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Risk-assessment of heat pumps as investment decision to decarbonize district heating and cooling systems – comparison between nine case studies in Europe

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Abstract

The ENABLE-DHC project is an EU-funded initiative aimed at developing investment plans for district heating and cooling (DHC) systems in seven countries: Austria, Croatia, Ireland, Italy, Latvia, Slovenia, and Ukraine. These plans are designed to support the transition toward energy-efficient and decarbonized DHC networks, with large-scale heat pumps playing a central role as a key technology for sustainable energy systems. This paper compares the technological, economic, social and environmental investment risks of different DHC decarbonization strategies. This approach enables the quantitative analysis of risks under different criteria and supports robust investment decisions. The ENABLE-DHC project is expected to trigger the generation of around 654 GWh/year of renewable energy and mobilize nearly EUR 100 million in sustainable energy investments. Across all participating countries, large-scale heat pumps were identified as the most promising solution. However, electricity prices uncertainties, unavailability or short-term funding scheme or financial incentives and high-investment costs are perceived are high risks and could be a barrier for the technological uptake. Furthermore, qualitative risk-assessment through operational optimization and Monte Carlo Analysis are expected by the end of the project for some country-specific examples (Vienna and Ljubljana), providing deeper insights into European techno-economic risks in the decarbonization of these DHC systems.

Keywords: Investment plans, district heating and cooling , decarbonisation, risk-assessment.

1. Introduction

According to ISO 31000, risk assessment is the overall process that enables an organization to understand and prioritize risks that may affect its objectives. It encompasses three key steps:

- risk identification, which aims to recognize and describe potential events or situations that could impact objectives.
- risk analysis, which evaluates the nature, sources, likelihood, and consequences of those risks.
- risk evaluation, which compares the analyzed risks against established criteria to determine their significance and the need for treatment.

This systematic approach can support informed decision-making and effective risk management at the different phases of an DHC investment and decarbonization project (e.g. initiation and prefeasibility assessment, planning, construction, operation). The central challenge in achieving an optimal and sustainable district heating and cooling (DHC) supply lies in meeting three requirements simultaneously, as emphasized [1]. First, systems must be affordable and available, meaning competitive both in terms of investment and operational costs, while also accounting for subsidies and financial risks. Second, they must be green and clean, reducing CO_2 emissions, primary energy consumption, land use, and noise emissions. Third, they must be secure and reliable, ensuring controllability, plannability, and overall availability. These constitute objectives that can be considered in the risk assessment procedure.
The achievement of these objectives is affected by systemic long-term [2]. Among the most critical sources of risk are: the *high capital intensity* of assets, which entails long amortization periods; the *long operational lifetimes* of systems, which increase their exposure to volatile energy prices and to the effects of climate change

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on supply and demand, thereby complicating profitability assessments over the full lifecycle; and finally, *uncertainty* regarding future regulations and incentives, which may discourage long-term investments and instead promote conservative short-term decisions oriented towards quick profits.
Risk assessment is therefore essential to anticipate and sufficiently mitigate these risks, to support robust, future-proof investment decisions in DHC decarbonization plans.
(Chaudry, et al., 2015) [3] identified uncertainties which could create technical, economic or policy barrier in the decarbonization of UK's heat sector. These included uncertain level of maturity of certain technologies, uncertain capital costs, uncertain fuel or carbon prices, heat demand variations, as well as the uncertainty of national policies and heat decarbonization pathways. The inter-related nature of these uncertainties was highlighted. (Ioannou, et al., 2017) [4] summarized the most cited risks in the literature related to sustainable energy investment projects. The authors stressed that the perception of these risks vary across stakeholders, e.g. investors, consumers or policymakers, as they do not all share the same concerns and objectives.

1.1. ENABLE-DHC case studies and their decarbonization strategy

In terms of decarbonization, the main challenge for the district heating and cooling utilities is the abrupt system change: the industry in changing from centralized systems mainly dominated by natural gas-CHPs to heterogeneous systems with many technology options. Besides that, there is not a unique solution applicable to all, each case study has its own specificities. Nevertheless, large-scale heat pumps are a commonly considered choice, having several energy sources: water, air, industrial waste heat and wastewater. Below, an overview of the ENABLE-DHC case studies are presented in terms of location, produced heat, supply and return temperature, main heat source and main decarbonization heat source:

