A Public Self-Assessment Platform for Power-to-Heat Integration in District Heating: Multidisciplinary Support for Early Decision-Making

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Abstract

This paper presents a public web platform designed to support municipalities and district heating operators in the early planning of large-scale heat pump integration, based on a multidisciplinary methodology combining social science, energy engineering and numerical simulation approaches, calibrated specifically for the Czech district heating landscape to accelerate the energy transition in this region. The platform combines a readiness self-assessment, which helps users identify initial organisational, financial and technical conditions affecting feasibility, with a techno-economic screening tool based on more than 45 000 pre-simulated annual scenarios. Using a small set of inputs, the tool provides estimates of heat pump utilisation, seasonal efficiency, production costs, emissions and indicative investment outcomes. The approach links governance context with realistic operational performance, offering transparent, easy-to-use analysis as a first step before detailed engineering studies. By enabling rapid screening and supporting structured dialogue between municipal authorities and heat suppliers, the platform helps build local capacity and guides users toward viable integration pathways under typical Czech district heating conditions.

Keywords: District heating; Power-to-Heat; Multidisciplinary research; Investment planning; Web-based tool

1 Introduction

District heating (DH) systems are undergoing a critical transformation as countries accelerate efforts to decarbonize local energy infrastructures. Among the key enabling technologies for this shift are large-scale electric heat pumps, which offer a flexible and low-emission alternative to fossil-fuelled heat generation. Despite a strong technical case for Power-to-Heat (P2H) integration, implementation remains slow, particularly at the municipal scale, where early-stage planning is often constrained by limited technical capacity, siloed governance structures, and high dependence on external consultancy.
This work targets the early-phase planning gap faced by municipalities and DH operators in their efforts to electrify heat supply through large-scale heat pumps. Although the environmental benefits of P2H are well established, adoption is frequently delayed by uncertain techno-economical barriers, organizational complexity and often limited internal expertise at municipal management level. These challenges impede municipalities from initiating investment dialogue and coordinating effectively across stakeholders to make informed decisions.
To address this, we developed a public, web-based platform that combines a governance self-assessment module with a techno-economic screening engine for early-stage planning. Before presenting the tool's design, we briefly review relevant literature to underscore the need for multidisciplinary, accessible instruments that can

- empower non-expert municipal actors,
- facilitate communication between planners and decision-makers,

- enable structured investment dialogue, and
- ultimately accelerate heat pump integration under real-world governance conditions.

Heating and cooling account for nearly half of the EU's final energy consumption, yet the sector remains heavily fossil-dependent. Cocciolo [1] highlights that 84% of EU heating demand continues to rely on fossil fuels, making thermal decarbonization central to achieving Fit-for-55 and long-term climate goals. In this context, electrification and sector coupling have become essential strategies. Rambsebner et. al [2] note that P2H technologies, such as heat pumps, are technically capable of providing demand response services to the electricity grid and can therefore deliver emission reductions in both district heating and the electricity sector, although their role is often underestimated or inconsistently defined across policy and modelling studies.

Empirical evidence shows that large-scale heat pumps are technically mature and already widely deployed in European district heating networks, but their techno-economic feasibility remains case dependent and requires significant upfront investment. A survey of 149 systems by David et. al. [3] demonstrates that heat pumps larger than 1 MW operate reliably across diverse heat sources such as wastewater, seawater, and industrial excess heat. Further analyses highlight their economic and operational advantages: Østergaard et. al. [4] shows that low-temperature DH supported by centralized and booster heat pumps can reduce operational costs, while study of Schweiger et. al. [5] identify substantial national-scale flexibility benefits when P2H is paired with thermal storage. Spatially resolved studies such reported by Fambri et. al. [6] emphasize that placing P2H units within electricity distribution networks allows to increase the intermittent renewable electricity sources within the system. Seasonal storage research, including Tosatto's study [7], further shows that coupling heat pumps with large-scale thermal energy storage enhances storage efficiency and reduces emissions in the energy system as whole.

Alongside these technical insights, several studies highlight organizational and social factors that strongly influence implementation outcomes. Research on Thermal Energy Communities in Germany by Hartmann et. al. [8] shows that municipal support, stakeholder alignment, and technical expertise are decisive for project success. Again, Cocciolo's study [1] similarly finds that although EU directives increasingly support community participation, governance and regulatory complexities continue to pose barriers. On the user side, Sovacool et. al. [9] shows that heating practices, cultural norms, and household behaviour play a substantial role in shaping heating transitions. Moreover, publication of Amin et. al. [10] demonstrates that energy system models often overlook such social and institutional dimensions, limiting their practical relevance for local planning.

Taken together, the literature indicates that while P2H and large-scale heat pumps are technically and economically viable, municipalities and DH operators face persistent challenges in early-stage planning: aligning stakeholders, assessing organizational readiness, navigating regulatory constraints, and linking these aspects to technical feasibility. Existing models and studies rarely integrate organizational, economic, and technical dimensions into a coherent workflow accessible to non-experts.

