Theoretical case study II:

Expanded heat pump system project in Malmö

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1. HEAT PUMP TECHNOLOGY IN SWEDEN

1.1. Technological and Strategic Developments

Heat pump technology has become a cornerstone of Sweden's sustainable heating strategy, particularly in urban district heating networks (Johansson, 2021). While the technology has a long history in the country, recent innovations in large-scale applications have positioned Sweden as a global leader in sustainable urban heating solutions. Heat pumps contribute significantly to Sweden's renewable heat production, with their role growing as cities like Malmö push toward climate neutrality by 2030, more than a full decade ahead of national targets (CDP, 2024).

Heat pumps in Sweden are deployed across various scales, from individual residential units to large-scale district heating applications. The technology has proven particularly effective when integrated with existing infrastructure and waste heat sources. Current installations range from small-scale residential units to industrial-scale systems, with the landmark 40 MW installation in Malmö's harbour area demonstrating the potential for urban-scale applications. This installation, comprising four 10 MW ammonia heat pumps, provides heating for approximately 10,000 households while achieving a coefficient of performance (COP) above 3.5 (Ammonia21, 2018).

The integration of heat pump technology with urban infrastructure represents a key innovation in Sweden's approach. In Malmö, the system harvests heat from sewage treatment facilities, where wastewater maintains a constant temperature of 14°C, significantly higher than alternative sources like seawater or ground source heat. This integration with municipal infrastructure has proven more efficient than traditional approaches, avoiding the challenges associated with variable temperature sources (Vahterus, 2018). The system's ability to deliver water at temperatures up to 80°C (though typically operating between 66-71°C) makes it ideal for district heating applications.

Sweden is actively advancing heat pump technology through research and development initiatives focused on both efficiency improvements and system integration. Key developments include the use of natural refrigerants like ammonia (with zero Global Warming Potential), advanced control systems for optimal operation, and innovative approaches to thermal storage. The country's expertise in district heating networks, which serve about 93% of apartment buildings, provides an ideal foundation for deploying these advanced heat pump systems.

1.2. Prospects, Economic Impact, and Strategic Considerations

The heat pump sector in Sweden shows strong growth potential, particularly in urban applications where waste heat sources are abundant. Studies indicate that large-scale heat pumps could provide up to 30% of urban district heating needs by 2030, representing a significant increase from current levels. This expansion aligns with Sweden's goal of achieving 100% renewable electricity by 2040 and complete carbon neutrality by 2045.

The economic implications of heat pump technology deployment extend beyond energy savings. Initial implementations, such as the Malmö harbour installation, demonstrate compelling economic benefits. With a COP of 3.5, these systems deliver 3.5 kWh of heat for every 1 kWh of electricity consumed, significantly reducing operating costs compared to traditional heating methods (Vahterus, 2018). The annual reduction of 50,000 tons of CO_2 emissions from a single installation also represents substantial environmental value, equivalent to removing 10,000 petrol cars from the roads.

However, the development of large-scale heat pump systems faces several challenges. Primary among these is the high initial investment cost, with projects requiring significant capital for heat pump units, infrastructure integration, and control systems. The Malmö installation demonstrates that these costs can be justified through operational savings and environmental benefits, but financing remains a crucial consideration for new projects.