Table 1. ENABLE-DHC case studies overview

Case study city	Country	Heat produced (GWh/year)	Supply/return temperatures	Main current heat source	Main decarbonized heat source
Acqui Therme	Italy	34,8	85°C/65°C	Natural gas	Geothermal and treated wastewater heat pump
Tallaght	Ireland	4	70°C/50°C	Waste heat from datacenters	Waste heat pumps from datacenters
Vienna	Austria	5.910	95-150°C / 55-65°C	Natural gas and waste	Geothermal and river, air and wastewater heat pumps
Weiz-Gleisdorf	Austria	68,3	105-80°C/ 50-60°C	Oil	Geothermal, solar thermal and treated wastewater heat pump
Poltava	Ukraine	756	90°C/65°C	Natural gas	Biomass, waste incineration and solar thermal systems
Stryi	Ukraine	64,88	115°C/70°C	Natural gas	Biomass, air heat pump
Riga	Latvia	3.170	120°C/70°C	Natural gas	wastewater heat pump
Ljubljana	Slovenia	1150	-	Coal and natural gas	Biomass, river heat pump, wastewater heat pump or waste incineration
Rijeka	Croatia	62,5	85°C/65°C	Natural gas	Waste incineration and water heat pump

2. Method/Approach

The proposed mapping presents a structured list of risks which may affect technical feasibility, financial viability or public acceptance of district heating and cooling decarbonization investment plans developed during the ENABLE-DHC project. The mapping adopts a cause-effect methodology to identify the origin of each risk factor and their down-stream impact on the project. All risks were mapped-based on the PESTEL (Political, Economic, Social, Technological, Environmental and Legal) framework (Figure 1 below), which is frequently used in project risk management.

Figure 1. PESTEL (Political, Economic, Social, Technological, Environmental and Legal) framework[1]

The most relevant risk factors for the DHC projects were identified resulting in a list classified by risk category, risk sub-category, cause and expected impact. The cause → risk factor → expected impact chain was formulated in a worse-case manner, i.e. only uncertainties leading to negative impacts were listed. The list started from the one established [4]. It was adapted for district heating and cooling systems and was then completed based on expert knowledge. The stakeholders filling in the survey were energy utilities and/or consultancy companies involved in the development of the decarbonization investment plans.
Internal management risks, contractual disputes, or human resource risks were not considered. Below follows a description of the risk mapping structure:

- **Risk Category (Higher level):** The macro-environmental domain in which the risk factor emerges. The risk categories follow the PESTEL framework, where the legal domain was merged with the political domain.
- **Risk Sub-category (Lower level):** More specific thematic grouping within each category. The list of sub-categories stems from the literature review of Ioannou et al. established for the planning of sustainable energy systems. Following sub-categories were dropped because they seemed less relevant in the scope of the study: Bureaucracy, Health risks Project development, Construction, Decommission.
- **Cause:** The underlying event, condition, or change that could trigger impacts on the project.
- **Risk factor:** The direct operational or market effect of the cause.
- **Expected impact:** The final impact for the project, expressed in financial (CAPEX, OPEX, revenues) or reputational terms.

The risk matrix approach is used, where a dual assessment of **likelihood** score (probability of occurrence) (Table 2) and **impact** level (severity of consequences) (Table 3) of each risk factor is performed – Equation (1):

$$risk - score = likelihood\ score * impact\ level \quad (1)$$

The **total risk-score** represents the multiplication by likelihood and impact level. The high-priority risks are those with both a high probability of occurring during the assessment period (by 2040) and severe consequences for the project feasibility, financial viability, or social acceptance, before implementing mitigation strategies. This structured approach will allow to focus resources and mitigation strategies on the most critical threats, while monitoring or accepting lower-priority risks.

[1] Source: What is PESTEL Analysis?

Table 2. Definition of the Likelihood score

Score	Description	Probability Range (approx.)	Definition	Example for District Heating Projects
1	Very unlikely	≤ 5%	The risk event may occur only in exceptional circumstances; highly improbable given current trends.	Sudden ban on all biomass boilers in a country with strong biomass support.
2	Unlikely	6–20%	The risk event is possible but not expected; would require several conditions to align.	Temporary suspension of national renewable heat subsidies due to short-term budget reallocation, despite long-standing policy support.
3	Moderate	21–50%	The risk event could occur and there is a reasonable chance; evidence or trends suggest potential.	Noticeable CO_2 price rise above projections within the next 15 years.
4	Likely	51–80%	The risk event will probably occur under most foreseeable scenarios.	Electricity prices remaining above projection levels for several years.
5	Almost certain	> 80%	The risk event is expected to occur in nearly all scenarios; strong evidence or historical precedent.	Gradual increase in minimum efficiency requirements for heating systems.

