billing (ReHeatEast, 2022). The Ministry of Energy also plays a vital role in shaping and implementing policies affecting DH operations (ReHeatEast, 2022). DH companies are required to adhere to various regulatory mandates, including obtaining licenses, following tariff regulations, adopting energy efficiency measures, and integrating renewable energy sources (RES). They must also report to the EWRC to demonstrate compliance with national and EU standards concerning emissions and renewable energy (ReHeatEast, 2022), (Ministry of Energy, Republic of Bulgaria, 2017).

Historically, Bulgarian DH systems were built in the 1950s and 1960s to offer a collective, subsidized heat supply without catering to individual consumer needs, which limited consumers' ability to adjust their heat consumption and reduce supply costs. Over time, inadequate funding for maintenance and new investments has led to a decline in the condition of DH assets, resulting in low operational efficiency and, in some cases, poor service quality, particularly in cities like Gabrovo (ReHeatEast, 2022). Despite being the most efficient heating option in cities with developed heat transmission networks, a significant amount of losses occur in the buildings' distribution networks. Common heating installations in multi-family residential buildings are often in poor operational condition, leading to substantial heat loss (Ministry of Energy, Republic of Bulgaria, 2017).

District heating services are available in 18 Bulgarian cities, but only 16% of Bulgarian citizens receive these services, a figure lower than the 23% to 64% seen in other EU Member States (Ministry of Energy, Republic of Bulgaria, 2017).

Heat pricing

Heat pricing in Bulgaria is centrally regulated by the State Commission for Energy Regulation under the Ordinance on Regulating the Prices of Heat Supply (Republic of Bulgaria, 2004). The pricing framework aims to allow energy companies to recover justified costs and achieve a reasonable return on capital, while also fulfilling public service obligations. Prices are determined using two primary regulatory approaches:

- Cost Plus Regulation: Prices are set based on approved annual revenue requirements, covering operating costs and a return on the regulatory asset base, with regular (at least annual) reviews to adjust for actual costs and unforeseen changes.
- Incentive-Based Regulation: Applied over longer periods (2 to 5 years), this includes a Price Cap (prices adjusted annually by inflation minus efficiency targets) and a Revenue Cap (similar adjustment to annual allowed revenues plus corrections for forecast errors).

Both models allow performance indicators related to energy and service quality to influence future revenue allowances, penalizing underperformance. Prices consist of two components: a commodity charge (covering variable costs) and a capacity/availability charge (covering fixed costs and return on capital). These charges apply to sales from producers to transmission companies and from transmission companies to end users. Prices are uniform for all customers using the same heat carrier within a licensed area. Energy companies must submit detailed applications for price changes, which undergo a transparent public consultation process, with approved prices typically taking effect the following month.

District heat capacity and supply

DH Capacity

The total installed capacity of district heating plants in Bulgaria in 2023 was just over 5 GW. Combined heat and power (CHP) plants using non-renewable fuels account for 2.63 GW or roughly 47% of the total capacity. Heat only boilers (HOBs) using non-renewable sources have a capacity of2.86 MW capacity, representing about 47%. Renewable energy plays a minimal role in Bulgaria's district heating infrastructure, with renewable heat-only boilers with 0.8 GW MW, which is less than 2% of the total installed capacity. This distribution, shown in Figure 1, indicates that Bulgaria's district heating sector remains heavily dependent on conventional fossil fuel technologies, with very limited integration of renewable energy sources for heat generation.

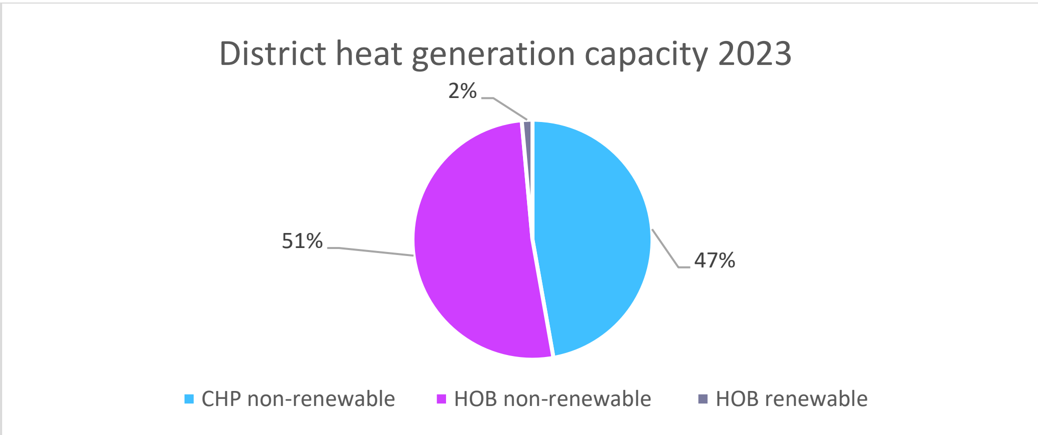

Figure 1 District heat generation capacity in 2023 (National Statistical Institute, 2023)

DH Heat Supply

In 2023, the total heat delivered to the district heating network in Bulgaria amounted to approximately 7.14 TWh, Figure 2. The majority of this heat, 5.41 TWh, was generated by CHP plants using non-renewable fuels, making them the dominant source of thermal energy. HOBs powered by non-renewable sources contributed an additional 1.61 TWh, while renewable HOBs supplied only 0.12 TWh. This highlights the continued heavy reliance on fossil fuels in Bulgaria's district heating sector, with renewable sources accounting for less than 2% of total heat production, while non-renewable heat supply accounts for 88%.

