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Guidelines

Activity A1.4

Identifying policy drivers for the introduction of circular economy concepts in heating and cooling

May 2026

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Executive Summary

This document aims to provide Green4HEAT partners and other policy makers with practical, evidence-based recommendations for promoting the use of waste heat in district heating (DH) and cooling (DC), including the transition to low-temperature heating networks (LTHN) and the integration of low-grade energy sources.

Overall, the document consists of the following:

- An overview of Green4HEAT project and Activity A1.4.
- Description of the document task, structure and used methodology.
- Explanation of the circular economy concept.
- Definition of policy drivers.
- Analysis of good practices and policies.
- Assessment of the most suitable good practices for adoption.
- Definition of sector and territorial specificities.
- Analysis of applicability.
- Pathway for the transition to LTHN and the integration of low-quality energy sources.
- Recommendations for synergies and most suitable sectors.
- Conclusions.

1. Introduction

1.1. Green4HEAT project

The Green4HEAT project is implemented under the Interreg Europe programme with the aim of promoting the uptake of sustainable heating and cooling solutions across the European Union. This contributes to achieving the goals of the EU Green Deal and reducing CO_2 emissions. The project represents a significant step towards a more sustainable and energy-efficient Europe, fostering the introduction of green technologies and innovations in the heating and cooling sector. More information about the project: https://www.interregeurope.eu/green4heat

Project partners:

1. Region of Eastern Macedonia and Thrace (Greece) (leading partner).
2. Province of Antwerp (Belgium).
3. Vidzeme Planning Region (Latvia).
4. Westpomeranian Region (Poland).
5. Public Regional Energy Entity of Castilla y León (Spain).
6. Pannon Novum West-Transdanubian Regional Innovation Nonprofit Ltd. (Hungary).
7. Public Institution National Regions Development Agency (Lithuania).
8. University of Patras (Greece).
9. Municipality of Postojna (Slovenia).

1.2. Document task, structure and used methodology

This document aims to provide Green4HEAT partners and other policy makers with practical, evidence-based recommendations for promoting the use of waste heat in DH/DC, including the transition to LTHN and the integration of low-grade energy sources.

The document is structured in several interconnected sections that provide a comprehensive vision of the drivers of waste heat, more effective policies, and the procedure for identifying and assessing waste heat sources. The document concludes with broad recommendations for supporting waste heat and circular economy concepts in DH/DC. The principal scheme of the document is presented in Figure 1.1.

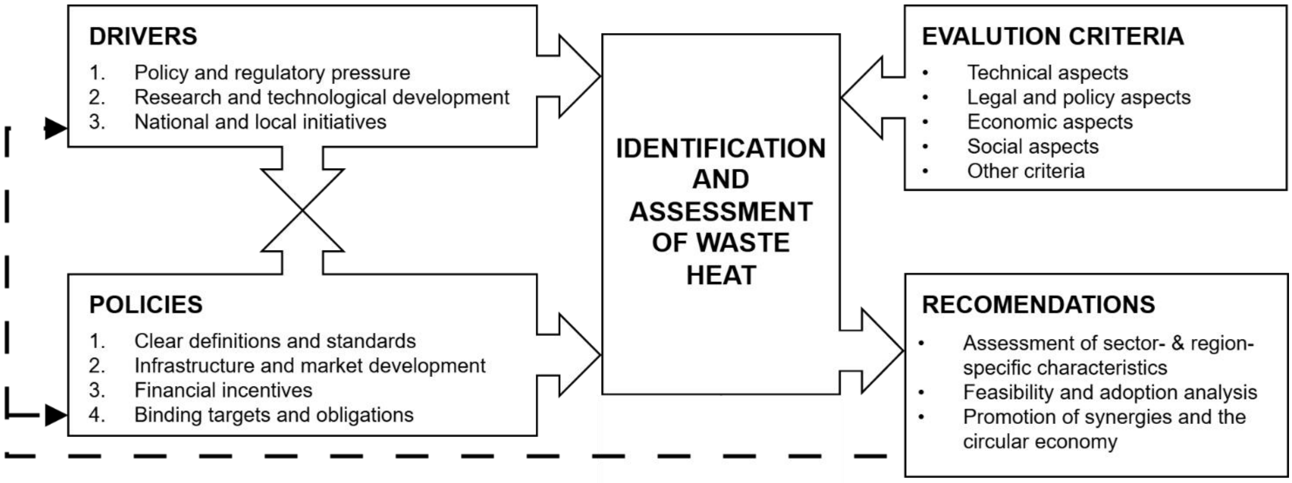


Fig. 1.1. Principial scheme of study performed

The methodology of the document is based on a survey result done by Green4HEAT partners. Survey provides an overview of the existing regulations on waste heat in the partner territories, as well as reflects existing examples of good practice in the use of waste heat. A multi-criteria decision analysis (MCDA) method is used to assess the examples of good practice, which helps to identify the strengths and weaknesses of each example. In addition, the document provides an extensive analysis of scientific literature, regulatory legal acts, national development plans and strategies, which helps to identify the main drivers of waste heat, more significant policies and provide an overview of other examples of good practice. As a result of used methodology, comprehensive and effective recommendations are obtained for policymakers.

Explanation of terms used

The explanation of the terms used in the assignment is provided below:

- CO_2 emissions reduction – Decreasing carbon dioxide (CO_2) released to the atmosphere by lowering fossil fuel use, improving efficiency, or switching to low-carbon energy;
- Greenhouse gas emissions (GHG) – Total emissions of heat-trapping gases (e.g., CO_2, CH_4, N_2O, F-gases), often expressed as CO_2-equivalent;
- Green technologies – Technologies that reduce environmental impacts, such as low-emission energy, efficiency solutions, pollution control, and resource-saving processes;

- Policy makers and policy drivers – Decision-makers (governments, regulators, municipalities) and the instruments that shape outcomes (laws, targets, taxes, subsidies, standards);
- Climate policy – Policies aimed at mitigating climate change (reducing GHG) and/or adapting to its impacts (increasing resilience);
- Circular economy – sustainable development approach that focuses on the efficient use of resources, reducing waste, and preserving the value of materials in the economy for as long as possible. Unlike the traditional linear model (“take-make-dispose”), the circular economy is based on closed cycles in which materials and resources are reused, recycled or recovered [1];
- By-products and secondary energy resources – Residual materials and energy streams from processes (e.g., process gases, residues, surplus heat) that can be used as inputs or energy in other applications;
- Good/best practice – Proven, replicable approaches that deliver effective results. "Best practice" typically refers to the most effective option under comparable conditions;
- Renewable energy sources – Energy sources naturally replenished on human timescales, such as solar, wind, hydropower, geothermal, and sustainably sourced biomass;
- Waste heat – Unused thermal energy released from industrial processes, power generation, buildings, or infrastructure that can be recovered for useful heating/cooling;
- District heating (DH) – Centralized heat production and distribution through a network of insulated pipes supplying multiple buildings or users;
- District cooling (DC) – Centralized cold production and distribution (often chilled water) through a network to provide space/process cooling to multiple users;
- Low-temperature heat sources – Heat sources at relatively low supply temperatures, such as ambient heat, geothermal, waste heat, or return-line heat;
- Low-temperature heating networks (LTHN) – District heating networks designed to operate with lower supply/return temperatures to reduce losses and enable integration of low-grade heat;
- Industrial symbiosis – Collaboration among industries where one company's by-products, waste, or energy streams become another's resources, improving efficiency and reducing impacts;
- Multi-criteria decision analysis (MCDA) and TOPSIS-AHP method – MCDA supports choosing among alternatives using multiple criteria. TOPSIS-AHP combines AHP for weighting criteria and TOPSIS to rank options by closeness to an ideal solution.

1.3. A brief explanation of the circular economy concept

The basic principles of the circular economy (see Fig. 1.2) include reducing resource consumption, extending product life cycles, using secondary raw materials, and turning waste into resources. This approach is considered an essential tool in the transition to a climate-neutral economy, as it reduces the need for primary resources and mitigates greenhouse gas emissions (GHG) [2]. Overall, the circular economy provides a framework that enables a shift from linear to circular resource management, promoting both economic efficiency and environmental sustainability.

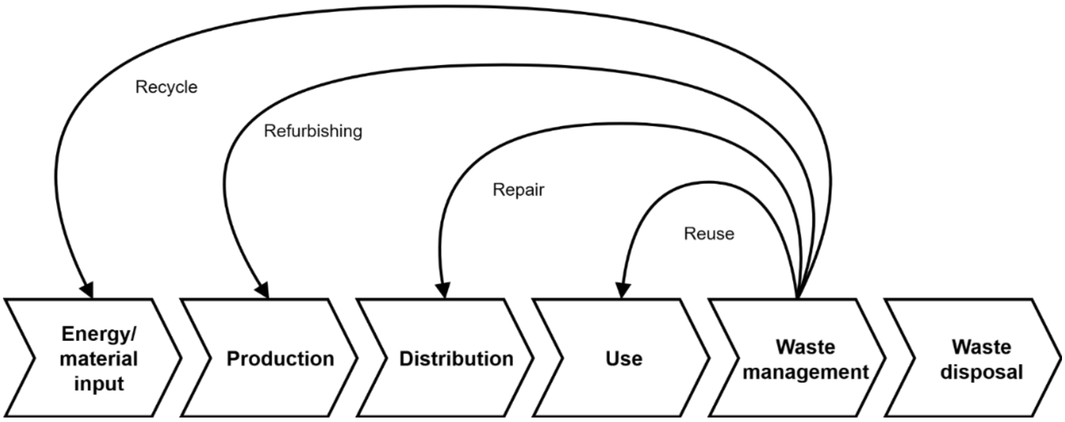


Fig. 1.2. Basic principles of the circular economy

In the energy sector, circular economy principles are reflected in a transition towards more efficient energy use and the integration of waste energy flows between different systems. One of the most important examples is the utilisation of waste heat, where energy is recovered and used, for instance, in DH systems (see Fig. 1.3). In this way, previously unused energy flows are converted into a resource, energy streams become circular, and the overall primary energy demand decreases [3]. In this context, DH systems can be regarded as one of the key infrastructure elements enabling the implementation of circular economy principles in urban areas, because they can integrate waste heat from a variety of origins, including industrial processes, data centres, wastewater, and commercial buildings. Moreover, the circular economy promotes a systemic approach in which cooperation across sectors allows by-products from one system to become resources for another system [4].