Despite increasing recognition of these barriers, few tools combine governance diagnostics with simplified technical modelling or support structured investment dialogue at early project stages. The platform [11] presented in this paper directly addresses this gap by integrating (1) an organizational self-assessment framework, (2) an interpretable techno-economic screening engine, and (3) guided pathways toward more detailed analysis, while requiring only limited input data. This approach responds to the fragmented treatment of technical and non-technical factors in existing research and supports more informed, coordinated decision-making during the initial phases of DH transformation. In this context, the Czech Republic represents a relevant application case due to its high prevalence of legacy district heating systems characterised by ageing infrastructure and limited operational flexibility, ongoing decarbonisation challenges, and strong policy-driven demand for accessible planning tools. The final public web platform following the depicted methodology is therefore tailored specifically to the Czech Republic, reflecting the climatic conditions and typical DH configurations in this region.

2 Methodology

This research combines energy-system modelling, organisational analysis, stakeholder co-creation and digital tool development into a single framework that supports early-stage planning of P2H in municipal DH systems. The methodology consists of four integrated steps: (i) defining representative DH typologies, (ii) developing a scalable simulation engine, (iii) validating assumptions with practitioners, and (iv) deploying the results as a public web platform. Together, these steps ensure both analytical robustness and practical usability for Czech municipalities and DH operators.

2.1 Typology of DH Systems

A technical and organisational mapping of 156 Czech DH systems was conducted using municipal energy plans, SECAPs and operator data. Systems were grouped by installed thermal capacity into six categories, from <5 MW to >250 MW as presented in previous literature [12]. For the purposes of the public tool, three small-to-medium typologies (5, 10 and 20 MW) were selected for further analysis, because these categories represent more than 70 % of all Czech DH networks and approximately 39 % of national heat supply. These systems are also the most relevant for early-stage planning support: unlike large metropolitan systems, which require bespoke engineering solutions and centralized investment frameworks, small and medium networks typically face capacity constraints, fragmented governance, and limited technical resources.
Each typology was characterised by empirically observed ranges of annual heat demand, temperature regimes, network length, losses and fuel mix. These profiles serve as boundary conditions for modelling P2H integration and ensure that outputs remain interpretable and transferable to typical Czech DH settings.
In parallel, organisational patterns were reviewed to understand governance constraints that strongly shape P2H feasibility. Three recurrent models were identified: (i) fully corporate utilities, (ii) mixed public–private arrangements with municipal oversight, and (iii) small community-influenced systems. These patterns informed the structure of the readiness self-assessment, which evaluates institutional capacity, stakeholder alignment and financial constraints.

2.2 Simulation Engine and P2H Representation

The analytical core of the platform is a physics-based dynamic model implemented in a widely used building and district-energy simulation environment. A multiprocessing Python workflow was created to automatically generate and run large scenario ensembles. More than 45 000 hourly simulations were produced, covering variations in DH size, seasonal loads, temperature levels, heat-source types and operating strategies. This dataset forms the knowledge base used by the KPI estimator. The subset of the generated scenarios was presented in studies [13][14]

Three representative P2H configurations were modelled:
- air-to-water heat pumps using ambient air,
- water-to-water heat pumps using surface or river water,
- water-to-water heat pumps using low-grade waste heat.

Two integration strategies were analysed: full-season operation sized to the base load, and off-season operation sized for summer and shoulder periods, defining the nominal heat pump capacity. The operational performance of the heat pump also reflects the desired temperature levels imposed by the characteristic control regimes (e.g. weather-dependent control, return temperature control) within the hourly simulation. As such, the desired temperature levels, especially high return temperatures, can limit the operational hours of the simulated heat pump configuration. Similarly, dispatch followed a cost-minimising logic within the hourly simulation, operating the heat pump whenever its marginal heat cost was below that of the existing heat source (typically a gas boiler). All simulation results were aggregated, standardised and indexed for multidimensional interpolation, enabling the public tool to return scaled KPIs for a specific case using only a minimal number of user inputs, while relying on the underlying detailed simulation engine.

2.3 Advisory Panel Co-validation

The methodological assumptions and assessment logic were iteratively refined through an advisory panel of DH operators, municipal representatives and regulatory experts. The panel ensured that the readiness survey reflected real governance and investment conditions, and that the simulation assumptions (temperature constraints, integration strategies, operating logic) aligned with typical Czech DH practice. This process reduced methodological blind spots and improved the interpretability and credibility of the final outputs.

2.4 Development of the Public Platform

The simulation engine and readiness framework were translated into a public web platform [11] structured into five user-oriented steps: identification data, technical characterisation, operating scenario, business inputs and model-based results. The platform integrates two components: (i) Readiness self-assessment, which captures key organisational, economic and technical conditions and computes a preliminary readiness score and (ii) the KPI estimator, which retrieves performance indicators—heat-pump utilisation, seasonal efficiency, production costs, emissions and investment characteristics—from the pre-simulated database.

To ensure accessibility, inputs are supported by contextual explanations and typology-based defaults. Results are presented as charts, tables and a downloadable report to support internal communication and early investment dialogue.