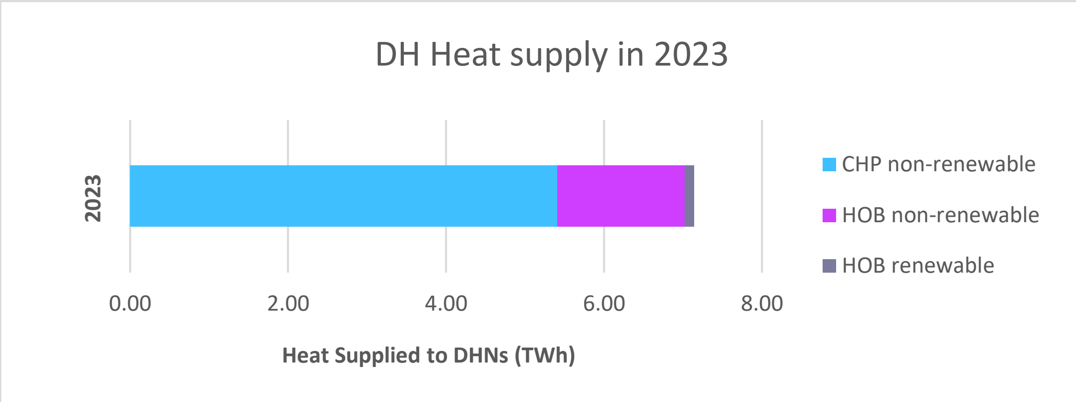

Figure 2 Heat supplied into the network in 2023 by heat source (National Statistical Institute, 2023)

4.2.2. Data centre waste heat potential

As the THUNDER project focuses on recovering waste heat from data centres, identifying the national potential for this source is critical.

The waste heat potential from data centres has not yet been systematically assessed in Bulgaria, and no country-specific mapping or dedicated studies are publicly available. The existing estimate comes from the ReUseHeat project (Deliverable 1.9), which modelled the waste heat potential of various urban waste heat sources across the EU28.

According to publicly available sources, there are an estimated 30 data centres in Bulgaria, primarily located in Sofia, though this figure varies depending on the inclusion of co-location, private enterprise, or edge facilities (Datacentermap, n.d.). Based on ReUseHeat's modelling, a typical urban data centre in Bulgaria could generate up to 163 TJ of recoverable waste heat annually (Persson, Atabaki, Nielsen, & Moreno, 2022). If this indicative figure is applied to Bulgaria, the potential heat recovery from just one data centre would represent approximately 39% of the total renewable heat supplied by heat-only boilers in 2023, which amounted to 422 TJ.

Although there are currently no publicly documented examples of data centre waste heat recovery in Bulgaria, it suggests significant potential. If successfully implemented, such systems could be widely replicated, as data centres operate continuously and provide a stable heat source.

Incentives for waste heat recovery– Opportunity

EU level funding schemes such as the Modernisation Fund, Innovation Fund, LIFE CET, and Cohesion Fund offer strong support for sustainable energy and energy efficiency projects, helping reduce investment risks and enabling replication if access and co-financing conditions are met. At the national level, support is currently focused primarily on energy efficiency in the building stock, but a shift is expected.

Market structure for district heating - Barrier

The DHC market in Bulgaria is mature in terms of reach but outdated in infrastructure and heavily reliant on fossil fuels, with limited regulatory frameworks to enable innovative solutions like seasonal heat storage or third-party heat recovery.

Maturity and regulation of the district heating and cooling market - Barrier

The DHC market in Bulgaria is mature in terms of reach but outdated in infrastructure and heavily reliant on fossil fuels, with limited regulatory frameworks to enable innovative solutions like STES or third-party heat recovery.

Cost structure of heat in district energy systems -Barrier

The regulated pricing models focus on cost recovery rather than efficiency or innovation, which can discourage investments in non-traditional technologies such as waste heat integration or seasonal thermal storage.

Age and depreciation of existing district heating infrastructure/assets - Barrier

Most of the district heating infrastructure was built in the mid 20th century, resulting in high losses and poor system efficiency, which might complicate the integration of new low-temperature heat sources.

Data centre waste heat potential - Barrier

The lack of country specific assessments or pilot projects limits the visibility and planning around data centre waste heat recovery. Although modelled potential is high, the absence of real world examples and national mapping constrains integration into district heating systems and delays the recognition of data centres as strategic low-carbon heat sources.

4.3. Social

The factors influencing the implementation and replication of waste heat recovery, heat storage and district heating solutions are closely tied to public perception, awareness levels, and behavioural attitudes toward new technologies and the opinion of the customers on the current systems. While these elements are not formally regulated, they play a key role in shaping how easily solutions like WHR and seasonal thermal energy storage can be deployed and accepted in practice.