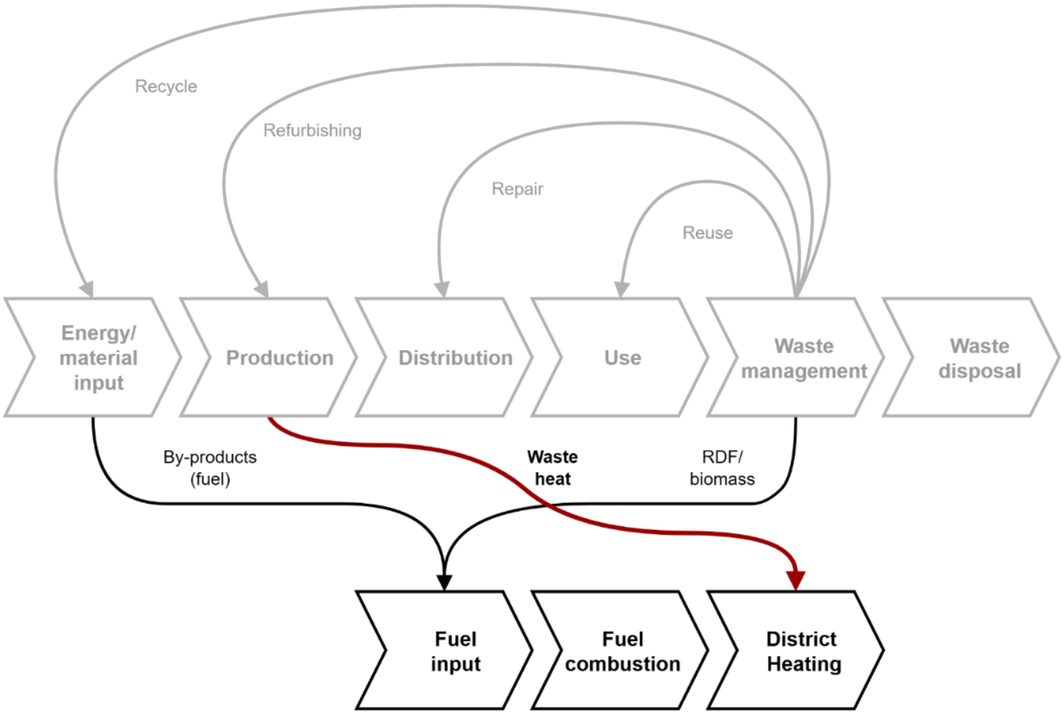


Fig. 1.3. Basic example of integration of circular economy principles in district heating systems

Such cross-sector integration is closely linked to the concept of industrial symbiosis, which is considered one of the practical mechanisms for implementing circular economy principles. The effective use of waste heat depends on its quality and on the technological options for integrating it into heating systems, for example, by using heat pumps to upgrade low-temperature heat [5]. This approach makes it possible to utilise even low-temperature heat sources. Studies on the waste heat potential of data centres show that a substantial share of consumed electricity ultimately dissipates as heat and, without recovery, is released into the environment. Integrating this heat into DH, using heat pumps and appropriate infrastructure, can provide an economically competitive and low-emission heat source. [6]

From a circular economy perspective, this approach aligns with industrial symbiosis principles; DH acts here as a connecting element between different sectors. The integration of waste heat, in combination with renewable energy sources, can significantly reduce CO_2 emissions and improve overall system efficiency [7]. This confirms that waste heat utilisation is not only a technological solution but also a strategic instrument for achieving climate policy and circular economy objectives. Overall, DH systems can be interpreted as a platform for implementing circular economy principles in the energy sector, because they enable (1) converting energy losses into a usable resource, (2) integrating energy flows from different sectors, (3) reducing fossil resource consumption, and (4) supporting the achievement of climate neutrality targets.

2. Policy drivers

The European Union policy framework increasingly highlights the utilisation of waste heat. The *Circular Economy Action Plan* developed by the European Commission sets a direction towards more resource-efficient use, whereby by-products (including waste heat) are reintegrated into the economy.

In the energy domain, this approach is operationalised through the **Energy Efficiency Directive (EED)** and the **Renewable Energy Directive (RED II/III)**, which promote the recovery of waste heat and cold and support the development of efficient DH/DC systems. The International Energy Agency emphasises that the use of such secondary energy resources is among the most cost-effective options for emissions reduction.

The introduction of circular economy principles in DH/DC is driven by several interrelated factors:

- **Policy and regulatory pressure**
  EU directives and climate targets (climate neutrality, energy efficiency) promote the integration of waste heat and set requirements for efficient heating and cooling systems.
- **Climate and emissions reduction targets**
  The need to reduce CO_2 emissions accelerates the transition towards low-carbon solutions, including the use of waste heat in DH systems.
- **Resource efficiency and cost optimisation**
  Using waste heat reduces primary energy consumption and can deliver a more cost-effective heat supply, especially when combined with heat pumps.
- **Technological development**
  Advances in heat pumps, low-temperature (4th generation) DH systems, and digitalisation expand the options for integrating low-quality heat sources.
- **Industrial symbiosis and sector integration**
  Cooperation between industry, data centres, and municipal utilities enables one system's by-products to become another system's resource, creating circular energy flows.

- **Urbanisation and infrastructure availability**
  In densely populated areas, district systems provide an efficient platform for heat collection and distribution.
- **International, national, and local studies and initiatives**
  Transfer and adaptation of international research and experience to national and local contexts.

Overall, the policy framework and technological progress together create the preconditions for DH/DC to become a platform for the practical implementation of circular economy principles, transforming waste heat from a loss into a strategic energy resource. The policy drivers listed above are further examined in this document within the Green4HEAT project territories. Specific policies, drivers and examples of good practice are presented below.

3. Good practices and policy analysis

Waste heat integration into DH/DC is progressing slowly, even though waste heat utilisation is one of the most effective ways to reduce inefficient energy use and the resulting GHG. The main reason is that this is a complex process shaped by a combination of technological, policy, legal, socio-economic, and environmental aspects. Therefore, ensuring effective waste heat utilisation requires an integrated, holistic approach.

This section compiles and analyses legislative and policy aspects that support waste heat utilisation. Existing barriers that hinder waste heat utilisation are identified, and potential solutions are proposed. In addition, the risks associated with the implementation of each policy are analysed. The second section provides practical examples of successful policies and initiatives for waste heat utilisation in DH/DC, helping to better understand the diversity of instruments in each group, their implementation sequence, benefits, and potential barriers. The third section summarises the waste heat examples identified by the Green4HEAT partners. The identified examples are aligned with the previously defined groups of policy instruments.

3.1. Legislative and policy aspects for promoting waste heat utilisation

When reviewing international experience in promoting waste heat utilisation, several **key aspects** can be highlighted that should be considered when designing policy in the field of waste heat.

Clear definitions and standards

Problem: The current national-level regulatory framework related to waste heat utilisation is weak. In regulatory acts, a waste heat definition is often missing, unclear, or contradictory, which hinders investment mobilisation and project development.

Solution: Binding documents should be developed, defining waste heat and specifying:

- Clear classification: Criteria should be established for when heat from industrial processes, data centres, and waste incineration facilities is recognised as waste heat. This is essential so that these sources can be included in national energy efficiency strategies.
- Guidelines regarding the relationship between waste heat owners and DH/DC operators.

Existing risks: There is a risk of introducing overly general definitions and requirements for waste heat utilisation, or, conversely, of setting overly specific requirements. Technologies evolve rapidly, affecting sectoral processes and the associated requirements. It is important to monitor trends and regularly review standards while ensuring transparency and maintaining close dialogue with sector stakeholders.

Promoting infrastructure and market development

Problem: Waste heat utilisation is often dependent on the availability and capacity of DH networks. In addition, standardised contracts and business models are lacking.

Solution: Support the modernisation of DH networks through structural funds and investment programmes, particularly their connection to industrial zones, data centres, and waste processing facilities. Promote the development and deployment of standardised waste heat contracts to reduce transaction costs and make heat transfer between parties simpler and more transparent. Recognise heat communities with a legal status that enables local companies to jointly produce, distribute, and use waste heat locally.

Existing risks: Although network modernisation is essential, there is a risk that funds are not used effectively. It is important that, when integrating waste heat, the efficiency of existing DH production technologies is not reduced due to decreased heat load factors. Due to overly generic standardised contracts and insufficient or ineffective regulation, waste heat projects often stall already at an early stage because of unclear mutual obligations. There is also a risk of unfair contract terms, where the agreement favours one party and causes losses for the other party.

Creating financial incentives

Problem: Waste heat projects require high upfront investments, mainly associated with the construction of heat pipelines. At the same time, operational revenues from delivered waste heat can be low. In addition, electricity prices and tax policy are often unfavourable, which limits the attraction of investments from local and international funds and programmes.

Solution: Review tax policy, including electricity taxes and levies, to make heat pumps and other waste heat technologies more competitive compared to fossil fuels. Establish support instruments that provide grants or low-interest loans and guarantees for waste heat infrastructure projects, with particular attention to municipal initiatives. A third option could be to include certain industries (e.g., waste incineration companies) in the Emissions Trading System (ETS), creating direct financial pressure to reduce emissions and promote heat recovery.

Existing risks: It is important to clearly define the conditions of support programmes so that funding is granted only to eligible activities and measures. Strong monitoring of allocated funds and feedback on the effectiveness of funding utilisation are needed. At the same time, it is important to avoid imposing an unreasonably high administrative burden that would discourage industrial and energy-sector actors from participating in support programmes. An additional risk relates to market distortion due to the redirection of funds into a sector. It is important to spread investments more evenly over a longer period to mitigate the risk of price increases in the sector.

Binding targets and obligations

Problem: Currently, waste heat utilisation largely depends on individual business initiatives, and there is no unified pressure that would require industrial and energy-sector actors to act.

Solution: Introduce mechanisms that restrict the non-utilisation or non-delivery of waste heat on the one hand and prevent refusal to accept waste heat on the other hand, in cases where there is an economically and technically justified possibility to use it in DH.

Existing risks: One of the key barriers is incomplete legal regulation. Each waste heat source and its potential users must be assessed individually, and the regulation tailored to the specific case. This creates an additional burden and a risk of errors. Weakly controlled mechanisms and agreements without thorough economic analysis can lead to the opposite outcome – not cheaper heat, but additional costs for both the DH company and end consumers.