3 Demonstration of the tools

The public portal presents the planning workflow in a simple, user-oriented form. Users begin with the Readiness Scoring Tool, a short survey that provides an indicative assessment of organisational, economic and technical conditions and highlights issues that may require attention before detailed planning. Those who wish to explore potential performance can then proceed to the KPI estimator, which uses a few basic inputs to generate expected operating hours, efficiency, cost impacts and emission changes for selected integration scenarios. Together, these modules allow municipalities and heat suppliers to quickly screen feasibility and then examine the likely outcomes of heat pump integration.

3.1 Readiness scoring tool

Scoring mechanism of the self-assessment tool evaluates DH readiness across three pillars: technical feasibility (9 questions), economic preparedness (17 questions), and organizational readiness (26 questions). Each pillar consists of a set of diagnostic questions formulated to reflect the constraints of existing states and drivers for future planning identified in the methodological studies and in interviews with operators and municipalities. The survey methodology is presented in study [15].
Questions are evaluated on a 0–100 scale, where 100 represents conditions that are highly favourable for heat-pump integration (e.g., low return temperatures, stable customer base, strong municipal governance), while 0 reflects conditions that fundamentally hinder feasibility (e.g., high temperature regimes, severe financial constraints, fragmented ownership).
Each question carries a weight corresponding to its relevance within the pillar. High-impact factors—such as supply and return temperatures in the technical pillar, investment capacity in the economic pillar, or governance structure in the organizational pillar—receive larger weights (10–20%). Lower-impact contextual questions (e.g., minor financial preferences or secondary governance aspects) receive smaller weights (5% or less).

3.1.1 Low-readiness example case

To illustrate how the scoring tool guides early reflection, consider a hypothetical municipality operating an older DH system. The network runs at high supply and return water temperatures, has noticeable distribution losses, and has seen demand decline over recent years. Financially, the operator faces tight budgets and relies heavily on external subsidies for even routine investments. The customer base is unstable, with several major users already considering alternative heating options, which increases sensitivity to tariff changes and limits the ability to plan long term. The organizational setting is equally challenging. Decarbonisation is not a strategic priority, cooperation between the operator and the municipality is limited, and decision making is largely reactive. The company has little capacity for joint projects or new investment models, and its governance structure offers only weak support for coordinated planning. When these conditions are entered into the readiness tool, the resulting scores reflect the constrained situation:

Table 1. Score from the low-readiness example case

Pillar	Score
Technical feasibility level	43
Economic preparedness	8
Organizational readiness	10

This hypothetical case illustrates how the tool helps a user recognise the overall readiness and identify other relevant issues, such as reducing temperature levels, improving the financial position, stabilising the customer base and strengthening governance, that may need to be addressed before even considering investment in P2H technologies.

3.1.2 High-readiness example case

A contrasting example can be imagined in a municipality with a well-maintained medium-sized DH network. The system operates at moderate supply temperatures and benefits from low return temperatures and limited

heat losses, reflecting recent refurbishment efforts. A suitable low-temperature heat source is available nearby, and the overall demand has remained stable, giving the operator confidence in future load conditions. Financially, the operator is in a strong position. The company can finance part of the investment from its own resources, maintains predictable revenues, and is not overly exposed to customer departures or tariff sensitivity. Access to credit is possible under reasonable conditions and expected payback periods remain within the organisation's tolerance for long-term planning. The organisational setting further supports readiness. The municipality and the operator share a clear decarbonisation objective, and cooperation between them is well established. Strategic documents already consider electrification as a potential development pathway, and both parties are open to exploring joint investment models. Decision making is coordinated, and the governance arrangement provides stability for future planning.
These conditions translate into consistently high readiness scores:

Table 2. Score from the high-readiness example case

Pillar	Score
Technical feasibility level	85
Economic preparedness	81
Organizational readiness	95

In this situation, the readiness tool serves as a structured preparation step, helping municipal staff and the heat supplier align on boundary conditions and priorities. With these foundations in place, both parties are well positioned to proceed to the more detailed analysis to examine shared integration scenarios and evaluate their operational and economic implications.

3.2 KPI estimator

The KPI estimator provides a streamlined, five-step workflow that allows users to translate a small set of technical and economic inputs into quantified performance indicators for a selected heat pump scenario. At each step, the tool visualises the implications of the user's choices through simple charts and summaries, showing typical load patterns, temperature regimes, efficiency trends and economic conditions. Once the inputs are confirmed, the estimator generates the full set of model-based results presented in the following figures, including heat-pump operation, seasonal performance, cost impacts and indicative investment outcomes. This structure lets users explore the feasibility and potential performance of P2H integration without requiring modelling expertise.

3.2.1 Input structure

The KPI estimator relies on three sets of user inputs i) heat supply profile settings, ii) operational settings and selection of P2H integration scenarios, iii) economic environment setting that define the technical and economic boundary conditions for the selected scenario.
In the first set, users enter the basic characteristics of their system, after which the tool visualises the corresponding load patterns:

- annual heat delivered to consumers,
- share of space heating and domestic hot water,
- typical ratios between residential and commercial demand,
- automatically generated monthly and hourly load curves for verification.