In Bulgaria, although district heating currently serves around 16% of households, public understanding of modern DH systems based on recovered or low-temperature heat remains limited (Bielig, Kutzner, Klingert, & Kacperski, 2025).The technology is still often perceived as inefficient and outdated, strongly associated with the legacy of the communist era (ReHeatEast, 2022). The protests in 2013 over high energy prices and poor service transparency showed ongoing public distrust in the DH sector (The Sofia Globe, 2013).

Cultural and behavioural factors also influence adoption. Research shows that perceived risk, trust in institutions, and social norms shape acceptance of green technologies. Communication strategies based on social proof have been found to be effective in raising acceptance (e.g., visible pilot installations), even if the research is not specific to Bulgaria (Bielig, Kutzner, Klingert, & Kacperski, 2025).

The stakeholder workshop conducted in Varna in January 2025 showed that there is interest in waste heat recovery, particularly when it can offer free or low-cost heating options. This highlights the importance of customer cost expectations as a key social factor. Public engagement will therefore be essential in the THUNDER implementation phase and future replications. Activities such as educational campaigns, guided site visits, and participatory planning processes are recommended to raise awareness, improve transparency, and foster local ownership of the solution.

In summary, the social conditions in Bulgaria allow for the implementation of the THUNDER solution but indicate a need for proactive engagement strategies. Building awareness, recovering trust, and addressing affordability concerns will be critical to ensure public support and smooth integration into the local context.

Public awareness and acceptance of waste heat recovery and district energy technologies - Barrier

Public understanding of modern district heating and waste heat recovery remains limited, despite district heating covering around 16% of households. Building awareness and trust will require sustained engagement and tailored communication efforts.

Perception of old district heating systems (outdated vs innovative) - Barrier

District heating is often seen as outdated and inefficient, tied to the legacy of the communist era. This perception, reinforced by past dissatisfaction with pricing and transparency, can negatively affect acceptance of new DH solutions.

Cultural and behavioural factors influencing adoption – Opportunity

Cultural factors such as trust and social proof play a role in adopting green technologies. Approaches like visible pilot projects and community endorsements can positively influence public perception and uptake.

Customer cost expectancy - Opportunity

Stakeholder feedback from Varna indicates interest in waste heat recovery is closely tied to expectations of free or low-cost heat. If the solution is positioned around affordability, it could increase social acceptance and willingness to adopt.

4.4. Technological

The technological framework for the THUNDER solution includes data centre waste heat recovery and emerging seasonal thermal energy storage technologies within the context of Bulgaria's district heating (DH) infrastructure. While data centre heat recovery has demonstrated commercial viability in low-temperature heat networks (Lygnerud K (Editor), 2022), the Key Exploitable Results workshop conducted in WP6, in May 2025 for Task 6.3, identified that integrating thermochemical seasonal storage presents both opportunities and technical challenges.

Maturity level of available technologies reflects a mixed landscape of established and emerging solutions within Bulgaria's energy infrastructure. Data centres are commercially mature and expanding in Bulgaria, operating continuously year-round with high operational safety standards, thus offering a reliable low-temperature heat source for DH integration. However, Bulgaria's district heating systems require significant modernisation, with reported heat losses of 17 percent in production and about 20 percent in transmission (Simeonova, 2023). Thermochemical seasonal energy storage remains at a lower technology readiness level at the moment (TRL 4). However, it offers advantages like high energy density and low heat loss, although practical implementation challenges remain, including commercial viability and performance (Jarimi, et al., 2019).

Replicability of waste heat recovery solutions across sites demonstrates strong potential due to standardised data centre operations. The diversity of district heating companies across Bulgarian cities, each with different technical specifications and operational standards, may complicate standardised implementation approaches on the district heating side. Thermochemical seasonal storage replicability faces greater challenges due to site specific requirements for storage design, material handling systems, and integration with existing heating infrastructure.

In summary, while data centre waste heat recovery is a mature and replicable technology, thermochemical seasonal storage introduces technical uncertainties that require further development and demonstration.

District heating infrastructure compatibility - Barrier

Bulgaria's aging district heating systems experience high heat losses (17% production, 20% transmission) and might require modernisation to optimally integrate advanced thermal storage solutions.

Replicability of waste heat recovery solutions across sites or sectors - Opportunity

Commercial-grade waste heat recovery systems are available and proven in operation

Thermochemical seasonal storage readiness - Barrier

Limited commercial availability and uncertain long-term performance of thermochemical storage materials under operational conditions may delay implementation.

Existing technical risks or uncertainties around waste heat recovery and seasonal heat storage - Barrier

The combination of multiple emerging technologies increases technical risk and requires specialised expertise for successful deployment and operation.

4.5. Legal

The legal framework relevant for the THUNDER solution is based on the Energy Sector Act (Republic of Bulgaria, 2018) and the Energy from Renewable Sources Act (ZEVI) (Rebublic of Bulgaira, 2023) and the licensing rules are set by the Energy and Water Regulatory Commission (EWRC). These define the licensing, planning, and regulatory environment for the integration of recovered heat and renewable energy in Bulgaria's heating and cooling sector, but they do not directly address data centre waste heat recovery or thermal energy storage solutions.