3.2. Practical examples and successful policies

Promoting infrastructure and market development

Heat communities. Denmark is one of the world leaders in waste heat utilisation in DH. This is achieved through a set of interrelated mechanisms, where the applied instruments complement each other. An important instrument is heat communities, which enable the transfer of waste heat from industry to the municipality through a community agreement. A good example is the cooperation between the cement plant "Aalborg Portland" and the utility company "Aalborg Forsyning". This public-industrial partnership has been operating for several years. Heat generated in the plant's production process is not released to the atmosphere but is captured and delivered into the city's DH network. As a result, this waste heat covers approximately 20 % of the utility's total demand, provides heat to around 30,000 households, and reduces CO_2 emissions by 150,000 tonnes annually [8].

In Sweden, a good practice example is the utilisation of waste heat from the MAX IV research facility, a national electron accelerator laboratory located in Lund (southern Sweden). Through cooperation between the energy utility Kraftringen and the Municipality of Lund, a strategic partnership has been established around MAX IV. Warm water (at ~ 30–50 °C) from MAX IV is transferred to Kraftringen's energy centre, where heat pumps raise the water temperature to an optimal level of ~ 65 °C so that it can be used for space heating and domestic hot water in households. The cooled water is then returned to the laboratory to provide cooling for its equipment. In total, MAX IV supplies around 28 GWh of waste heat per year [9].

Creating financial incentives

Investments in climate measures. In many countries, dedicated funds and programmes are established to financially support measures aimed at reducing CO_2 emissions and saving energy resources. Waste heat utilisation is classified under such measures in several countries. For example, Vancouver, Canada, received project support of USD 2.5 million to collect waste heat from the city metro system and deliver it into the DH system. It is expected that the project will provide waste heat to up to 50,000 homes, reducing emissions by 70,000 tonnes of CO_2 per year [10].

In several EU Member States, national programmes provide financial support for the development of infrastructure required to receive waste heat, primarily for the construction of heat pipelines, heat pumps, and other technologies for integrating low-temperature heat sources. Examples include the Heat Fund (Fonds Chaleur) in France and the Federal Funding for Efficient Heat Networks programme (BEW) in Germany [11].

Binding targets and obligations

Binding quotas for data centres. Germany has introduced binding quotas for the utilisation of data centre waste heat. The regulation requires data centres to actively seek ways to transfer heat further instead of simply dissipating it into the atmosphere. Waste heat utilisation from data centres is not regulated directly through binding documents in Finland, but despite this it is treated as a self-evident practice nationally and is implemented at scale. The "Google Hamina" data centre, in cooperation with "Haminan Energia", will supply up to 80 % of the city's heat demand using server-generated heat. In the Helsinki region, the DH system operated by Gren (ex Fortum) receives heat from a "Microsoft" data centre. This waste heat covers approximately 40 % of heat demand, providing heat to around 250,000 users [12].

Ireland, in turn, distinguishes categories of DH in its regulatory framework; the "efficient" category includes DH systems that use at least 50 % renewable energy, 50 % waste heat, or 75 % heat from cogeneration [13].

In Belgium (Flanders), regulation and public support increasingly aim to avoid a lock-in effect to fossil or insufficiently decarbonised heat sources [14]. In the 2025 support context, DH expansions based on waste heat from waste incineration were discouraged; for example, the Flemish Government refused a major subsidy application for the Antwerp South DH expansion supplied by the ISVAG incinerator, explicitly referring to lock-in risk and misalignment with the policy direction to reduce incineration capacity towards 2030. At the same time, Antwerp is moving towards "open access" DH models (e.g., the Antwerp North Heat Network), allowing waste heat to act as a transitional source while enabling later switching to more sustainable suppliers as alternatives become available [15].

3.3. Practical examples from Green4HEAT partner territories

A total of 9 case studies from 8 counties were analysed. While examples reflect different national contexts and levels of waste heat implementation, all case studies demonstrate a clear connection to EU energy efficiency goals.

- A1: Finland (waste heat from data center) - non-project area example, reviewed during the Green4HEAT online working group on 27 February. Waste heat utilization from a data center in Kajaani. Data centers act as a heat provider for the local district heating network. Since the temperature of data centre waste is low (~ 30 °C), industrial heat pumps are used to increase the temperature to around 85 °C. The project includes six industrial heat pumps with a combined heat capacity of 18–30 MW. The data center is located directly next to the district heating plant, reducing transfer heat losses, technological complexity, and related infrastructure costs.
- A2: Lithuania (waste heat from supermarkets) – the national approach to waste heat planning highlights the need to review waste heat policies systematically. Mapping heat sources, establishing national registers, and clear regulations would allow for more effective planning and integration of waste heat into the centralized heat supply network. Currently, the main focus in Lithuania is on developing policy instruments to support already widely implemented waste heat integration projects;
- A3: Poland (waste heat from waste incineration) – EcoGenerator is an example of good practice in successfully integrating waste heat (approximately 25000 – 30000 MWh/year) from exhaust gases, where heat pumps increase output water temperature to a maximum of 105°C in winter. A key success factor is that the waste heat source is already part of the municipal heat supply system, meaning less complex cooperation with external market participants. Only obstacles remain in technical issues, which include heat flow optimization and maintaining system efficiency;
- A4: Greece (Feres) (waste heat from natural gas compression station) – the Feres project highlights the policies supporting the project, and the use of waste heat is linked to the EU Energy Efficiency Directive and national targets. Potential recovery of waste heat from natural

gas compression station shows a high technical potential, with approximately 65000 MWh/year waste heat at a suitable temperature level (80 – 120 °C). However, despite clearly established regulations, project implementation is still limited by several practical factors, such as insufficient infrastructure, lack of funding, and the absence of specific regulations regarding the integration of waste heat into heating networks;

- A5: Greece (Lemnos) (waste heat from combined heat and power plant) – BIOG-Lemnos project used a biogas CHP unit as a potential waste heat source. Agroculture waste and municipal biowaste could be used to produce biogas that would provide electricity and recoverable waste heat. The project could provide around 900 MWh/year of excess heat with a suitable temperature (85 – 95 °C) for district heating system, meaning no temperature increase would be necessary. However, the project is still in the development stage, and implementation depends on financing and local heat network infrastructure availability.
- A6: Hungary (waste heat from car production facility) – Audi's factory illustrates a completely different approach to utilizing waste heat (around 5000 MWh/year), where it is primarily used for on-site consumption. Regulatory frameworks and definitions remain unclear and do not fully address this specific practice, in which waste heat is used to meet the factory's thermal energy demand. The unclear objectives of the political drivers create significant barriers to further project development and integration into the centralized heat supply network; however, they do not restrict current practices;
- A7: Belgium (waste heat from industrial park) – The Warmte Verzilverd project primarily reflects support for the use of waste heat. The project has a farouable technical solution, as industrial waste heat is available at around 90 °C and can be directly integrated into district heating, where connection to 158 residential houses and 5 businesses has been made. Nevertheless, in practice, the implementation steps are relatively complex and fragmented. Legal restrictions affect cooperation between heat producers and network operators, and the financing conditions are complex, thereby negatively impacting project development and the availability of support mechanisms;
- A8: Latvia (waste heat from data centre) – The project to integrate waste heat from the Salaspils data centre has been implemented similarly to the Slovenian model, where the implementation in Salaspils is based on EU sustainability policies and close cooperation with the DH operator. The expected waste heat output (~ 30 – 80 °C) is around 2 MW, which could provide heat for up to 400 houses or 1000 apartments. The project involves cooperation between the Heat Supply Company and the data center. The driving forces of the project are the companies themselves, concluding a joint agreement that will promote benefits for each participant, as well as for the public, as the ultimate beneficiary of the potential reduction in heat tariffs. The state is not directly involved in the implementation of the project;
- A9: Slovenia (waste heat from steel production facility) – The integration of industrial waste heat into the DH system is being successfully implemented in line with the EU's energy efficiency and decarbonization goals. Waste heat covers around 41% (8611 MWh/year) of DH demand, with a temperature range from 60 – 90 °C, allowing integration without major temperature lift. This good practice project has been in operation since 2016 without significant legal or political obstacles, ensuring a stable operational system.

Summary. All selected examples are mainly driven by companies, municipalities, and DH companies, creating mutually beneficial agreements and cooperation models (category "Promoting infrastructure and market development") and, in some cases, attracting support from national infrastructure development programs (category "Creating financial incentives"). Results clearly show that it is possible to implement the integration of waste heat even in the current situation without additional taxes and requirements from the state (policy instruments from the category "Binding targets and obligations”). At the same time, to increase the number of successful examples and ensure a significant proportion of waste heat in DH, it is also recommended to use tools from this category.

4. Most suitable for adopting good practices

This section presents a good pratice analysis based on examples identified by the Green4HEAT partners. The assessment was carried out using two approaches: a MCDA method and a voting method. First, a methodology for identifying waste heat was developed. The methodology requires a pre-assessment to determine the most relevant parameters associated with the waste heat source under consideration. In total, 14 indicators are defined, grouped into five categories, providing a comprehensive overview of waste heat (see Fig. 4.1). A detailed description and justification of the indicators are provided in the methodology document “Activity A1.4 Identifying policy drivers for the introduction of circular economy concepts in heating and cooling”.

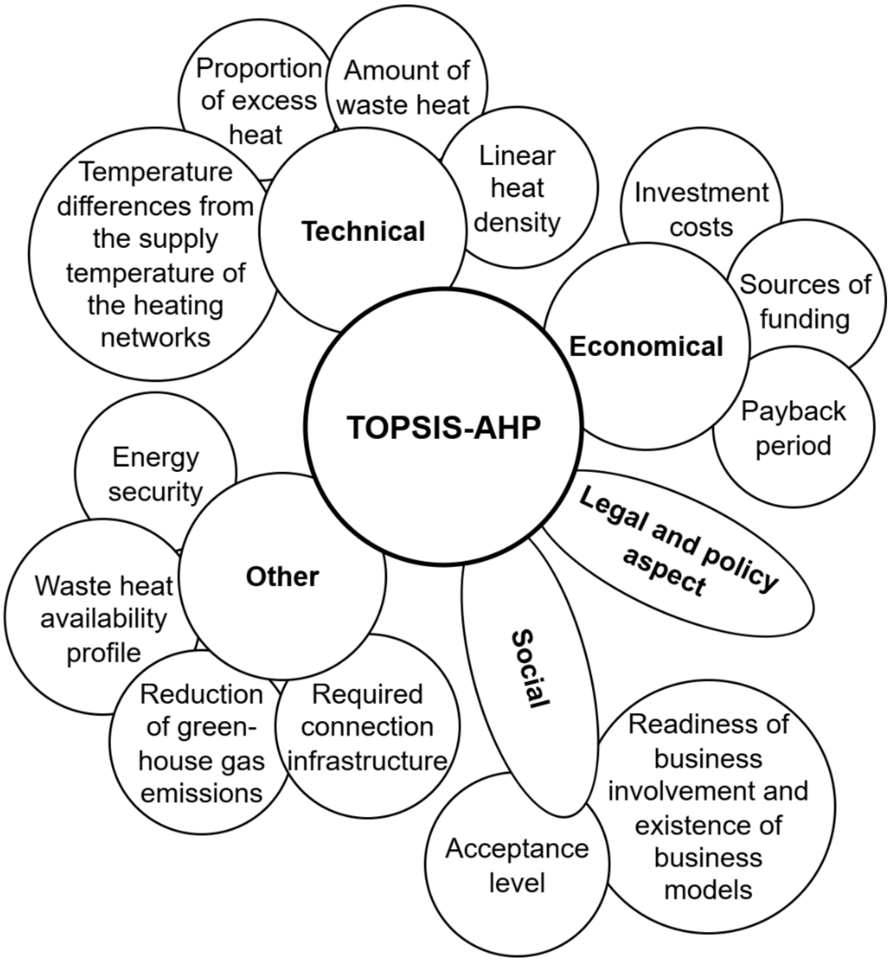


Fig. 4.1. Indicators included in evaluation

4.1. Multi-criteria decision analysis method

After determining the value of each indicator, the project partners complete a questionnaire describing their waste heat source. The results are then compiled, processed, and compared against each other.