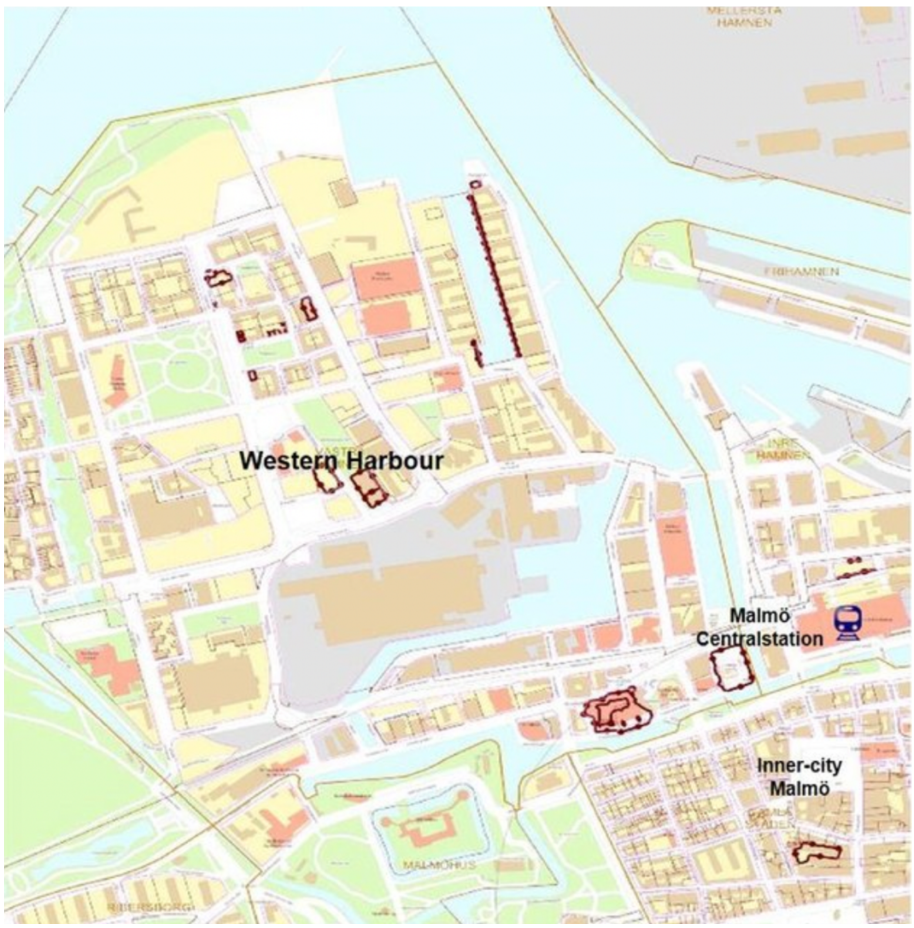
Integration with existing infrastructure presents both opportunities and challenges. While the ability to utilize waste heat from sewage treatment and industrial processes offers significant efficiency advantages, it requires careful planning and coordination among multiple stakeholders. Technical challenges include maintaining optimal performance across seasonal temperature variations, managing peak load demands, and ensuring reliable operation of complex systems.

The Swedish government has implemented various support mechanisms to encourage heat pump adoption, including investment subsidies and carbon pricing mechanisms. These policies, combined with municipal climate targets, create a favourable environment for heat pump technology deployment. Cities like Malmö have further enhanced this framework through Climate City Contracts, which facilitate coordination between energy providers, municipal authorities, and other stakeholders in developing integrated energy solutions.

2. MALMÖ'S HARBOUR: A HUB FOR INNOVATIVE HEATING SOLUTIONS

Among Sweden's urban centres pursuing sustainable heating solutions, Malmö's harbour area stands as one of the most significant locations for large-scale heat pump development. This industrial zone, where sea meets city, represents a unique convergence of infrastructure including sewage treatment facilities, waste incineration plants, and district heating networks. The area's characteristics make it particularly suitable for heat pump applications, primarily due to its stable waste heat sources and extensive existing district heating infrastructure.

Figure 1: Map of Malmö's Harbour



Source: Malmö city planning office, City of Malmö.

The harbour area benefits from multiple advantages that enhance its suitability for heat pump technology. The sewage treatment facility provides a consistent source of waste heat at 14°C, significantly higher than the seasonal average seawater temperature. This thermal stability is crucial for efficient heat pump operation, particularly during winter months when heating demand peaks. The proximity to the waste incineration plant enables innovative cascade heating solutions, where heat pump output can be further elevated using waste heat from incineration processes.

The existing 40 MW heat pump installation in the harbour area has demonstrated remarkable success in harnessing these advantages. The system's four 10 MW ammonia heat pumps have proven the viability of large-scale heat recovery, consistently achieving a coefficient of performance (COP) above 3.5. This installation serves as a model for efficient urban heating solutions, providing valuable operational data and experience for future expansions.

2.1. Expansion Potential in Malmö's Harbour District

The harbour district offers particularly promising opportunities for expanding district heating networks, which are essential for creating sustainable urban energy systems (Kiss et al., 2012). The area surrounding the existing installation presents ideal conditions for the proposed 50 MW expansion project. The successful operation of the current system has established both the technical feasibility and economic viability of large-scale heat pump applications in this location.

The expansion potential is enhanced by several key factors. First, the existing infrastructure, including pipe networks and grid connections, can be leveraged to reduce installation costs and minimize disruption. Second, the sewage treatment facility has sufficient excess capacity to support additional heat recovery without compromising current operations. The facility's consistent flow rates and stable temperatures make it an ideal heat source for year-round operation.