Under the Energy Sector Act (Republic of Bulgaria, 2018), producing, transmitting, and distributing thermal energy requires a license (Articles 39-43, 92-96). While the law allows district heating operators to expand or change their systems, it does not clearly explain how to include recovered heat from third parties or seasonal thermal storage. Licensing is handled by EWRC (Rebublic of Bulgaria EWRC, 2004) and the rules and conditions are listed, which are mainly built around conventional district heating systems. Applying these rules to new solutions like data centre heat recovery may require clarification. Even if the solution is technically eligible, it has to be fitted into existing licensing categories. As a result, further clarification and additional documentation might be required. This can create an administrative burden and may affect the implementation timeline.

ZEVI (Rebublic of Bulgaira, 2023) supports the use of renewable energy and recovered heat in the heating sector and encourages municipalities to include these in local planning. However, the act does not specify binding requirements or procedures for integrating waste heat or converting existing district heating networks to more efficient systems at the local level. There is also no reference to seasonal thermal energy storage or recovered heat from data centres. Local authorities may play a supportive role, but their responsibilities are broadly framed and non-binding. This may delay municipal engagement or lead to uneven implementation across regions.

The Energy Efficiency Act (Republic of Bulgaria, 2021) complements the Energy Sector Act and ZEVI by defining "efficient district heating" as systems using at least 50% waste heat or renewables and requiring cost-benefit analyses for large energy installations (>20 MW), supporting integration of waste heat into district networks. It also introduces obligations for industrial systems, such as data centres, including mandatory energy audits and energy management reporting. However, the Act does not explicitly regulate seasonal thermal energy storage**,** and recovered heat from data centres is not specifically addressed.

In summary, while the legal framework permits the implementation of the THUNDER solution in principle, the absence of regulations for waste heat recovery and seasonal storage means deployment may require additional coordination at both at local and national levels.

Permission processes for waste heat integration and heat storage -Barrier

The Energy Act does not provide specific guidance for permitting third-party waste heat integration or seasonal thermal energy storage. The permit process may require case by case clarification with EWR, which can complicate and slow down the process.

National or regional legislation related to waste heat recovery from data centres – Opportunity

The Energy Sector Act and ZEVI permit the use of recovered heat in district heating systems and promote the uptake of renewable heat sources. Data centres are not explicitly mentioned. While municipalities are encouraged to support these measures, clear legal obligations are lacking, which can result in inconsistent implementation across regions. The Energy Efficiency Act further supports the integration of waste heat into heat supply systems, but regulatory specifics are currently limited.

Specific regulations for data centre waste heat recovery and reuse of waste heat- Barrier

There are no explicit legal provisions for data centre heat recovery or seasonal thermal energy storage. Classification and integration depend on interpretation within existing frameworks (e.g., data centres might be included in the “industrial systems” in the Energy Efficiency Act), which are focused on conventional systems. This regulatory ambiguity can lead to uncertainty for project developers and delay implementation.

4.6. Environmental

Waste heat recovery in combination with seasonal heat storage in the heating sector has the potential to reduce emissions and improve air quality in Bulgaria. While national planning documents such as the NECP (Rebuplic of Bulgaria Ministry of Energy & Ministry of the Environment and Water, 2024) support the use of waste heat in district heating systems, the absence of structured tools and dedicated reporting requirements creates practical limitations.

The integration of waste heat into district heating networks contributes to national targets for increasing the share of renewable and recovered heat (Rebuplic of Bulgaria Ministry of Energy & Ministry of the Environment and Water, 2024). However, the actual impact on emissions of the waste heat integration in the DHN depends on how much fossil fuel-based heat it replaces. Since data centre waste heat does not involve combustion, it can improve local air quality, particularly during periods of high demand in winter, where the seasonally stored heat would be utilized in the heat network. However, these benefits are difficult to quantify due to the absence of national systems to monitor recovered heat volumes or emissions avoided.

In Bulgaria, district heating plants using fossil fuels are subject to national emission thresholds for SO_2, NO_x, CO, and particulate matter, as set under the Clean Ambient Air Act (Rebuplic of Bulgaria, Ministry of Environment and Air, 2023). These limits are aligned with EU directives, including the Medium Combustion Plant Directive (2015/2193/EU) (European Comission, 2015) and the Industrial Emissions Directive (2010/75/EU) (European Comission, 2024). Article 8 of the Clean Ambient Air Act mandates that the Council of Ministers establish and update these threshold values to protect public health and environmental quality. The limits apply to all stationary combustion sources. By displacing fossil-based heat with non-combustion sources, like data centre waste heat, the THUNDER solution supports operators in maintaining compliance with emission limits, especially during peak winter periods.

Monitoring and reporting requirements are specified in the Environmental Protection Act (EPA) in Articles 117 to 127 (Republic of Bulgaria Ministry of Environment and Air, 2023). Thermal plants with a 50 MW or more capacity are subject to integrated permitting under Chapter 7 of the EPA and must comply with emission limits, energy efficiency, and reporting obligations set by the Executive Environment Agency. Operators must monitor emissions and report data on pollutants, fuel use, and environmental measures. However, the legislation does not require operators to report on recovered heat volumes or avoided emissions. As a result, the environmental benefits of solutions like THUNDER, meaning integrating waste heat from data centres with seasonal storage in the heat network, are not directly reflected in official statistics or planning documents, which limits visibility and incentives for replication.