A brief overview of the data processing workflow and an assessment of the resulting outcomes is provided below. The TOPSIS-AHP method was used in this study to evaluate the selected waste heat alternatives (different solutions). A summary of the methodology is presented in Figure 4.2.

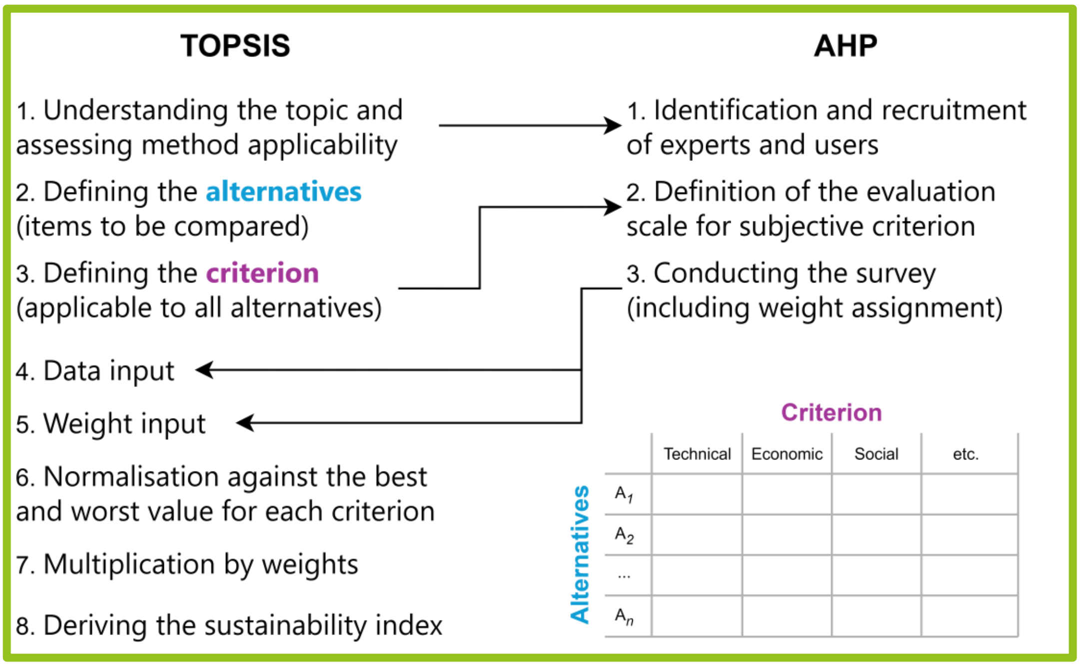


Fig. 4.2. Summary of the TOPSIS-AHP method

The decision matrix (X_{ai}), where a indexes alternatives and i indexes criterion. Each criterion is labelled as benefit (+) or cost (−). To compare heterogeneous units on a common, dimensionless scale, vector normalisation to obtain intermediate normalized value (r_{ai}) was used:

$$r_{ai} = \frac{x_{ai}}{\sqrt{\sum_{a=1}^{m} x_{ai}^2}}, \tag{1}$$

Weighted normalized values (v_{ai}):

$$v_{ai} = w_{ai} \cdot r_{ai}, \tag{2}$$

Ideal and anti-ideal solutions by criterion sign:

$$\begin{aligned} For\ i \in (+)\!: \quad p_i^* &= \max(v_{ai}), \quad p_i^- = \min(v_{ai}) \\ For\ i \in (-)\!: \quad p_i^* &= \min(v_{ai}), \quad p_i^- = \max(v_{ai}) \end{aligned}, \tag{3}$$

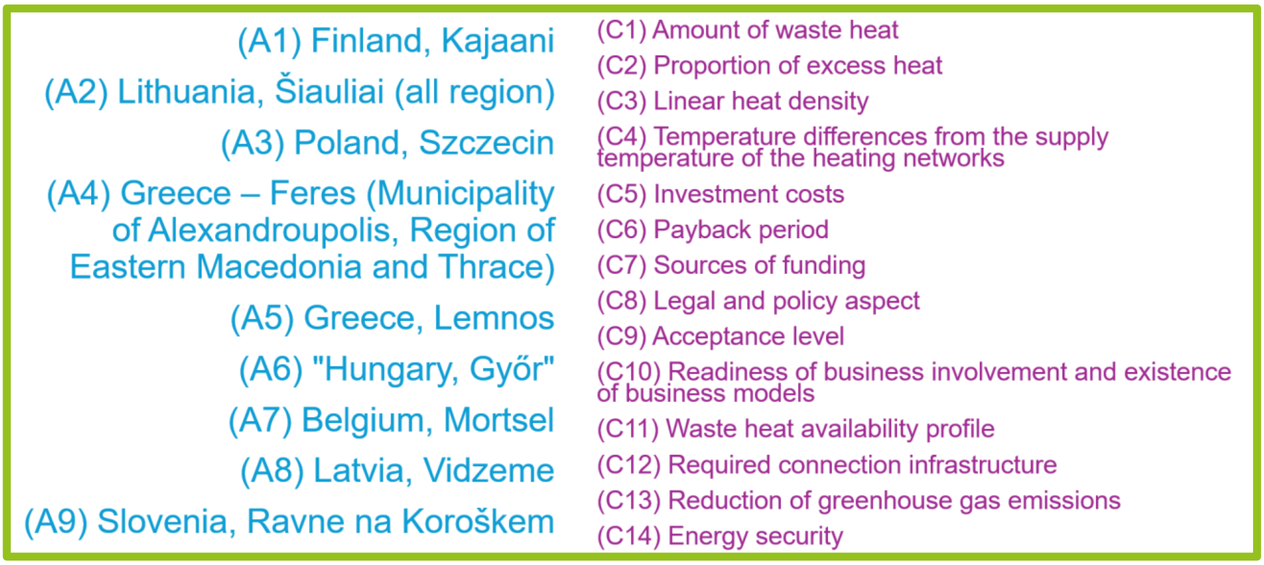
Distances to ideal and anti-ideal (Euclidean metric across criteria):

$$\begin{aligned} For\ ideal\!: S_a^* &= \sqrt{\sum_{i=1}^{n} (v_{ai} - p_i^*)^2} \\ For\ anti - ideal\!: S_a^- &= \sqrt{\sum_{i=1}^{n} (v_{ai} - p_i^-)^2} \end{aligned}, \tag{4}$$

Relative closeness:

$$C_a = \frac{S_a^-}{S_a^* + S_a^-} \tag{5}$$

The alternatives (Ax) and criteria (Cx) included in the evaluation are shown in Fig. 4.3.



(A1) Finland, Kajaani
(A2) Lithuania, Šiauliai (all region)
(A3) Poland, Szczecin
(A4) Greece – Feres (Municipality of Alexandroupolis, Region of Eastern Macedonia and Thrace)
(A5) Greece, Lemnos
(A6) "Hungary, Győr"
(A7) Belgium, Mortsel
(A8) Latvia, Vidzeme
(A9) Slovenia, Ravne na Koroškem

(C1) Amount of waste heat
(C2) Proportion of excess heat
(C3) Linear heat density
(C4) Temperature differences from the supply temperature of the heating networks
(C5) Investment costs
(C6) Payback period
(C7) Sources of funding
(C8) Legal and policy aspect
(C9) Acceptance level
(C10) Readiness of business involvement and existence of business models
(C11) Waste heat availability profile
(C12) Required connection infrastructure
(C13) Reduction of greenhouse gas emissions
(C14) Energy security

Fig. 4.3. Alternatives and criteria used in the evaluation

The criterion values were collected through a survey conducted from 2026-01-26 to 2026-02-27. Representatives of each alternative provided the available information, while missing data were substituted with the average value of the respective criterion across the remaining alternatives. Criterion weights were assigned by experts through a survey held during the Green4HEAT partner workshop on 2026-02-27. All criteria were assessed for their importance. The highest average weight was assigned to “legal and policy aspects” (4.09), while the lowest weight was assigned to “proportion of waste heat” (2.82) (see Fig. 4.4).