In the second set, users define the technical conditions for P2H operation:

- typical supply and return temperatures in and outside the heating season,
- expected level of distribution heat losses,
- type of heat pump technology and the assumed heat source,
- intended operating mode (off-season or extended contribution),
- optional spot-price optimisation.
- These inputs determine whether the selected technology can operate effectively and how many hours of the year it is likely to run.

In the third set, the cost structure of heat production is selected:

- current electricity and fuel prices,
- regulated distribution tariffs for electricity and the existing fuel,
- current heat price for end users,
- typical fixed operating costs,

- financing assumptions (share of debt, interest rate, discount rate),
- expected investment cost per installed unit of capacity,
- optional projections for inflation and future price trends.

Together, these parameters define the techno-economic boundary conditions under which the performance indicators will be evaluated.

3.2.2 Example decision -making support provided by the KPI estimator

The example considers a mid-sized municipal district-heating (DH) system with an annual heat delivery of 27.8 GWh and a balanced mix of residential and commercial consumers. Heat demand is evenly divided between space heating and domestic hot water. The system operates with relatively high supply and return temperatures typical for existing Czech DH networks, which may limit achievable heat-pump efficiency and the number of viable operating hours. Full settings of technical and economic parameters applied in the calculation are summarised in table 3 and table 4

Table 3. Input – technical parameters

Input – technical parameters	Case 1	Case 2	Case 3	Case 4
Annual heat delivery [GWh]	27.8			
Share of heat for space heating / domestic hot water [%]	50 % / 50 %			
Share of residential / commercial heat delivery [%]	50 % / 50 %			
Average supply / return temperature, heating season [°C]	90 / 70	**70 / 50**	90 / 70	90 / 70
Average supply / return temperature, non-heating season [°C]	70 / 50	**60 / 40**	70 / 50	70 / 50
Network heat losses [%]	Low (0–10 %)			
P2H technology	**Air–water HP**		**Waste heat HP**	
Design capacity of P2H integration	Off-season			
Spot-price operation	Yes			

To explore how different technical and economic conditions shape the feasibility of P2H integration, the paper presents four hypothetical cases calculated by the tool. Each scenario represents a realistic step in a municipal decision process, ranging from a basic low-temperature intervention to a targeted efficiency upgrade and finally to economic risk assessment.

Case 1 – Air–water heat pump at current temperature levels.

The first scenario examines the most straightforward option: installing an air–water heat pump that operates at the existing temperature regime (90/70 °C in winter, 70/50 °C in summer). This requires minimal organisational coordination and reflects the conditions of many older Czech DH systems. The aim is to understand the baseline potential for P2H under unfavourable temperature levels when applying spot-price optimisation.

Case 2 – Air – water heat pump after temperature optimisation.

In the second scenario, the investor team assesses whether preparatory measures, such as modernising substations or improving return-water control, can reduce operating temperatures to 70/50 °C in the heating season and 60/40 °C in summer. Lowering the temperature regime is known to increase seasonal COP and operating hours. This scenario therefore tests the impact of a commonly recommended pre-integration measure without changing the heat-pump technology.

Case 3 – Waste-heat - heat pump at current temperature levels.

The third scenario introduces a water-water heat pump supplied by low-temperature waste heat from an external provider, such as a data centre. Although it requires stronger organisational cooperation and contractual arrangements, this configuration benefits from more favourable source temperatures and typically achieves higher efficiency. The operating temperatures remain at the original system levels 90/70 °C and 70/50 °C, allowing direct comparison with Case 1.

Case 4 – Waste-heat heat pump under increased electricity-price risk.

The final scenario tests the sensitivity of the waste-heat configuration to less favourable economic conditions. While the technical setup remains identical to Case 3, the market electricity price is increased from 2 500 CZK/MWh to 3 400 CZK/MWh, raising the electricity-to-fuel price ratio from 2.5 to 3.5. This scenario represents a realistic risk consideration for municipalities and heat suppliers, reflecting potential volatility in electricity markets or changes in tariff structures.

Table 4. Input – economical parameters

Input –economical parameters	Case 1	Case 2	Case 3	Case 4
Market electricity price [CZK/MWh]	2 500	2 500	2 500	**3400**
Regulated electricity distribution charges [CZK/MWh]			1 000	
Distribution charges of existing fuel [CZK/MWh]			800	
Price ratio electricity / existing fuel [-]	2.5	2.5	2.5	**3.5**
Heat sales price [CZK/MWh]			750	
Fixed operating costs [CZK/MWh]			350	
Share of bank loan [%]			50	
Long-term inflation (CZK, 15 years) [%]			1.49	
Interest rate [%]			4	
Investment cost (CAPEX) [CZK/kW]			22 000	
General inflation [%]			2	
Fossil fuel price growth [%]			2	
CO_2 price growth [%]			2	
Profit margin on emission-free heat [%]			5	
NPV horizon [years]			10	

3.2.3 Results visualization in the platform

For demonstration purposes, the visualisation is shown for the air–water heat pump case. After the user completes the inputs, the estimator provides a small set of charts that summarise the key operational and economic characteristics of the selected scenario presenting monthly overview of heating demand coverage by P2H technology, monthly average temperature levels, coefficient of performance and also net present value scenarios in next decade.