The availability of other low-temperature waste heat sources (e.g. data centres, supermarkets, food processing, waste water, and metro systems) could significantly support the replication and scaling of the THUNDER concept beyond the current demo site. However, Bulgaria does not have a national framework or municipal level instruments to systematically map or facilitate access to these sources. Although platforms developed in EU-funded projects, such as The European Waste Heat Map, developed in ReUseHeat project provide indicative estimates for the country (Moreno, Nielsen, & Persson, 2022), there are no local heat atlases available combining these urban heat sources with the heat demand.

In summary, while the environmental conditions support the value of the THUNDER solution, institutional gaps in data availability, source mapping, and environmental reporting can limit the replicability and speed of deployment across Bulgaria.

Emissions reduction potential of waste heat recovery from data centres and impact on local air quality - Opportunity
Recovered heat from data centres can reduce fossil-based heat generation in DH systems. Bulgaria's NECP targets a 2.2 percentage point annual increase in recovered and renewable heat. Additionally, waste heat recovery avoids combustion emissions (NO_x, SO_2, PM), supporting cleaner air.

Availability of low temperature waste heat sources (e.g., data centre, sewage water, food retail) - Barrier
Low-grade heat sources exist, but currently there is no national or local registry or support scheme for the identification of these sources and their integration into heating networks. This lack of visibility and institutional support limits the ability to use these sources effectively.

Mapping and quantification of waste heat potential - Barrier
Tools like the European Waste Heat Map Europe (Moreno, Nielsen, & Persson, 2022) show national waste heat recovery potential in Bulgaria, which can provide a base for replication. However, Bulgaria currently lacks a national heat atlas or detailed local spatial planning datasets. This absence makes it difficult to assess the alignment between waste heat sources, building heat demand, and district heating networks at the local level. This limits the ability to identify viable WHR opportunities and to plan their integration effectively.

Role of environmental monitoring and reporting - Barrier
While district operators are required to report fuel consumption, there are currently no specific monitoring or disclosure obligations related to recovered heat or the avoided emissions. As a result, the environmental benefits of waste heat recovery, such as reduced primary energy demand and lower CO_2 emissions, often remain unquantified or not visible in official data. This lack of transparency limits the recognition of the full value of waste heat integration, potentially weakening the case for replication and broader adoption.

4.7. Summary

This section summarises the key barriers and opportunities identified through the PESTLE analysis, as outlined in Table 1 below.

Table 1 Summary of the factors identified as barriers and opportunities

PESTLE	Barrier	Opportunity
Political	Lack of defined national incentives Temporary suspension of energy taxes	NECP aligned with RED and EED EU-level directives supportive of waste heat recovery
Economical	Monopolistic district heating market Outdated infrastructure Price regulation	EU funding schemes reduce investment risk and support replication
Social	Low public awareness of waste heat recovery Negative perception of district heating	Interest in low cost or free heating
Technological	Aging infrastructure with high losses System integration complexity Low TRL of thermochemical storage	Commercial availability of data centre heat recovery
Legal	Permission processes No explicit regulations for data centre heat recovery	National legislation related to waste heat recovery and district energy
Environmental	Lack of waste heat mapping tools No monitoring of avoided emissions	Emissions reduction potential of waste heat recovery

5. Conclusions

Based on the PESTLE analysis conducted for the THUNDER project, the overall landscape for implementing and replicating the THUNDER solution in Bulgaria presents a complex interplay of significant opportunities and substantial barriers. The core objective of this analysis was to systematically identify and assess macro factors that could influence the success of recovering waste heat from data centres and supplying it to the local district heating network.

Overall Opportunities for THUNDER in Bulgaria:

Strong Policy Alignment: Bulgaria's National Energy and Climate Plan (NECP) is explicitly aligned with key EU Directives like the Renewable Energy Directive (RED III) and the Energy Efficiency Directive (EED), which strongly emphasize the integration of waste heat and renewable sources into heating and cooling systems. This creates a favourable political environment for solutions like THUNDER, supporting targets for efficient district heating and cooling and promoting an increase in the share of renewable and recovered heat. The existing legal framework, including the Energy Sector Act and the Energy from Renewable Sources Act (ZEVI), generally permits the use of recovered heat in district heating systems.

Access to EU Funding: Various EU funding schemes are available and well-aligned with the THUNDER solution's goals, including the Modernisation Fund, Innovation Fund, LIFE CET, Cohesion Fund, Horizon Europe, and the European Investment Bank. These can significantly reduce the high upfront investment risks associated with innovative heating and cooling solutions involving waste heat recovery and thermal energy storage.

Resource availability and Social Interest: Data centre waste heat recovery technologies are commercially mature and proven in operation, offering a reliable, year-round, low-temperature heat source due to standardized data centre operations. Socially, there is a clear interest in waste heat recovery when it can offer free or low-cost heating, which suggests a pathway for increased public acceptance if affordability is emphasized. Cultural factors like trust in institutions and the impact of visible pilot installations (social proof) can also positively influence public perception and adoption.