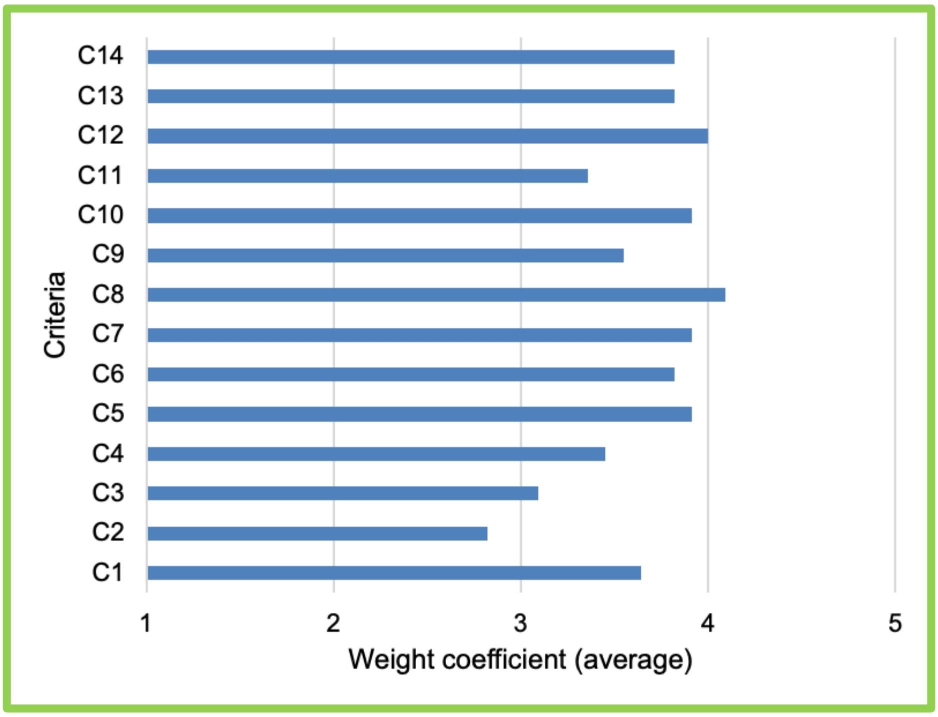


Fig. 4.4. Average weight coefficient of each criteria (legend for the criteria titles is provided in Figure 4.3)

The evaluation results are presented in Figure 4.5. The highest sustainability index was assigned to the A9: Slovenian case (waste heat from steel production facility) (0.684), followed by the A2: Lithuanian case (waste heat from supermarkets) (0.666). The lowest sustainability index was found for the A3: Polish case (waste heat from waste incineration) (0.429) and the A8: Latvian case (waste heat from data centre) (0.317).

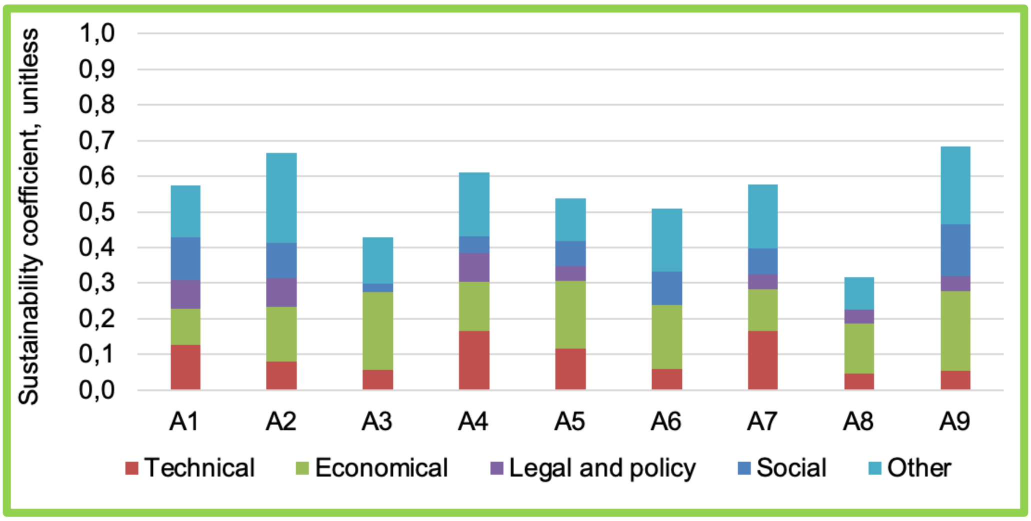


Fig. 4.5. TOPSIS-AHP results (legend for the alternative titles is provided in Figure 4.3)

The TOPSIS-AHP category scores show clear high and low contributors within each criterion group, which can be interpreted as relatively harder (higher score, more influential/stricter) versus easier (lower score, less influential/weaker) requirement groups for the compared options. In the Technical group, the highest scores are for A7: Belgian case (waste heat from industrial park) (0.167) and A4: Greece (Feres) case (waste heat from natural gas compression station) (0.166), while the lowest score is for A8: Latvian case (waste heat from data centre) (0.046), indicating that technical requirements are easiest to satisfy (or most strongly supported) in A7: Belgian and A4: Greece (Feres) cases and weakest (hardest to satisfy or least supported) in A8: Latvian case (waste heat from data centre). In the Economical group, the highest scores are for A9: Slovenian example (waste heat from steel production facility) (0.224) and A3: Polish case (waste heat from waste incineration) (0.217), whereas the lowest score is for A1: Finnish case (waste heat from data center) (0.103), suggesting that economic requirements are the most demanding and most decisive for A9: Slovenian example (waste heat from steel production facility) and A3: Polish case (waste heat from waste incineration), while A1: Finnish case (waste heat from data center) is the least economically favourable case. In the Legal and policy group, the maximum score is only 0.080 and the minimum is 0.000, with most options clustered at 0.040, which implies that legal/policy requirements are comparatively easy to meet or weakly differentiating in this dataset, except for the zero-contribution cases. In the Social group, A9: Slovenian example (waste heat from steel production facility) has the highest score (0.146) and A8: Latvian case (waste heat from data centre) has the lowest (0.000), meaning that social requirements are strongest (harder and more influential) for A9: Slovenian example (waste heat from steel production facility) and weakest for A8: Latvian case (waste heat from data centre), with A3: Polish case (waste heat from waste incineration) also low (0.023). In the Other group, A2: Lithuanian case (waste heat from supermarkets) has the highest score (0.254) followed by A9: Slovenian example (waste heat from steel production facility) (0.220), while A8: Latvian case (waste heat from data centre) is again the lowest (0.091), indicating that "Other" factors are highly demanding and strongly differentiating for A2: Lithuanian and A9: Slovenian cases, but least constraining for Latvian case (waste heat from data centre). Overall, the categories that most often represent harder-to-satisfy or more decisive requirements are Economical and Other (largest top scores and clearer separation), Technical and Social are moderately differentiating depending on the option, and Legal and policy is generally the easiest/least differentiating category due to its low level and narrow spread across options.

The created tool is universal, freely available and customizable for each Green4HEAT partner [16]. It is possible to supplement the tool with new waste heat examples, change the importance of existing criteria, or introduce new criteria, or remove some of the existing criteria.

4.2. Voting method

In parallel with the completed survey on the identified waste heat example, each Green4HEAT partner prepares a presentation, which is presented at the Green4HEAT partner workshop. During the online meeting, an interactive voting session was conducted in which participants evaluated all partner-provided good practice examples. The voting was based on a numerical scale from 1 to 5. A total of 13 respondents participated in the vote. As shown in Figure 4.6, the average scores for all alternatives were above 4.0, indicating an overall positive perception of the presented solutions. The highest average score was received by the Belgian example (4.7), followed by Slovenia (waste heat from steel production facility) (4.6) and Poland (4.6). The lowest average score was assigned to the example from the Greek Region of Eastern Macedonia and Thrace (4.1). Overall, the voting results show that the participants appreciated clear, practically implemented, and well-structured solutions. The Belgian solution was recognized as the best for several reasons:

- A clear governance model involving municipalities, businesses, and the community.
- A detailed description of technical and financial aspects.
- Demonstrated high replicability in other regions.
- Transparent cost structure and representation of heat flows.

- Emphasis on fast implementation opportunities.

Partners particularly highlighted that the Belgian solution demonstrates simple yet effective steps for using waste heat without requiring substantial upfront investment. At the same time, it should be noted that the initial investments for the company that supplied the surplus heat were lower due to the fact that the participating energy cooperatives had to cover certain costs. This makes the example especially attractive for regions with limited resources. Cooperation between local decision-makers and the business sector was also positively evaluated.

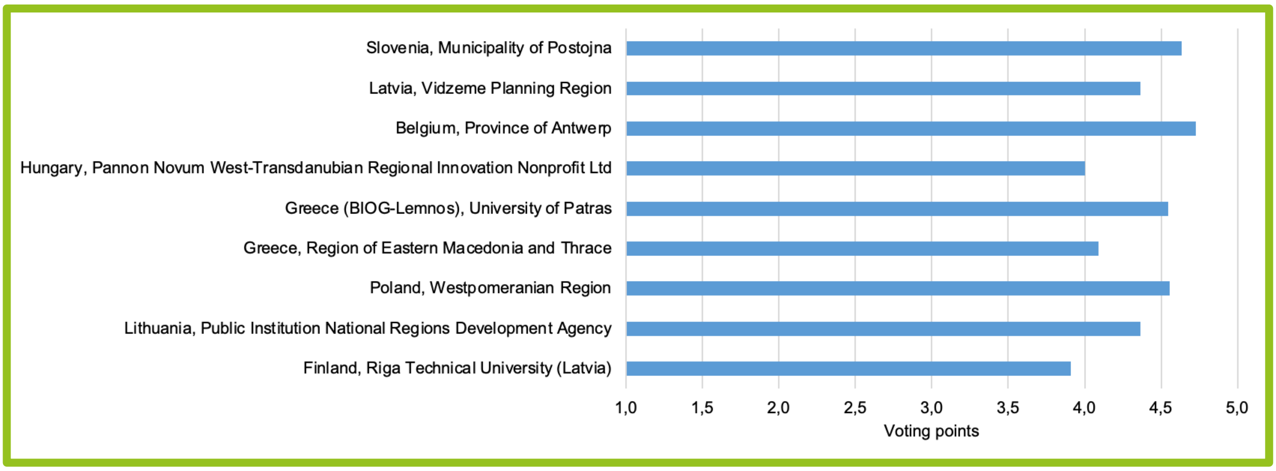


Fig. 4.6. Good practice assessment by partner voting method

When comparing the voting results with the formal TOPSIS-AHP evaluation, several correlations can be observed:

- Regions with stable political and regulatory environments (Belgium, Slovenia (waste heat from steel production facility), Lithuania) were also rated higher in subjective voting. This corresponds to the fact that “legal and policy aspects” received the highest weight in the formal analysis.
- Solutions with clear funding opportunities and existing cooperation models received higher scores. This correlates with criteria C7 (sources of funding) and C10 (business involvement).
- Regions with a well-developed DH sector received higher scores because their implementation risks were perceived as lower.
- Solutions requiring significant regulatory changes were assessed more cautiously, even if their technical potential was high.

This indicates that participants considered not only technical optimization but also the realistic feasibility of implementing the solution within the local regulatory and market context. Integrating the TOPSIS-AHP results with the subjective voting data, the following conclusions can be drawn:

- The A9: Slovenian (waste heat from steel production facility) and A2: Lithuanian (waste heat from supermarkets) cases are the most balanced from a sustainability perspective and are suitable for long-term heat planning needs in other regions.
- The A7: Belgian case is the most suitable for fast deployment and replication. It is characterized by practical orientation, a clear process, and an effective governance model. At the same time, such examples are not common. Also, to adopt this example, it is necessary that the prerequisites are met.
- The A1: Finnish and A5: Greek (Lemnos) cases are useful in specific conditions, such as sparsely populated areas or island regions with unique heat-source configurations.