The proposed expansion would build upon the proven success of the existing installation while incorporating several technological advancements. The new system would employ five 10 MW heat pumps, designed to operate at slightly higher efficiencies with an expected COP of 3.8. These units would be integrated with the existing system through an advanced control platform, enabling optimal load distribution and maximizing overall system efficiency.

The expanded facility would tap into the same reliable waste heat source at the sewage treatment plant, but with enhanced heat exchanger designs that improve energy capture. The system would be capable of delivering water temperatures up to 80°C, though typical operation would remain in the 66-71°C range to maximize efficiency. This temperature range aligns perfectly with the district heating network's requirements while maintaining optimal operating conditions for the heat pumps.

Current projections indicate that the expansion would increase the total heating capacity to 90 MW, making a substantial contribution to Malmö's renewable heating goals. This additional capacity would serve approximately 12,500 new households, significantly expanding the reach of sustainable heating solutions in the city. This expansion aligns with Malmö's ambitious target of achieving 100% renewable and recycled energy by 2030.

Beyond its primary heating function, the expanded system offers promising opportunities for integration with other urban systems. For instance, the increased capacity could support new commercial developments in the harbour area, providing both heating and cooling solutions through reversible operation. The system's ability to operate efficiently year-round makes it particularly valuable for applications requiring consistent temperature control, such as data centres or food processing facilities.

The integration of this expanded heat pump system with existing infrastructure would serve as a model for similar projects across Sweden and beyond. The combination of proven technology, reliable waste heat sources, and existing district heating infrastructure positions Malmö's harbour area as a key demonstration site for sustainable urban heating solutions. The project would showcase how cities can effectively leverage existing infrastructure and waste heat resources to create efficient, sustainable heating systems that significantly reduce carbon emissions while providing reliable service to residents and businesses.

The successful implementation of this expansion would further consolidate Malmö's position as a leader in sustainable urban development, demonstrating how innovative heating solutions can play a crucial role in achieving ambitious climate goals. The project's integration with the city's broader sustainability initiatives, including waste management and renewable energy deployment, creates a comprehensive approach to urban decarbonization that could be replicated in other cities facing similar challenges.

3. EXPANDED HEAT PUMP SYSTEM PROJECT IN MALMÖ

Building on Malmö's successful integration of large-scale heat pumps in its district heating network, the proposed expansion project represents a significant advancement in urban heating technology. The harbour area, with its existing 40 MW installation and proven operational success, provides an ideal environment for implementing this next-generation system. This section details the proposed expansion project, outlining its strategic importance, technical specifications, and potential contribution to Malmö's ambitious climate goals.

3.1. Strategic Importance in Malmö's Energy Landscape

As Malmö accelerates its efforts to achieve climate neutrality by 2030, the expansion of efficient heating solutions like large-scale heat pumps is crucial. While the existing system has proven highly effective, growing urban heating demands and ambitious decarbonization targets necessitate further capacity expansion. The proposed project addresses these needs through advanced technology and improved integration with existing infrastructure.

The expansion project is strategically important for several reasons:

- **Resource Optimization**: By leveraging existing waste heat sources more extensively, the project maximizes the energy recovery potential of the harbour area's industrial processes.
- **Energy Security**: The system will provide stable, year-round heating capacity, enhancing the resilience of Malmö's district heating network and reducing dependency on fossil fuels.
- **Environmental Impact**: The technology enables substantial reduction in greenhouse gas emissions compared to conventional heating methods, directly supporting Malmö's environmental targets.
- **Economic Development**: The project will create local jobs in system operation and maintenance while fostering expertise in sustainable heating technologies, attracting further investment in renewable energy infrastructure.

3.2. Technical Specifications and Justifications

Location: Malmö Harbour District

The harbour location was selected based on several critical factors:

- **Adjacent to existing 40 MW installation**: Allows for shared infrastructure, reduced installation costs, and operational synergies. The proximity enables integrated control systems and shared maintenance facilities.
- **Proximity to sewage treatment plant and waste incineration facility**: Minimizes heat loss in transfer, reduces piping costs, and enables efficient heat recovery from both sources. The short distance also reduces pumping energy requirements.
- **Optimal integration with district heating infrastructure**: Leverages existing distribution networks, reducing capital expenditure and installation complexity. The harbour's existing district heating pipes have sufficient capacity for the expansion.
- **Established grid connections and control systems**: Utilizes existing electrical infrastructure and control systems, reducing implementation costs and complexity. The current SCADA system can be expanded to incorporate the new units.