Environmental Benefits: The THUNDER solution has a substantial potential for emissions reduction and improved local air quality by displacing fossil-based heat generation and avoiding combustion emissions. This directly supports Bulgaria's NECP targets for increasing renewable and recovered heat shares.

Key Barriers and Challenges for THUNDER in Bulgaria:

Insufficient National Incentives and Taxation Disadvantages: Despite national strategic alignment, there is a lack of clearly defined and implemented state-level incentive schemes for waste heat recovery and seasonal thermal storage, creating uncertainty for deployment. Furthermore, the temporary suspension of energy taxes on heat until June 2025 and the absence of a direct carbon tax on heating reduce the financial incentive to transition from fossil fuels to low-carbon alternatives like waste heat recovery. Fossil-based systems remain financially favoured at the national level.

Outdated District Heating Infrastructure and Market Structure: Bulgaria's district heating market, while mature in reach, is outdated in infrastructure and heavily reliant on fossil fuels (77% of total capacity from non-renewable CHP plants). Much of the infrastructure, built in the mid-20th century leading to high heat losses (17% in production, 20% in transmission) and poor system efficiency. The monopolistic market structure and regulated pricing models prioritizing cost recovery over innovation can discourage investments in non-traditional technologies such as third-party heat recovery.

Limited Public Awareness and Negative Perceptions: Public understanding and acceptance of modern district heating and waste heat recovery technologies in Bulgaria are limited, with systems often perceived as outdated and inefficient due to their association with the communist era and past dissatisfaction with pricing and transparency. Building trust and addressing affordability concerns will be critical for public support.

Technological Readiness and Integration Complexities: Thermochemical seasonal energy storage remains at a lower Technology Readiness Level (TRL 4) with limited commercial availability. The system integration complexity of combining multiple emerging technologies introduces technical risks, and Bulgaria’s aging district heating systems require significant modernization to efficiently integrate advanced thermal storage solutions.

Regulatory Ambiguity and Permitting Challenges: The existing legal framework, despite permitting recovered heat in general, lacks explicit legal provisions for data centre heat recovery or seasonal thermal energy storage. This leads to regulatory ambiguity, and the complexity and lack of clarity in permission processes for third-party heat integration may require case-by-case clarification with regulators, potentially delaying project implementation. Furthermore, local authorities' responsibilities in this area are broadly framed and non-binding, which can result in inconsistent implementation across regions.

Data Gaps and Lack of Mapping Tools: Bulgaria lacks structured tools and dedicated reporting requirements for recovered heat volumes or avoided emissions. There is also no national framework or local instruments to systematically map or facilitate access to other low-temperature waste heat sources, nor a national heat atlas or detailed local spatial planning datasets to assess the alignment between waste heat sources, demand, and district heating networks effectively. This limits the ability to identify and plan for wider replication.

In conclusion, while the THUNDER solution is strategically aligned with EU and national energy objectives and leverages data centre heat recovery technology, its successful demonstration and replication in Bulgaria face considerable barriers. These challenges are primarily rooted in the association of waste heat recovery with district heating systems, which are outdated and fossil fuel dependent, an emerging yet unclear regulatory landscape for innovative waste heat solutions, limited public awareness and perception issues, and significant data gaps on waste heat potential from data centres and reporting for waste heat utilization. Addressing these barriers through targeted policy interventions, regulatory clarity, strategic infrastructure modernization investments, and proactive public engagement will be crucial for unlocking the full potential of the THUNDER solution.

References

Bennet, V. (2025). *EBRD launches InvestEU programme in Bulgaria's financial sector to boost sustainable investment*. Retrieved from https://www.ebrd.com/home/news-and-events/news/2025/ebrd-launches-investeu-programme-in-bulgaria-s-financial-sector-.html

Bielig, M., Kutzner, F., Klingert, S., & Kacperski, C. (2025). Understanding Intention to Adopt Smart Thermostats: The Role of Individual Predictors and Social Beliefs Across Five EU Countries. *In Proceedings of the 14th International Conference on Smart Cities and Green ICT Systems*, 36-47. doi:10.5220/0013356200003953

Bulgaria Energy Snapshot. (2022). Retrieved from https://energy.ec.europa.eu/system/files/2022-10/BG_2022_Energy_Snapshot.pdf

Delchev & Partners Law Firm. (2022). *Tax Measures for Tackling the Increasing Energy Prices in Bulgaria.* Retrieved from https://www.delchev-lawfirm.com/wp-content/uploads/2022/07/Tax-measures-for-tackling-the-increasing-energy-prices-Jul-2022.pdf

EC. (2023). *Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast).* Retrieved from Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast)

EC. (2023). Renewable Energy Directive Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413

EC. (n.d.). *EU funding possibilities in the energy sector.* Retrieved from https://energy.ec.europa.eu/topics/funding-and-financing/eu-funding-possibilities-energy-sector_en

European Comission. (2015). Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants. Retrieved from https://eur-lex.europa.eu/eli/dir/2015/2193/oj/eng

European Comission. (2024). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Official Journal of. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02010L0075-20240804

IEA. (n.d.). *Bulgaria energy mix*. Retrieved from https://www.iea.org/countries/bulgaria/energy-mix

Jarimi, H., Aydin, D., Yanan, Z., Ozankaya, G., Chen, X., & Riffat, S. (2019). Review on the recent progress of thermochemical materials and processes for solar thermal energy storage and industrial waste heat recovery. *International Journal of Low-Carbon Technologies*. doi:https://doi.org/10.1093/ijlct/cty052

Lygnerud K (Editor), N. S.-G.-G. (2022). *Handbook for increased recovery of urban excess heat.* ReUseHeat Project, Grant Agreement 767429, European Commission.