- The A8: Latvian (waste heat from data centre) and A3: Polish cases (waste heat from waste incineration), although receiving lower index values, provide important insights into data availability, market barriers, and regulatory challenges, which are essential for policy development.

The most suitable practices for further transfer to Green4HEAT territories are:

- Belgium (Mortsel) as the most effective solution in terms of replicability,
- Slovenia (waste heat from steel production facility) as the most sustainable solution according to the multi-dimensional assessment,
- Lithuania (Siauliai) as a technically and economically balanced and adaptable solution.

5. Sectoral and territorial specificities

This subsection reflects the specifics of sectors and territories in relation to the use of waste heat. The first section (5.1) identifies several sectors with the greatest potential for transferring excess heat to district heating. The technological characteristics of each sector are reflected, as well as examples of the use of excess heat in each sector are provided. The second section (5.2.) pays attention to territorial factors, analyzing whether there are differences between the use of excess heat in urban and rural areas.

5.1. Sector-specific context

Industrial sector, data centers, wastewater treatment plants, the commercial sector, and the energy sector are the most significant sources of waste heat. Each sector has its own specific characteristics, advantages, and disadvantages.

In this chapter, best practice examples across different sectors (industry, data centres, wastewater treatment, commercial and energy sectors) are primarily analysed through their technical parameters and characteristics of waste heat. This approach is deliberate, as key technical indicators—such as temperature level, stability of heat flow, seasonal availability, and distance to potential end-users—determine the actual potential for establishing cooperation models and synergies between stakeholders.

Therefore, synergies between companies, cooperation between companies and residents, as well as public–private partnerships cannot be considered independently of the technological context. It is precisely the combination of these technical parameters that defines whether solutions such as industrial symbiosis, integration into district heating systems, or local heat utilisation at the building level can be effectively implemented.

In the following subsections, each sector is analysed individually by identifying its specific waste heat sources, their characteristics, as well as associated benefits and risks. This structure allows not only for the assessment of technical potential but also for the indirect identification of the most suitable cooperation and synergy models that can be developed within each specific context.

5.1.1. Industrial sector

Main waste heat sources:

- Flue gases/hot air from boilers, furnaces, dryers, melting and thermal treatment equipment.
- Process cooling (compressors, chillers, reactors), oil/water cooling loops.

- Condensate from steam systems.
- Compressed-air systems (compressor heat).
- Refrigeration systems in the food industry.

Typical temperature levels:

- Low temperature: ~ 25–60 °C (cooling, chillers, condensers).
- Medium temperature: ~ 60–150 °C (hot water, condensate, part of drying processes).
- High temperature: ~ 150–>500 °C (furnaces, flue gases, metallurgy, glass, etc.). [17], [18]

Advantages:

- Large capacity potential and often high temperature level (higher exergy).
- Possibility to implement cascading within the plant site.
- In many cases, direct heat recovery with heat exchangers is possible without heat pumps (if the temperature is sufficient).

Disadvantages and risks:

- Heat capacity is not guaranteed due to changes in production output.
- Integration complexity for the industrial operator.
- Industrial sites are often outside densely populated areas; distance to DH can make the project unviable.
- Risk of source contamination, affecting technology selection.

Examples: One widely applied approach for utilising waste heat is on-site use, where waste heat is recovered for the facility's own needs, primarily space heating. For example, at Audi's plant in Hungary, the main heat supply is already based on an environmentally friendly source - geothermal energy - covering around 90–95 % of the heat demand (~ 82,000 MWh/year). The remaining share, about 5.5 %, is provided by efficiently recovering waste heat (5,000 MWh/year) from compressor cooling, which is then used for space heating and domestic hot water preparation. Implementing such solutions reduces the company's primary energy consumption and CO_2 emissions. A clear CO_2 reduction impact is also demonstrated by the EcoGenerator project in Szczecin, Poland, where recovered waste heat comes from a municipally operated waste incineration facility. The recovered heat enables an annual reduction of about 12,000 tonnes of CO_2 by replacing 5,000 tonnes of coal per year. The recovered waste heat, accounting for roughly 2 % of total heat demand (25,000–30,000 MWh/year), is integrated into the city's DH network. In example from Slovenia, a steel production company supplies waste heat (~ 8,611 MWh/year), covering approximately 41 % of the city's DH demand.

5.1.2. Data centres and digital infrastructure

Main waste heat sources:

- Cooling of servers, data storage, and network equipment.
- UPS and power electronics (inverters), distribution cabinets.
- Telecommunications nodes, 5G base stations.

Typical temperature levels:

- Air cooling: exhaust air heat is often ~ 20–40 °C.
- Water/liquid cooling: can reach ~ 40–60 °C and, in some solutions, higher. [19]

Advantages:

- Stable and predictable heat release over the year (relatively low seasonality).
- Heat arises in a concentrated cooling loop and can be recovered with heat exchangers.
- Electricity consumption can become a base-load heat source, but for a LTHN.

Disadvantages and risks:

- Low temperature level.
- Seasonality of heat demand – waste heat continues to arise even when heat demand is low.
- Security and access regimes – high security requirements complicate operation and third-party access.

Examples: In Finland, the Kajaani data center uses heat pumps that raise waste heat to approximately 85 °C, in accordance with the heating network's requirements, thereby significantly increasing the amount of technologically recovered waste heat to as much as 30 MW. In Latvia, the heat generated by the data center (~ 2 MW in the temperature range of 30–80 °C) is redirected to the DH system, providing heat for up to 400 private homes or ~ 1,000 apartments, resulting in lower heating costs for residents. Similarly, in Belgium, by utilizing heat waste from various industrial companies, it is possible to provide thermal energy to 158 households and 5 businesses, fostering successful collaboration between companies, residents, and energy cooperatives.

5.1.3. Wastewater treatment

Main waste heat sources:

- Heat of treated wastewater at outlet and inlet.
- Heat rejected by aeration and pumping systems.
- Heat from biological processes.

Typical temperature levels:

- Wastewater: ~ 10–30 °C (depends on season, infiltration, share of industrial contamination).
- Treatment: ~ 30–80 °C (depends on operating regime). [20]

Advantages:

- Wastewater generation intensity is relatively continuous.
- Good heat source for LTHN and heat pumps.
- Easier integration of systems related to heat diversion.

Disadvantages and risks:

- Low temperature level.
- Wastewater treatment plants are often outside densely populated areas; distance to DH can make the project unviable.

Examples: In the *Buikslotermeer* project in Amsterdam, an innovative technology is used to recover heat from untreated wastewater in a pressurised sewer pipeline. The project is implemented through a public-private partnership between the housing association Lieven de Key, the wastewater utility *Waternet*, the heat supply company Firan, and the Municipality of Amsterdam. The project provides heat for 600 social rental apartments [21].

5.1.4. Commercial sector

Main waste heat sources:

- Condensation heat from refrigeration equipment (in supermarkets, warehouses, and logistics centers).
- Heat from ventilation systems.
- Heat from kitchens and other food-service-related processes.

Typical temperature levels:

- ~ 20–90 °C (strongly depends on the source, e.g., 30 °C from swimming pools [18]). [22]

Advantages:

- Facilities are located in urban environments, making integration with DH justifiable.
- High potential for covering on-site heat demand.

Disadvantages and risks:

- Low temperature level.
- Diversity of facilities and a wide range of scales.
- Variable operating regimes (e.g., air heating in winter and cooling in summer).
- Legal risk between the building's owner and tenant (e.g., the project is justified but construction works cannot be implemented).

Examples: A Danish example from the town of Augustenborg shows that modernized supermarkets can cover a large share of their heat demand using waste heat from refrigeration systems and deliver the waste heat to the local DH network, effectively becoming a decentralized heat supplier [23]. The CITY2 shopping centre is an example of how a commercial building can become a heat producer for the surrounding community. Residual heat from the shopping centre’s cooling systems is recovered using a 1.3 MW cascade heat pump, which raises the temperature to 70 °C. The heat is supplied to the LTHN system in the Østerby area [24].

5.1.5. Energy sector

Main waste heat sources:

- Heat losses from electricity generation (if not cogeneration).
- Heat losses from electricity distribution-related equipment (e.g., transformers, batteries).
- Intermediate steps in biofuel production (e.g., heat from anaerobic digestion in biogas production).
- Heat losses from hydrogen electrolysis equipment.
- Heat losses with flue gases (if no economizer).

Typical temperature levels:

- Electricity distribution equipment: ~ 55–150 °C (e.g., in an oil transformer, waste heat temperature ~ 70–90 °C [25]).
- Electrolysis equipment: ~ 50–90 °C (from alkaline and proton exchange membrane electrolysers [26]).
- Flue gases: > 100 °C.

Advantages:

- Large-scale capacity and the potential to integrate with DH as a system balancing resource.
- Electrolyser waste heat can become new, concentrated heat sources at specific infrastructure nodes (e.g., ports, industrial parks).

Disadvantages and risks:

- Some waste heat is difficult to capture (e.g., from transformers).
- In the energy sector, energy-efficiency measures to reduce heat losses are often implemented outside the waste-heat context.
- Long investment cycles, regulated tariffs, and high security requirements.
- Hydrogen infrastructure is still under development in many places; therefore, heat availability may be uncertain.

Examples: Hydrogen production via electrolysis generates a waste heat stream as a by-product of the process. In the future, this process is expected to become a significant source of waste heat for DH. Even today, the first implemented examples demonstrate mutual benefits for both the hydrogen producer and the DH operator. In Estonia, the *Utilitas Väo* CHP plant is the first green hydrogen project in the Baltic States; it can produce up to ~ 432 kg of hydrogen per day and delivers the residual heat to the district heating network in Tallinn [27]. An additional example from Germany (Fraunhofer IEG) confirms that recovering waste heat from the electrolysis process and supplying it to DH can improve the economic performance of hydrogen production [28].

Cooperation and synergy models include collaboration between companies (e.g. industrial symbiosis, shared infrastructure), interaction between companies and residents (e.g. utilisation of waste heat in the residential sector, energy communities), as well as public–private partnerships (e.g. infrastructure development, joint investment projects, and regulatory frameworks). The applicability and feasibility of these models are directly determined by the technical parameters of the specific waste heat source, including temperature level, availability stability, and geographical location.