Fig. 1 shows the seasonal distribution of heat production in the DH system, distinguishing the contribution of the existing source and the P2H unit. The heat produced by the existing source follows the typical pattern of high winter output and reduced summer operation, driven by lower space-heating demand. The heat pump is sized for off-season operation as a secondary source and contributes mainly during periods when operating temperatures are more favourable and when market conditions related to renewable generation allow cost-effective operation. The black line indicates the total heat supplied from both sources, which peaks in winter and reaches its minimum in summer, reflecting the underlying seasonal heat demand.

Fig. 2 presents the monthly variation of key temperature levels in the DH network. The orange line shows the desired supply temperature governed by weather-dependent control, while the blue line represents the return temperature based on the applied temperature drop. The purple line indicates the heat pump outlet temperature for an off-season-sized configuration, reflecting the selected sizing requirements and the hourly operating efficiency and temperature lift calculated from the applied performance map. Because the selected configuration is optimised for off-season operation relative to winter peak demand, the outlet temperature does not reach the desired supply level in this illustrative case. Together, the curves illustrate the temperature boundary conditions for heat pump operation and the seasonal influence on achievable efficiency and operating hours.

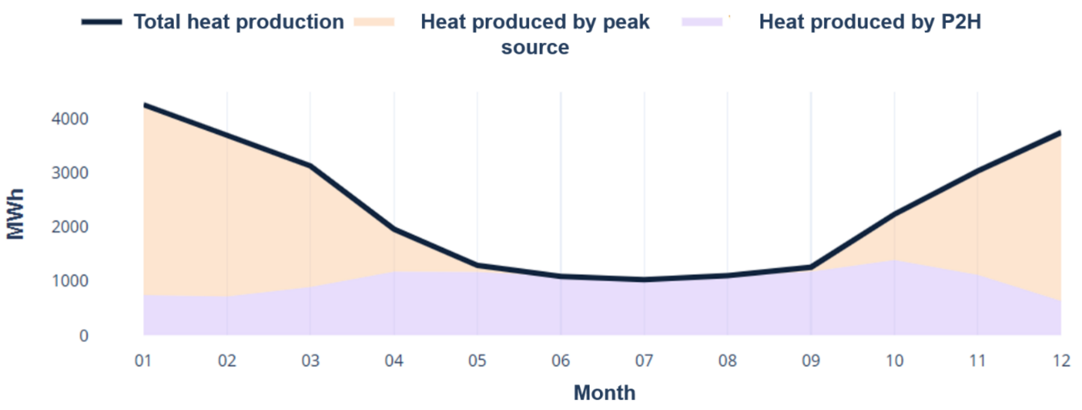

Figure 1. Visualization from the web-tool - Monthly distribution of heat production: Total heat delivery, Heat produced by existing source, heat produced by P2H

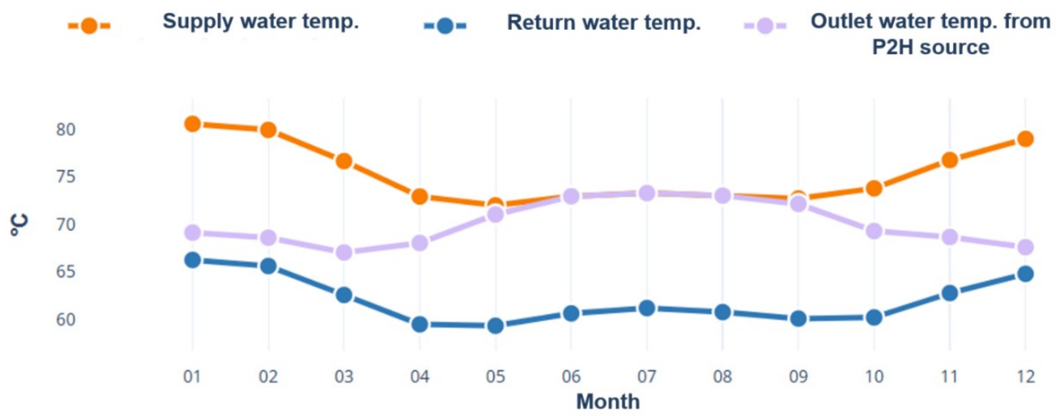

Figure 2. Visualization from the web-tool - Monthly average of system water temperature: Supply water temperature to the network, Return water temperature from the network, P2H outlet water temperature

Fig. 3 shows the monthly variation in the heat pump coefficient of performance (COP) for this illustrative case, defined as the ratio between useful heat delivered and electricity consumed. The values range between approximately 2.2 and 2.7, reflecting the operating conditions of the selected configuration. The variation responds to hourly and seasonal changes as represented by the applied performance map.