Lygnerud. (n.d.). *ReUseHeat: Recovering urban excess heat*. Retrieved from https://www.ivl.se/english/ivl/our-offer/research-projects/energy/reuseheat-recovering-urban-excess-heat.html

Ministry of Energy, Republic of Bulgaria. (2017). National long-term programme for the promotion of investments in measures aimed at improving the energy performance of the national stock of public and private residential and commercial buildings 2016–2020. Retrieved from https://energy.ec.europa.eu/system/files/2018-06/bg_building_renov_2017_v2_en_0.pdf

Moreno, D., Nielsen, S., & Persson, U. (2022). *The European Waste Heat Map*. Retrieved from ReUseHeat project - Recovery of Urban Excess Heat.: https://tinyurl.com/2wvh7ud7

National Statistical Institute. (2023). *District heating systems and efficiency for district heating for 2023* . Retrieved from https://www.nsi.bg/en/statistical-data/76/270

OECD. (2024). *Carbon pricing in Bulgaria.* Retrieved from Pricing Green House Gas Emissions Country Notes: https://www.oecd.org/content/dam/oecd/en/topics/policy-sub-issues/carbon-pricing-and-energy-taxes/carbon-pricing-bulgaria.pdf

Rebublic of Bulgaira. (2023). *Energy from Renewable Sources Act (ZEVI).* Retrieved from https://seea.government.bg/documents/Energy_from_Renewable_Sources_Act.pdf

Rebublic of Bulgaria EWRC. (2004). *Ordinance on Licensing of Activites in the Energy Sector.* Retrieved from https://www.dker.bg/files/DOWNLOAD/licensing_ordinance_en.pdf

Rebuplic of Bulgaria Ministry of Energy & Ministry of the Environment and Water. (2024). *Integrated Energy and Climate Plan of the Republic of Bulgaria.* Retrieved from https://commission.europa.eu/publications/bulgaria-final-updated-necp-2021-2030-submitted-2025_en

Rebuplic of Bulgaria, Ministry of Environment and Air. (2023). Clean Ambient Air Act. Retrieved from https://www.moew.government.bg/static/media/ups/tiny/file/PNOOP/Acts_in_English/Clean_Ambient_Air_Act.pdf & https://faolex.fao.org/docs/pdf/bul164792.pdf

ReHeatEast. (2022). Analysis of Challenges, Gaps and Good Practices in District Heating and Cooling: Deliverable 1.2.1. Retrieved from https://interreg-danube.eu/storage/media/01JFCWJG5F7KEZHAM89Z9MGQKC.pdf

Republic of Bulgaria. (2004). Ordinance on Regulating the Prices of Heat Supply. Retrieved from https://www.dker.bg/files/DOWNLOAD/ordinance_heat_en.pdf

Republic of Bulgaria. (2018). *Energy Sector Act.* Retrieved from https://www.me.government.bg/en/library/energy-act-256-c25-m258-1.html

Republic of Bulgaria. (2021). Energy Efficiency Act. Retrieved from https://seea.government.bg/documents/ZEE_12.03.2021_ENG.pdf

Republic of Bulgaria Ministry of Environment and Air. (2023). Environmental Protection Act. Retrieved from https://faolex.fao.org/docs/pdf/bul52883.pdf & https://www.moew.government.bg/en/environmental-protection-act-7628/

Republic of Bulgaria Natioanl Statistical Insitute. (2019). *Environmental Taxes*. Retrieved from https://www.nsi.bg/en/quality-reports/environmental-taxes-353

REWARDHeat. (2024). *REWARDHeat*. Retrieved from https://www.rewardheat.eu/

Simeonova, V. (2023). *Warming Bulgaria*. Retrieved from Alfa Laval: https://www.alfalaval.com/media/stories/industries/warming-bulgaria

The Sofia Globe. (2013, February 25). *Bulgarian political crisis: protesters' demands, in English*. Retrieved from The Sofia Globe: https://sofiaglobe.com/2013/02/25/bulgarian-political-crisis-protesters-demands-in-english/

World Bank Group. (2018). Project Performance Assessment Report: Bulgaria District Heating Project (IBRD-47030, 47040). Retrieved from https://ieg.worldbankgroup.org/sites/default/files/Data/reports/ppar-bulgariadistrictheating.pdf

Appendix I

EU Directives and Regulations

5.1.1. Energy Efficiency Directives

The definition of efficient heating and cooling systems is detailed in Article 26 of the Energy Efficiency Directive (EED III) (EC, 2023), as listed in Table 2. Member States may choose to apply either energy source-based criteria or greenhouse gas (GHG) emission-based criteria.