5.1.6. Summary

- Each of the five sectors examined has its own characteristics, which present both advantages and disadvantages regarding the use of waste heat:
- The industrial sector stands out for having the highest temperatures and the largest amounts of waste heat, but it often faces the greatest geographical constraints due to its greater distance from cities or heat consumers.
- Data centres and wastewater are stable sources, but their waste heat has a low temperature, so its utilisation often requires additional technologies (primarily heat pumps), resulting in additional investment and operating costs.
- The commercial sector is located in urban areas, which means there are fewer barriers to connecting waste heat, but it is characterized by fluctuating operating modes, which negatively impact heat management capabilities.
- The energy sector (particularly electrolysis facilities) is a new, promising source, but it is still in the development stage with uncertain heat availability.

5.2. Regional characteristics

Urban environment and industrial areas

The most effective **transfer of waste heat to a centralized heating system is feasible in urban areas where the distances between the waste heat source and the consumer or network are short**. Industrial areas located in densely populated urban areas allow for relatively simple connection to the DH system, thereby reducing the need for major investments in heating networks. There are often cases where, in a dense industrial zone, several waste heat sources are connected to a single branch of a heat pipeline. In this way, it is possible to reduce the necessary investments by spreading them across multiple businesses.

At the same time, there are also risks and limitations. When multiple waste heat sources are connected to a single DH operator, heat management becomes more complex. This is due to the need to develop a system for integrating waste heat into the overall system, forecasting waste heat supply, and coordinating it with existing heat generation technologies. Inefficient management increases the risk of misusing the received waste heat and failing to achieve the planned energy savings.

The selected examples of waste heat can be divided into the following:

Urban areas:

- Finand, Kajaani data centre – waste heat used in the city district heating network. The source is located directly next to DH plants.
- Latvia, Salaspils data centre -waste heat from server operation is planned to be supplied into the “Salaspils Siltums.”

Industrial areas:

- Hungary, Audi factory in Győr – waste heat is used to sustain the industrial facility's hall heating and hot water demand. No connection to public district heating network has been made.

Urban and industrial areas:

- Poland, EcoGenerator Szczecin – waste heat from municipal waste incineration plant is recovered and supplied to the Szczecin municipal district heating network.
- Belgium, warmte verzilvered – waste heat from Agfa-Gevaert Group production process is directly fed into municipal distric heating network due to suitable loacation – dense urban area.
- Slovenia, SIJ Metal Ravne – waste heat from steel production is integrated into the municipal distric heating network.
- Greece, Feres – waste heat from natural gas compressor satation planned to supply wider Feres region with a new DH network

Rural regions and peripheral areas

In rural and sparsely populated areas waste heat-based heat supply is more complex. The main challenges relate to investments in the construction of new infrastructure, primarily the development of heat distribution networks. Long heat supply networks are required to provide heat, and even if the potential for waste heat recovery is high, economic implementation can often be problematic. In Greece, several projects are still in the planning or feasibility study stage and are not being implemented due to high capital costs and a lack of infrastructure. Unfortunately, rural regions often face population decreases and the departure of businesses. This aspect can negatively impact the potential for waste heat utilization. As heat consumption declines, connecting new heat sources (including waste heat) is often not justified.

At the same time, there are also advantages and positive examples. In rural and peripheral areas, it is easier for new industrial facilities to enter the market because land is more readily available and the price per unit of land is generally lower. Furthermore, by connecting to a waste heat source, it is possible to reduce heating costs, which increases the area’s attractiveness for new consumers.

The example of BIOG-Lemnos (Greece) can be included among rural regions and peripheral areas:

- Greece, BIOG-Lemnos – waste heat from a planned biogas CHP unit, where the source would be agricultural residues and municipal biowaste is used for biogas production to generate electricity and revoerable waste heat to support nearby local consumers through a distribution system.

6. Applicability analysis

Introduction and explanation of applicability. Practices for utilizing waste heat can vary significantly across different regions, and their implementation depends on legal, social, economic, climatic, geographical, and other aspects. A total of 14 criteria were identified for identifying waste heat and presented in the document *“A1.4 Identifying policy drivers for the introduction of circular economy concepts in heating and cooling”.* All criteria were divided into 5 groups: technical, social, economic, legal and policy and other criteria. The technical aspect group includes the most criteria. This is because the characteristics of the heat source (temperature, volume, seasonality, etc.), as well as consumer characteristics (distance, density, and capacity of existing DH infrastructure) play an important role in the potential for using residual heat. Climatic and geographical aspects are not listed separately, but are included under technical aspects. Climate directly affects the required heat demand and the required temperatures in the heating network (criterion T4: temperature differences from the supply temperature of the heating networks). Geographical aspects, on the other hand, have the greatest impact on the location of heat residues and consumers and the resulting distances of heat lines. (part of criterion T3: linear heat density). This section presents an applicability analysis that combines various aspects that affect the use of waste heat. Limitations have been mentioned as waste heat utilization practices must be individually adapted to different sectors and regions. At the same time, there are relatively universal technological solutions for integrating heat sources in practice. An assessment of suitability is provided below.

From an organizational and legal standpoint (legal and policy aspects), the most effective example of good practice in most regions is a cooperation model between the owner of the waste heat source (a production facility, commercial enterprise, or other supplier) and the heat distribution network operator, who ensures the collection, transmission, and delivery of the waste heat to end users.

From a technological standpoint (technical aspects), direct heat recovery using a heat exchanger can be defined as a universally applicable practice. This is particularly effective when the waste heat source is located close to the consumer or a centralized heat supply network and the waste heat temperature is suitable for immediate use. Such waste heat often comes from the metallurgy sector or natural gas and biogas cogeneration plants, where waste heat can be directly utilized for feeding into the DH network. For example, waste heat (approximately 60–90 °C) from a steel plant in Slovenia is integrated into the city’s DH network without any temperature increase. This practice has been successful in Slovenia thanks to the plant’s location (an industrial zone adjacent to the district heating network) ensuring low costs and easy waste heat transfer.

A widely used practice is to raise the temperature using heat pumps. Often, the recovered waste heat has a low temperature (approximately 30–40 °C) and cannot be directly integrated into the DH network. With the help of heat pumps, waste heat can be raised from approximately 30 °C to as high as approximately 85 °C, thereby ensuring temperature compatibility with the DH network. This practice has been implemented by the Kajaani data center in Finland; however, the technology is also widely applicable in other sectors where low-temperature waste heat is generated, such as in cooling systems, food processing plants, and other industrial processes where intensive cooling of equipment or technological processes takes place.

Less common, but still widely used, is the practice of waste heat self-consumption, where companies use the waste heat they generate for their own needs or for the local area (climatic and geographical aspects). The self-consumption approach is economically viable in production facilities with a well-developed internal heat supply network. Most often, the heat source is located right where it is consumed, thus allowing the recovered waste heat to be used for its own needs (e.g., room heating), thereby reducing the energy input or fuel consumption of the heat source. This practice is implemented at the Audi production facility in Hungary, where the primary heat source is a geothermal resource that covers most of the demand, while waste heat increases the resource's efficiency. This model can be considered a relatively site-specific principle of energy synergy; however, it is technically adaptable to other heat sources, such as solar collectors, where these heat sources would serve to meet primary or backup heat demand.

On an island or peripheral areas, the use of waste heat is most often limited by the lack of centralized heat supply systems, the construction of a centralized network is limited by lower population density and high construction costs. In such areas, local solutions are most commonly observed, where heat is provided to small groups of consumers or communities. Two Greek project examples illustrate this scenario; one of them is the Lemons project, where a biogas cogeneration plant, utilizing the potential of agricultural, food, and household biowaste, could provide thermal energy; however, no central heating network has been established near the cogeneration plant, and the waste heat is not being utilized. Similarly, in the Feres project, which examines a natural gas compressor station, the potential for recovering waste heat is estimated at up to 65,000 MWh per year. This amount could cover the majority of local heat demand; however, due to the significant investment required, the project is currently stalled at the feasibility study stage. To implement the project, it is necessary to construct approximately 40 km of DH networks, and although Greece generally supports the construction of DH networks, there remains stagnation in the practical implementation of such projects.

7. Technical and policy recommendations for the transition to low-temperature heating networks and the integration of low-quality energy sources

The transition to LTHN systems is a key prerequisite for the efficient integration of low-grade energy sources, such as waste heat from industry, data centres, and wastewater. Such a transition requires both technological improvements and supportive policy and regulatory frameworks. As highlighted in "*A3.1 Workshop Summary Report" (Executive Summary*), LTHN systems are widely recognised as a key technology for improving energy efficiency and enabling the integration of renewable and waste heat sources. [29]

From a technical perspective, the transition can be supported through a set of interrelated measures, including:

- reduction of network temperatures,
- modernisation of building-level heating systems,
- integration of heat pumps,
- connection of decentralised heat sources,
- implementation of thermal energy storage, and
- digitalisation and smart system management.

Reducing supply and return temperatures in DH networks is a fundamental condition for enabling the use of low-grade heat sources, as it decreases distribution losses and broadens the range of usable energy inputs. LTHN (4th generation DH) are specifically designed to operate below ~ 70 °C, thereby significantly improving system efficiency and facilitating the integration of renewable and waste heat [30]. The importance of temperature reduction was also emphasised during the workshop discussions (A*3.1. Workshop Summary Report, Workshop Findings*).

At the same time, building-level adaptations are required, including improvements in energy efficiency and the installation of LTHN such as underfloor heating or appropriately sized radiators. The integration of heat pumps is essential to upgrade low-temperature heat to usable levels, particularly when utilising sources such as wastewater, data centres, and industrial processes. Scientific studies confirm that the combination of heat pumps and building-level improvements enables deeper system-wide temperature reductions and more efficient use of waste heat.

Furthermore, the development of technical solutions for connecting decentralised and distributed heat sources supports the emergence of prosumer-based systems and circular heat flows. This aligns with workshop findings highlighting the need for flexible and interconnected systems rather than reliance on single technologies (*A3.1. Workshop Summary Report, Good Practice Examples*).

Thermal energy storage solutions, including short-term and seasonal storage, play a critical role in balancing supply and demand, especially when integrating variable or intermittent heat sources. In addition, digitalisation and smart control systems enable real-time optimisation of temperature regimes, load distribution, and system efficiency. Both the workshop discussions and scientific literature emphasise that combining storage and digitalisation significantly improves system flexibility and the utilisation of low-grade heat (*A3.1. Workshop Summary Report, Workshop Findings*).