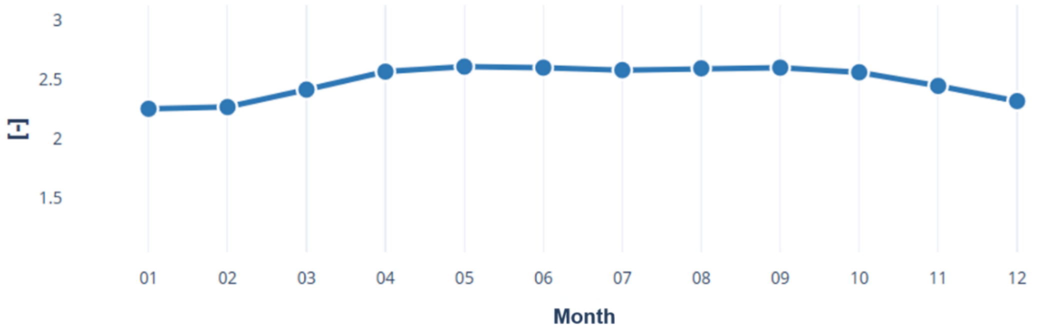

Figure 3. Visualization from the web-tool - monthly average of coefficient of performance (COP) of the heat pump

Fig. 4 compares the cumulative net present value of the project over a ten year period for two cases: the installation of the P2H system and the continuation of the current operating strategy. Both curves reflect the combined effect of capital expenditure, operating costs and expected fuel price developments. The P2H trajectory initially drops due to the upfront investment but rises more rapidly in later years as operating cost savings accumulate in this case. The existing system shows a slower but steady increase driven by rising commodity prices. The comparison illustrates how P2H integration may improve long term economic performance despite a longer payback period, and provides a quantitative basis for assessing the financial viability of the project under the given assumptions.

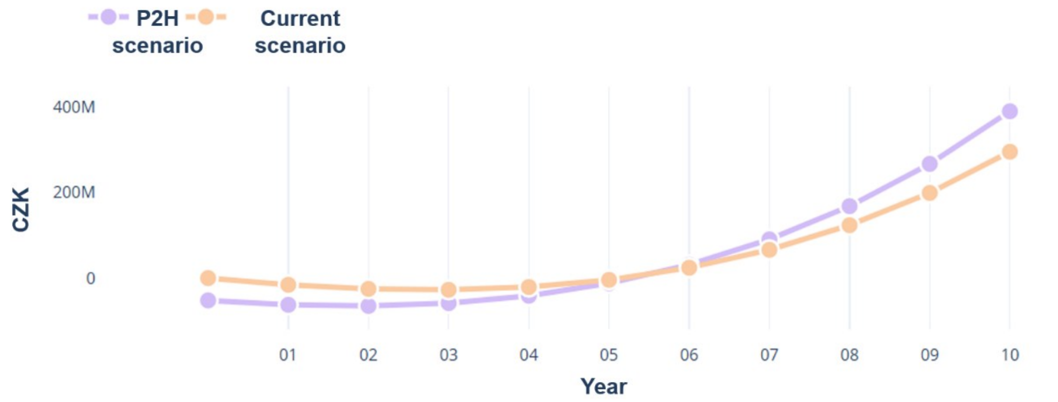

Figure 4. Visualization from the web-tool - Development of cumulative net present value over the project horizon: P2H scenario, Current scenario

3.2.4 Comparative interpretation of the example integration scenarios

The results from the four scenarios illustrate how a municipal investor team might iteratively evaluate P2H options under technical and economic constraints. The full list of technical and economical outputs are in table 5 and table 6

Table 5. Output – technical KPIs

Technical KPIs	Case 1	Case 2	Case 3	Case 4
Total heat produced [MWh]	27 800	27 800	27 800	27 800
Heat produced by P2H [MWh]	12 300	12 400	14 000	11 800
Heat produced by existing source [MWh]	15 500	15 400	13 800	16 000
Heat delivered to consumers [MWh]	26 500	26 800	26 500	26 500
Distribution losses [MWh]	1 400	1 200	1 400	1400
Average COP	2.5	2.6	3.5	3.5
P2H emission factor [kg CO_2/MWh]	200	190	140	140
Annual operating hours of P2H [h/yr]*	7 235	7 239	7 886	7031
Nominal HP capacity [MW]	4.6	4.3	4.2	4.1

*bivalence temperature point 0°C

Case 1 provides the initial reference point: an air–water heat pump operating at the existing high-temperature regime. The heat pump covers roughly 12.3 GWh per year with an average COP of 2.5, reducing system-wide operating costs but only modestly. This naturally leads to the question whether improving the temperature regime can unlock more value. **Case 2** shows that even a moderate reduction in supply and return temperatures increases the COP to 2.6 and slightly raises the P2H contribution. The economic gains, while not dramatic, show a consistent improvement: lower commodity costs and a shorter simple payback (8.7 years). For many operators, this scenario can justify preparatory measures aimed at temperature optimisation, especially if network refurbishment is already planned.
With this baseline established, the investor team may explore a more efficient heat source. **Case 3** demonstrates the clear performance advantage of a waste-heat heat pump. The COP rises to 3.5, P2H production increases to 14 GWh, and annual system costs fall to 76 million CZK, the lowest across all variants. The simple payback improves to 5.5 years, making this option the strongest candidate from both a technical and economic perspective. The results therefore support pursuing organizational arrangements with the waste-heat provider, as the expected performance gains outweigh the added coordination effort.
However, any realistic investment process also considers risk exposure. **Case 4** introduces this by examining

the waste-heat configuration under a higher electricity-price environment. The heat pump maintains high technical efficiency, but the increased electricity-to-fuel ratio shifts the cost balance: existing-source operation rises, commodity-related heat costs increase, and the total annual system cost grows to 83 million CZK. While it is still competitive compared to the baseline, the economic advantage narrows and the payback extend to 6.2 years. This highlights that even efficient P2H concepts remain sensitive to electricity-price volatility, reinforcing the need for forward contracts, tariff negotiation, or partial hedging.
These outcomes suggest that while technically feasible, the solution offers limited economic leverage at current conditions.