Table 2 EU Targets and requirements for Efficient District Heating and Cooling, alternative ways (EED)

Timeframe	Minimum share of energy source	GHG emission limit
Until 31 Dec 2027	≥50% renewable energy OR ≥50% waste heat OR ≥75% high-efficiency cogenerated heat OR ≥50% of a combination	≤200 gCO_2/kWh
From 1 Jan 2028	≥50% renewable OR ≥50% waste heat OR ≥80% cogenerated OR ≥5% renewable + ≥50% total (renewable, waste heat, cogenerated)	≤150 gCO_2/kWh
From 1 Jan 2035	≥50% renewable OR ≥50% waste heat OR ≥80% total (renewable, waste heat, cogenerated) with ≥35% renewable or waste heat	≤100 gCO_2/kWh
From 1 Jan 2040	≥75% renewable OR ≥75% waste heat OR ≥95% total (renewable, waste heat, cogenerated) with ≥35% renewable or waste heat	–
From 1 Jan 2045	≥75% renewable OR ≥75% waste heat OR ≥75% renewable + waste heat	≤50 gCO_2/kWh
From 1 Jan 2050	100% renewable OR 100% waste heat OR 100% renewable + waste heat	0 gCO_2/kWh (climate neutrality target)

Waste heat, including waste heat from data centres, is addressed throughout the directive as a key element of energy efficiency. Relevant references and provisions are summarized in Table 3.

Table 3 Waste heat recovery in EED

Provision	Requirement
Mandatory waste heat use (Data Centres)	Data centres >1 MW must recover and utilize waste heat unless proven technically/economically unfeasible
Cost-Benefit Analysis (CBA)	Required for: - Thermal power plants >10 MW - Industrial facilities >8 MW - Data centres >1 MW - Large service sites >7 MW
Exemptions from CBA	Allowed for peak/back-up generators (<1,500 h/year) or data centres already supplying waste heat locally
Infrastructure planning	Existing DHC systems >5 MW (not meeting 2028 targets) must submit plans by 2025 and every 5 years thereafter
Fuel use restrictions (new/refurbished systems)	No increase in fossil fuels (except natural gas) post-refurbishment; no new fossil-fuel sources after 2030
Waste heat mapping & inclusion in heating and cooling plans (Article 25)	Member States must identify and assess waste heat recovery potential from industry, power generation, etc.
Data collection and publication	CBAs must provide and publish technical and geographic data on waste heat sources
Public financial support	Must comply with EU State aid rules if supporting DHC using waste heat

5.1.2. Renewable Energy Directive

In RED III (EC, 2023), district heating and cooling systems are recognized for their potential to provide cost-effective solutions for integrating renewable energy, increasing energy efficiency, and deepening energy system integration. They contribute to the overall decarbonization of the heating and cooling sector, which accounts for approximately half of the Union's energy consumption. The directive explicitly highlights the inclusion of renewable energy sources, as well as waste heat and cold, in these systems

Targets and Increases

Member States are encouraged to increase the share of energy from renewable sources and from waste heat and cold in district heating and cooling by an indicative 2.2 percentage points as an annual average calculated for the period 2021 to 2030, starting from the 2020 share. This increase is a rise from the previous 1 percentage point indicative increase. Member States should lay down the measures necessary to achieve this in their integrated national energy and climate plans. Renewable electricity used for district heating and cooling can be counted towards this annual average increase, with Member States needing to inform the Commission of this intention and include estimated capacities in their plans and reports.

Member States with a share of renewable energy and waste heat/cold in district heating and cooling above 60% may count this as fulfilling the average annual increase. If the share is between 50% and 60%, it may fulfil half of the average annual increase.

Integration of Energy Sources and Waste Heat/Cold:

District heating and cooling networks should increasingly accommodate a wider range of renewable heat and cold sources, such as solar thermal energy, solar photovoltaic energy, renewable electricity-driven heat pumps using ambient energy and geothermal energy, biomass, biogas, and bioliquids.

The integration of thermal energy storage is required as a source of flexibility, greater energy efficiency, and more cost-effective operation.

Waste heat and cold, when supplied from efficient district heating and cooling systems, can count towards partial fulfilment of targets for renewable energy in buildings, industry, and general heating and cooling, and full fulfilment of district heating and cooling targets.

Waste heat or cold delivered via a district heating and cooling operator from another industrial site or building can be included, differentiating it from internal waste heat recovered within the same enterprise or buildings.

Third-Party Access and Cooperation:

Operators of district heating or cooling systems above 25 MWth capacity should be encouraged to connect third-party suppliers of energy from renewable sources and waste heat and cold, or to offer to purchase heat or cold from them based on non-discriminatory criteria.

A coordination framework should be established between district heating and cooling system operators and potential sources of waste heat and cold in industrial and tertiary sectors to facilitate the use of waste heat and cold. This framework should involve dialogue among operators, industrial/tertiary enterprises, local authorities, scientific experts, and renewable energy communities.