The integration of waste heat is particularly important, as it represents a technically mature and underutilised resource with significant potential to reduce emissions and improve system resilience. The workshop results highlighted the importance of mapping and utilising such resources, which is also strongly supported by recent research on waste heat recovery and utilisation in DH systems.

In parallel, technical measures must be complemented by a supportive policy framework that facilitates implementation. Key policy recommendations include:

- adapting regulatory frameworks to support low-temperature operation,
- introducing targeted economic incentives,
- strengthening integrated energy planning,
- improving data availability and heat mapping,
- developing technical standards and guidelines,
- enhancing institutional capacity and stakeholder collaboration.

Regulatory adaptation should focus on enabling lower temperature regimes and simplifying the integration of distributed and low-grade heat sources into existing networks. As identified during the workshop, one of the key barriers is the early stage of LTHN deployment and limited involvement of private sector actors (*A3.1. Workshop Summary Report, Stakeholder Findings*). This challenge is also reflected in the literature, which highlights regulatory and market barriers as major obstacles to wider implementation.

Economic instruments, such as investment support schemes and risk-sharing mechanisms, are essential to reduce upfront costs and accelerate the deployment of innovative technologies. Integrated energy planning at the municipal level is particularly important to ensure alignment between urban development and DH infrastructure. This includes the spatial coordination of heat demand and available waste heat sources, which was highlighted as a critical factor during the workshop (*A3.1. Workshop Summary Report, Workshop Findings*).

Improving data availability, including systematic mapping of waste heat potential, is essential for informed decision-making and long-term planning. In addition, the development of technical standards and guidelines can support the harmonisation and scaling of solutions, while strengthened collaboration between municipalities, industry, and research institutions facilitates knowledge transfer and innovation.

To support practical implementation, a stepwise approach is recommended. This includes (1) technical assessment of existing systems, (2) mapping of waste heat potential, (3) stakeholder engagement and identification of cooperation models, (4) development of pilot projects, and (5) gradual infrastructure modernisation and system integration. The importance of modelling and scenario-based planning for supporting these steps was emphasised during the workshop (*A3.1. Workshop Summary Report, Workshop Findings*) and is also widely recognised in the literature as a key decision-support tool.

Overall, the transition to LTHN systems should be approached as a systemic transformation that combines technological innovation, policy support, and cross-sectoral collaboration, thereby supporting the implementation of circular economy principles and more efficient use of energy resources.

Presented examples from partner territories and international good practices discussed in Section "Review of best practices and policy framework" clearly demonstrate that the use of waste heat is closely linked to the development of LTHN and the integration of low-quality energy sources.

For instance, in Finland (A1), waste heat from a data centre is upgraded via large-scale heat pumps and integrated into the district heating network, illustrating the importance of temperature reduction and technological adaptation. A similar approach is observed in Latvia (A8), where cooperation between a data centre and a district heating operator enables the utilisation of low-temperature waste heat, highlighting the role of market-driven initiatives.

In contrast, examples such as Poland (A3) and Slovenia (A9) demonstrate that when waste heat is available at higher temperatures, integration into district heating systems becomes technically simpler and more efficient, requiring less temperature lift and fewer system modifications. Meanwhile, cases like Belgium (A7) and Greece (A4) show that despite favourable technical conditions, regulatory complexity, financing barriers, and infrastructure limitations can significantly delay or hinder implementation.

Finally, the example of Lithuania (A2) emphasises the importance of systematic planning, including heat mapping and policy frameworks, as a prerequisite for scaling up waste heat integration at the national level.

Overall, these examples highlight that successful integration of waste heat depends on a combination of temperature levels, technological solutions, infrastructure availability, and supportive policy and regulatory conditions.

8. Recommendations for synergies and most suitable sectors

In thermodynamics, heat is not a property of a substance but a mode of energy transfer that arises due to a temperature difference. In practical energy systems, this means that the usability of heat depends not only on its quantity but also on its quality, i.e., exergy - the higher the temperature level and the better the match to the required consumption temperature, the more effectively heat can be converted into work or delivered as useful heating. Therefore, integrating waste heat is often technically and organizationally more complex than producing heat specifically for DH needs. Typical key barriers are:

- it cannot serve as the only heat source because the temperature must be additionally raised to meet DH requirements,
- variability of flow and capacity over time (daily, weekly, seasonal patterns),
- geographical mismatch (the source is far from the DH network or the heat consumer),
- connection and integration costs,
- allocation of data and responsibilities among the involved parties.

Waste heat utilization should be viewed through the lens of multi-sector synergies: aligning the heat source, the heat consumer, and the infrastructure into a single integrated system.

Principle No. 1: Systematic planning

This approach is closely linked to the circular economy, where the core energy principle is energy cascading: using higher-temperature heat for higher-temperature demands is primary solution, then using the remaining heat for lower-temperature needs as secondary solution, thereby minimizing primary energy consumption and CO_2 emissions as much as possible. Before integrating, it is important to understand the stability, seasonality, and risks of each potential source.

Principle No. 2: Stakeholder coordination

Technological aspects alone are not sufficient to ensure successful project implementation. A shared vision and trust among project participants play a critical role in creating and sustaining synergies. Several measures can support this:

- Long-term contracts (10-20 years) that secure stable cooperation between the heat source owner and DH operators. Such contracts provide the predictability needed for investment decisions and reduce investment risk for both parties.
- Use of a "complementary" heat supply model, in which waste heat covers the base load, while DH-produced heat covers the remaining heat demand (peak and backup). This enables flexible management of fluctuations and guarantees a reliable heat supply.
- Engagement of a neutral coordinator, i.e., an independent project lead positioned "above" the partners, who supports the resolution of legal and financial issues and facilitates alignment across stakeholders.

Principle No. 3: Transparent business models

For a project to be viable, it must be beneficial for all parties involved. This can be achieved through:

- Clear pricing principles that result in a predictable and appropriate waste heat price. The price should be lower than fossil-based alternatives, yet sufficient to motivate waste heat delivery and to cover relevant costs.
- Innovative business models, such as involving energy service companies (ESCOs) or establishing energy cooperatives.

Real examples of sector synergies are most clearly visible where a developed DH network exists and a marketplace for waste heat suppliers has been established. As already mentioned, there are 5 sectors in which significant sources of waste heat can often be identified: (1) data centers and digital infrastructure, (2) industry, (3) wastewater treatment, (4) the commercial sector, (5) the energy sector. Each sector has different strengths and weaknesses in the context of waste heat, and it is precisely the combination of these differences that determines the synergy potential. Several successful examples of synegrigs are presented in the section “Sectoral and territorial specificities”. Additional examples are provided below.

Stockholm is one of the clearest cases, where multiple sector waste heat sources are integrated simultaneously within a single urban system [31]. Stockholm Exergi's "Open District Heating" concept explicitly enables data centres and other urban sources to sell waste heat into the DH network, thereby linking the digital sector with heat supply infrastructure and consumers in one chain [32]. At the same time, Stockholm provides an industrialized example of how the wastewater treatment sector becomes a stable heat source [33]. The Hammarby heat pump plant uses treated wastewater as a low-temperature heat source and, using heat pumps, converts it into DH heat, which helps smooth seasonal demand and improves overall system sustainability [34]. Another synergy example is Odense, Denmark, where data centre waste heat is integrated into DH using large-scale heat pumps [35]. In the case of Meta's (formerly Facebook's) data centre, waste heat is captured in the data centre cooling loop and transported via pipeline to a heat pump, where the temperature is raised to meet DH requirements; as a result, the system supplies heat to thousands of households [36], [37]. In the commercial sector, synergy with DH is most often realized through supermarket refrigeration systems, where cooling creates a large, concentrated heat rejection stream [38]. In the energy sector, a particularly interesting sector coupling is where waste heat arises in electricity distribution infrastructure and is used for DH purposes [39]. A United Kingdom project implements this idea by connecting a substation to a nearby residential heat network and using transformer heat to preheat the heat-pump source side, thereby improving performance and reducing electricity consumption for heat production [40].

Conclusions

The document provides developed guidelines for the utilisation of waste heat in DH/DC in order to promote the transition towards circular economy principles in the energy sector. The document presents evidence-based recommendations. The main target audience includes policy makers as well as municipalities, urban planners, waste heat owners, district heating and district cooling companies, and related organisations.

Waste heat is a significant but largely underutilised resource. Its integration into heat supply networks can substantially reduce primary energy consumption and CO_2 emissions. The key barriers that hinder the use of this resource include:

- High upfront investments in infrastructure;
- Technical complexity of integrating low-temperature sources (e.g., data centres).
- Unclear legal framework and the absence of a clear definition of waste heat.
- Insufficient cooperation between waste heat owners and heat network operators.

Several interrelated drivers have been identified that support overcoming these barriers and enable the implementation of circular economy principles in DH/DC:

- Policy and regulatory pressure that sets GHG reduction targets.
- Research and technological development that creates the technical preconditions for integrating low-temperature sources.
- National and local initiatives, as well as industrial symbiosis, which promote stakeholder cooperation and the development of a supportive business environment.

These drivers are translated into national and local policy instruments. Existing good practice examples for enabling waste heat uptake can be grouped into several main categories:

- Clear definitions and standards, including measures aimed at developing a legally binding framework.
- Infrastructure and market development, including support for network modernisation, the introduction of standard contracts, and the legal recognition of heat communities.
- Financial incentives, which include not only direct financial support but also the review of tax policy and the introduction of grants and low-interest loans.
- Binding targets and obligations, i.e., a set of mechanisms that limit the non-use of waste heat through mandatory requirements.

The document provides a variety of real-world examples of waste heat utilization in Green4HEAT partner territories and beyond. Based on the results of the examples considered, it was:

- A MCDA method has been developed for the assessment of good practice examples, which helps to understand the strengths and weaknesses of each individual case and the potential and obstacles to project implementation.
- The specifics of sectors and territories have been analyzed, identifying the most promising sources of waste heat (industrial sector, data centers and digital infrastructure, wastewater treatment plants, commercial sector and energy sector).
- An applicability analysis has been carried out and opportunities for transferring good practice examples have been identified.
- The need for a transition to LTHN has been demonstrated and recommendations have been developed to promote the transition.

The document concludes with the definition of 3 main synergy principles for the successful use of waste heat in district heating and cooling, which will facilitate the transition to the principles of the circular economy in the energy sector:

- Systematic planning, which involves using the energy cascade principle.
- Stakeholder coordination, which includes concluding long-term contracts, using a "complementary" model to cover the heat load, and attracting neutral coordinators.
- Transparent business models, i.e. clear pricing and the use of innovative models (ESCO, energy cooperatives).

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