Table 6. Output – economical KPIs

Economical KPIs	Case 1	Case 2	Case 3	Case 4
Commodity-only heat cost – P2H [CZK/GJ]	330	320	240	260
Commodity-only heat cost – existing source [CZK/GJ]	590	590	590	640
Operating costs without P2H [CZK/yr]	59 260 K	59 260 K	59 260 K	64 200 K
Operating costs with P2H [CZK/yr]	49 140 K	48 520 K	42 620 K	49 830 K
P2H operating cost contribution [CZK/yr]	16 020 K	15 730 K	13 160 K	12 960 K
Existing source operating cost (future) [CZK/yr]	33 110 K	32 800 K	29 460 K	36 870 K
Fixed operating costs [CZK/yr]	33 380 K	33 760 K	33 380 K	33 410 K
Total annual system cost – baseline [CZK/yr]	92 640 K	93 020 K	92 640 K	97 610 K
Total annual system cost – with P2H [CZK/yr]	82 520 K	82 280 K	76 000 K	83 230 K
Investment cost (CAPEX) [CZK]	100 930 K	93 570 K	92 010 K	89 730 K
Simple payback [yrs]	10.0	8.7	5.5	6.2

Taken together, the four cases reflect a realistic decision trajectory:

1. Initial assessment (Case 1): technically workable but only marginally beneficial.
2. System optimization (Case 2): small improvements that strengthen the business case.
3. High-performance option (Case 3): strong justification if organizational cooperation is achievable.
4. Risk check (Case 4): viability persists, but exposure to electricity-price movements becomes a key decision factor.

This structured comparison demonstrates how the platform supports early strategic dialogue by revealing the trade-offs, sensitivities and preconditions that determine whether P2H integration should proceed to detailed design.

1. Discussion

The four-scenario comparison illustrates how the public platform supports early stage evaluation of Power to Heat options under different technical and economic conditions. The examples were intentionally simplified to preserve clarity and demonstrate the workflow, rather than to represent the full diversity of real district heating systems. More complex analyses that combine different DH typologies, temperature regimes or variable market conditions are fully supported by the underlying simulation knowledge base, but they are not shown here because they would reduce the interpretability of the example.
The broader dataset reveals several characteristic trends that are relevant for planning. Lowering operating temperatures is one of the strongest drivers of heat pump performance. Even moderate reductions in supply and return temperatures increase seasonal COP, expand the number of viable operating hours and reduce marginal heat production costs. Systems supplied by stable low temperature waste heat show consistently higher efficiency and lower annual operating costs compared to air source configurations, provided that organisational arrangements can be established. The electricity to fuel price ratio also remains a dominant economic factor. When spot price optimisation is used, relatively small changes in relative prices can shift a considerable part of annual production between the P2H technology and the existing heat source. This behaviour was visible in the risk scenario where higher electricity prices reduced the economic advantage of

the waste heat option.
These insights highlight the role of the platform as an initial screening and learning tool. It is not intended to replace detailed engineering design or professional consultancy. Its typology-based structure limits system specific tailoring, but this simplification allows municipalities to identify situations where P2H integration is clearly unsuitable, situations where feasibility depends on preparatory measures and situations where a full feasibility study is justified. At this preliminary stage, the outputs already provide useful information about expected performance, indicative sizing, sensitivity to technical and economic conditions and the potential value of improved coordination between local actors.
Combined with the readiness self-assessment, the platform also strengthens the capacity of municipal energy managers. It helps them understand both the technical and institutional factors that determine successful implementation and it supports structured dialogue between municipalities, heat suppliers and external partners.

4 Conclusion

This paper has presented the methodological basis and first demonstration of a public web platform that supports early planning of large heat pump integration in municipal DH systems in Czech Republic. By combining an organisational readiness self-assessment with a simulation based KPI estimator, the tool connects governance conditions, technical boundary parameters and economic performance within a single, accessible interface. The underlying knowledge base of more than 45 000 simulations allows users to explore realistic operating regimes without needing direct access to specialised modelling environments.
The two illustrative applications show how the platform can distinguish between low and high readiness contexts and how different integration options perform under identical boundary conditions. The readiness scoring tool highlights institutional, financial and technical constraints that may need to be addressed before detailed project preparation. The KPI estimator then quantifies key technical and economic indicators for four cases such as utilisation, seasonal performance, operating costs, emissions and indicative payback. Together, these modules act as a screening instrument that can identify clearly unfavourable cases, borderline situations that depend on improvements in local conditions, and promising projects that warrant full feasibility studies.
The platform is not intended to replace detailed design work or professional consultancy. Its typology-based structure limits the degree of system specific tailoring, and its outputs should be interpreted as indicative. Nevertheless, the level of detail provided is sufficient to structure early investment dialogue, support the formulation of tender criteria and strengthen the position of municipal energy managers in negotiations with heat suppliers and network operators. In this way, the tool contributes both to advanced analytical capacity and to the broader education of local stakeholders.
Future development will focus on extending the range of conditions that can be evaluated, including additional weather zones, flexible bivalence points and hybrid operating strategies, and optional coupling with intermittent renewable sources, e.g. photovoltaic generation at community level. These enhancements will broaden the scope of scenarios that can be assessed while preserving the simplicity required for non-expert users. More generally, the approach demonstrated here suggests that carefully designed public tools, grounded in robust simulation and informed by practitioner input, can play a meaningful role in accelerating the practical uptake of P2H solutions in municipal DH.