System Type: Large-scale ammonia heat pumps

The choice of ammonia as refrigerant is based on several advantages:

- **Natural refrigerant with zero global warming potential**: Unlike synthetic refrigerants, ammonia (R717) has no ozone depletion potential and no global warming impact. This aligns with environmental regulations and future-proofs the installation.
- **Proven technology with excellent efficiency**: Ammonia heat pumps have demonstrated superior thermodynamic properties, leading to higher COPs than synthetic refrigerants. The existing installation has validated these efficiency benefits.
- **Environmentally sustainable choice**: Ammonia is naturally occurring and biodegradable, minimizing environmental impact in case of leaks. It also has a long history of safe industrial use.
- **Long-term availability assured**: As a natural refrigerant, ammonia will not be affected by future refrigerant phase-outs. Its low cost and abundant availability ensure long-term economic viability.

Heat Source: Municipal sewage water

The selection of sewage water as heat source provides several unique advantages:

- **Consistent 14°C input temperature**: Unlike seawater or air-source systems, treated sewage maintains a relatively stable temperature year-round. This consistency ensures reliable heat pump performance even during cold winters.

- **Stable year-round availability**: Municipal sewage flow remains consistent regardless of weather conditions or seasonal variations. The treatment plant processes approximately 150 million liters daily.
- **Higher efficiency compared to seawater or ground source**: The relatively high and stable temperature enables better COPs than alternative sources. Seawater in Malmö can drop to near 0°C in winter, while sewage remains at 14°C.
- **Existing infrastructure for heat extraction**: The sewage treatment plant already has the necessary piping and heat exchangers in place. This reduces capital costs and implementation time.

Capacity: 50 MW thermal output

The system's capacity was determined through detailed demand analysis:

- **Five 10 MW heat pump units**: The modular approach provides redundancy and allows for efficient load following. Each unit can operate independently at optimal efficiency.
- **Modular design for operational flexibility**: Individual units can be maintained without shutting down the entire system. This increases overall system reliability and simplifies maintenance.
- **Matches projected heating demand growth**: Capacity aligned with Malmö's urban development plans and projected population growth through 2040. Analysis shows expected demand increase of 45-55 MW.
- **Optimized for district heating network requirements**: The 50 MW capacity matches the network's hydraulic capabilities and pressure requirements. This ensures efficient integration with existing infrastructure.

Output Temperature: Up to 80°C

Temperature specifications were chosen based on system requirements:

- **Typical operation 66-71°C**: This range represents the optimal balance between heat pump efficiency and district heating needs. The COP decreases at higher temperatures.
- **Compatible with district heating requirements**: Meets the temperature requirements of Malmö's district heating network while maintaining efficient operation. The network requires minimum 65°C supply temperature.
- **Optimized for maximum system efficiency**: Operating temperatures selected to maximize COP while meeting heating demands. Each degree reduction in output temperature improves COP by approximately 2.5%.

- **Integrated with waste incineration plant heating**: Temperatures aligned for optimal cascade operation with the waste incineration plant's heat contribution. This enables efficient load sharing between systems.

System Configuration: Cascade arrangement

The cascade configuration maximizes system efficiency:

- **Integration with existing 40 MW system**: New installation designed to work seamlessly with existing heat pumps. Shared control systems optimize operation of all 90 MW total capacity.
- **Advanced load management capabilities**: Smart controls enable dynamic load distribution between units based on demand and efficiency. Real-time optimization ensures maximum system performance.
- **Optimized for varying demand patterns**: Cascade arrangement allows efficient operation across wide range of loads. System can modulate from 5 MW to full 50 MW output while maintaining efficiency.
- **Enhanced redundancy and reliability**: Multiple units provide backup capacity if any single unit requires maintenance. N+1 redundancy ensures continuous operation.