Table 3. Definition of the Impact level

Score	Level	Qualitative definition	Indicative Financial Operational Impact	Example for District Heating Projects
1	Negligible	Minimal impact on cost, performance, or reputation; easily absorbed without corrective action.	<1% increase in CAPEX/OPEX; no delay; no service disruption.	Minor permit clarification required, resolved without extra cost.
2	Minor	Small, manageable impact; limited stakeholder concern.	1–5% increase in CAPEX/OPEX; negligible performance loss.	Slight fuel price fluctuation causing marginal OPEX increase.
3	Moderate	Noticeable impact requiring some adjustments; moderate stakeholder concern; limited-service loss.	6–15% increase in CAPEX/OPEX; measurable efficiency loss.	Unexpected seasonal temperature rise leading to a 10% drop in winter heat demand over one year
4	Major	Significant impact on cost, schedule, performance, or reputation; could threaten part of the project.	16–30% increase in CAPEX/OPEX; significant revenue reduction.	Unplanned redesign due to regulation change, adding 20% to CAPEX.
5	Critical / Severe	Threatens overall project viability; major financial loss, service failure, or reputational damage.	>30% increase in CAPEX/OPEX; loss of major customer base.	Permanent loss of primary heat source, requiring costly system overhaul.

3. Results and Discussion

Table 4 below summarizes the risk-scores perceived by the district heating utilities regarding the risk-assessment of their decarbonization strategy. From Table 1 (above), one can see, that heat pumps are the most promising technologies, present in almost all case studies. The risk matrix below (Table 4) classifies the risks in political, economic, social, technological and environmental, and identifies the risk factor related to them. Furthermore, the colours represent following risk-score classification: “green” represents low risks (between 1 and 8), “yellow” represents medium risks (between 9 and 12), and “red” represents high risks (higher than 13). When generally comparing all case studies, a heterogenous pattern is observed – reinforcing the individual character of each case study and their local singularities. However, following risks are perceived as “high” in most case studies:

- Political: Unavailability of financial incentives and funding schemes
- Economic: High electricity prices or fuel prices
- Economic: High investment or maintenance costs

These political and economic risks represent a barrier, especially in an uptake of electricity based new technologies – as heat pumps. There is a need of a clear and constant political narrative and strategy, that provides confidence for a stable financial incentives and funding schemes. Otherwise, district heating energy utilities will avoid long-term investments and will prefer short-term solutions. On other hand, lack of social acceptance and technological risks on installing SCADA systems were considered low risky in all countries.

Table 4. Risk-score

Risk category	Risk factors	Ljubljana	Poltava_Stryi	Riga	Rijeka	Weiz-Gleisdorf	Tallaght	Acqui Terme	Wien
Political	Restricted use of some heat sources (e.g. natural sources like acquiferes) or technology bans	1	12	4	8	3	1	12	6
	Stricter constraints on land-use	1	1	4	8	2	2	2	6
	Conflicting interests between municipality, utilities, and investors	1	4	8	6	6	6	16	9
	Changes in EED/RED targets, taxation, or subsidy eligibility	4	4	2	8	9	6	3	12
	Unavailability of financial incentives and funding schemes	12	4	8	12	12	12	6	9
Economic	Higher electricity or fuel prices	12	12	6	12	6	9	10	8
	Higher CO2 prices	16	9	3	6	4	6	2	10
	Unforeseen demand decrease	9	4	2	4	4	2	12	8
	Unforeseen demand decrease	9	2	1	4	4	2	9	10
	Unforeseen demand decrease	6	9	1	9	6	1	6	6
	Higher investment or maintenance costs	4	12	4	12	16	4	16	12
	Interest rate swings	1	12	1	4	12	4	12	10
Social	Lack of public acceptance	4	1	1	2	6	6	3	4
	Unpredictable user interaction with Demand Side Management, thermostats, etc.	1	6	1	9	2	4	4	1
Technological	Unavailability of certain technologies or designs (e.g. hydrogen, special heat pump designs)	4	6	4	9	1	6	2	9
	Critical failures of components	2	12	1	4	4	1	6	4
	Decreased efficiency (e.g. lower COP of heat pumps)	1	6	1	4	2	4	12	4
	Challenges integrating supervisory control and data aquisition system (SCADA), Energy Management System (EMS), smart metering	1	6	1	4	4	3	2	2
	Intermittent renewable sources or unavailability of thermal storage	1	6	1	9	2	2	12	12
	Unavailability of primary sources (e.g. hydrogen, biofuels)	1	9	1	9	2	2	8	20
	Unavailability of heat/cooling sources (e.g. waste heat, heat pump sources, depletion of geothermal potential)	1	9	1	6	2	2	8	12
	Challenge to extend and to connect assets or consumers to the grid	1	6	1	12	6	9	8	12
Environmental	Environmental harm	4	4	1	4	1	1	1	8
	No achievement of EED requirements - CO2 Emission requirements	4	9	1	4	1	1	16	8

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5. References

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