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2. References

[1] E. Cocciolo, “The role of energy communities for thermal networks: An EU legal perspective,” *Rev Eur Comp Int Environ Law*, vol. 33, no. 3, pp. 494–506, Nov. 2024, doi: 10.1111/REEL.12558;WGROUP:STRING:PUBLICATION.

[2] J. Ramsebner, R. Haas, A. Ajanovic, and M. Wietschel, “The sector coupling concept: A critical review,” *Wiley Interdiscip Rev Energy Environ*, vol. 10, no. 4, p. e396, Jul. 2021, doi: 10.1002/WENE.396;WEBSITE:WEBSITE:WIRES;WGROUP:STRING:PUBLICATION.

[3] A. David, B. V. Mathiesen, H. Averfalk, S. Werner, and H. Lund, “Heat Roadmap Europe: Large-Scale Electric Heat Pumps in District Heating Systems,” *Energies 2017, Vol. 10, Page 578*, vol. 10, no. 4, p. 578, Apr. 2017, doi: 10.3390/EN10040578.

[4] P. A. Østergaard and A. N. Andersen, “Economic feasibility of booster heat pumps in heat pump-based district heating systems,” *Energy*, vol. 155, pp. 921–929, Jul. 2018, doi: 10.1016/J.ENERGY.2018.05.076.

[5] G. Schweiger, J. Rantzer, K. Ericsson, and P. Lauenburg, “The potential of power-to-heat in Swedish district heating systems,” *Energy*, vol. 137, pp. 661–669, Oct. 2017, doi: 10.1016/J.ENERGY.2017.02.075.

[6] G. Fambri, A. Mazza, E. Guelpa, V. Verda, and M. Badami, “Power-to-heat plants in district heating and electricity distribution systems: A techno-economic analysis,” *Energy Convers Manag*, vol. 276, p. 116543, Jan. 2023, doi: 10.1016/J.ENCONMAN.2022.116543.

[7] A. Tosatto, A. Dahash, and F. Ochs, “Simulation-based performance evaluation of large-scale thermal energy storage coupled with heat pump in district heating systems,” *J Energy Storage*, vol. 61, p. 106721, May 2023, doi: 10.1016/J.EST.2023.106721.

[8] K. Hartmann and J. Palm, “The role of thermal energy communities in Germany’s heating transition,” *Frontiers in Sustainable Cities*, vol. 4, p. 1027148, Jan. 2023, doi: 10.3389/FRSC.2022.1027148/BIBTEX.

[9] B. K. Sovacool *et al.*, “Decarbonizing household heating: Reviewing demographics, geography and low-carbon practices and preferences in five European countries,” *Renewable and Sustainable Energy Reviews*, vol. 139, p. 110703, Apr. 2021, doi: 10.1016/J.RSER.2020.110703.

[10] R. Amin, D. Mathur, D. Ompong, and K. K. Zander, “Integrating Social Aspects into Energy System Modelling Through the Lens of Public Perspectives: A Review,” *Energies 2024, Vol. 17, Page 5880*, vol. 17, no. 23, p. 5880, Nov. 2024, doi: 10.3390/EN17235880.

[11] J. Šafránek, J. Cígler, V. Zavřel, and N. Pokorný, “Tools for Coordinating System Integration Processes of Thermal Networks at the Level of Czech Cities.” Accessed: Nov. 14, 2025. [Online]. Available: https://www.elektrifikaceteplarenstvi.cz

[12] J. Boháč, V. Zavřel, and M. Nesládek, “Typologie soustav centralizovaného zásobování teplem v ČR,” *Vytápění, větrání, instalace*, Jan. 2024.

[13] N. Pokorny, V. Zavrel, and J. Safranek, “Scenarios for Integration of Power to Heat Technology in Czech District Heating Systems,” pp. 1–10, Feb. 2025, doi: 10.18086/EUROSUN.2024.05.04.

[14] N. Pokorný *et al.*, “Případové studie: modelové scénáře systémové integrace tepelných sítí na úrovni českých měst a čtvrtí,” Praha, 2023.

[15] W. Belch *et al.*, “Metodika pro plánování chytrých tepelných sítí prostřednictvím Power2Heat technologií,” 2024. Accessed: Nov. 16, 2025. [Online]. Available: https://forms.gle/JKh6dnqDuJcjQjXk8