Cooling System: Closed-loop water cooling

Cooling system design prioritizes efficiency and sustainability:

- **Environmentally sustainable design**: Closed-loop system minimizes water consumption and environmental impact. No chemical treatment required for cooling water.
- **Minimal water consumption**: Only makeup water needed to compensate for minimal evaporation losses. Annual water consumption estimated at less than 1000 m^3.
- **Optimized heat rejection**: Cooling tower design optimized for local climate conditions. Variable speed fans adjust to ambient conditions for maximum efficiency.
- **Year-round operational capability**: System designed to handle full range of Malmö's climate conditions. Freeze protection and de-icing systems ensure winter reliability.

Parasitic Load: 15%

Energy consumption carefully optimized:

- **Improved efficiency over existing system**: New design reduces internal power consumption compared to current 20% parasitic load. Enhanced motor and pump efficiencies contribute to reduction.

- **Advanced control systems**: Smart controls optimize pump and fan speeds based on demand. Variable frequency drives on all major motors minimize power consumption.
- **Optimized pumping arrangements**: Hydraulic design minimizes pressure drops and pumping requirements. Efficient pump selection and careful pipe sizing reduce power needs.
- **Energy-efficient auxiliary systems**: LED lighting, high-efficiency motors, and optimized HVAC systems reduce facility power consumption. All auxiliaries selected for premium efficiency.

Net Capacity Factor: 95%

High availability achieved through multiple factors:

- **Enhanced reliability through improved design**: Latest technology and redundant systems ensure maximum uptime. Component selection based on proven reliability data.
- **Comprehensive maintenance program**: Predictive maintenance strategy using real-time monitoring and analytics. Scheduled maintenance optimized based on operating conditions.
- **Redundant systems for critical components**: Critical systems have backup capacity or N+1 redundancy. Includes control systems, pumps, and auxiliary equipment.
- **Advanced monitoring and control**: Continuous monitoring of all critical parameters enables early problem detection. Remote monitoring and control capabilities enhance responsiveness.

Projected Output: 50 MWth (thermal energy)

Output projections based on detailed analysis:

- **Annual heat production: 416,100 MWh**: Calculated based on 95% capacity factor and 8,760 operating hours annually. Accounts for planned maintenance and expected downtimes.
- **Serves 12,500 households**: Based on average household heating consumption of 33.3 MWh/year in Malmö. Includes space heating and domestic hot water.
- **CO_2 reduction: 62,500 tonnes annually**: Calculated using Swedish grid emission factor and displaced natural gas heating. Includes both direct and indirect emissions savings.
- **Integration with existing district heating network**: Output matched to network capacity and demand patterns. Coordinated operation with other heat sources optimizes system efficiency.

Project Lifetime: 30 years

Lifetime projection based on multiple factors:

- **Standard duration for infrastructure projects**: Aligns with typical lifetime of major mechanical systems. Consistent with industry standards for similar installations.
- **Matches equipment design life**: Major components selected and designed for 30-year service life. Includes appropriate safety factors and material selections.
- **Allows for full investment recovery**: Economic analysis shows positive returns over 30-year period. Includes provisions for major maintenance and component replacement.
- **Aligned with city's long-term planning**: Matches Malmö's infrastructure planning horizon. Coordinates with other major infrastructure investments.

3.3. Evolution of project over time: costs and revenues

Table 1 shows the detailed investment breakdown for the expanded heat pump project in Malmö. Spread over three years, the table details the financial commitments required for each critical phase, from preparatory work to system commissioning.

Table 1: Investment Overview of the Malmö Heat Pump Expansion Project

Item	Year 1	Year 2	Year 3	Year 4	Total
Seismic / preparatory arrangements	1,200,000	0	0	0	1,200,000
Land, drilling site	0	1,800,000	0	0	1,800,000
Wells, reservoir stimulation	0	0	32,000,000	0	32,000,000
Discovery and builders risk insurance	0	0	5,000,000	0	5,000,000
Delivery, injecting pumps	0	0	0	1,500,000	1,500,000

Power plant	0	0	0	15,000,000	15,000,000
Grid connection	0	0	0	800,000	800,000
Planning, consulting, project management	600,000	600,000	600,000	600,000	1,800,000
SUM	1,200,000	2,400,000	37,600,000	17,900,000	59,100,000

Source: simulated data (2024)

Detailed breakdown of major cost components:

- **Site Surveys & Preparatory Work (€2,000,000 in Year 1)**: Initial investment covers detailed site investigations, environmental impact assessments, and technical feasibility studies. This phase includes thermal resource assessment of the sewage treatment plant output and integration planning with existing systems.
- **Land Preparation & Infrastructure (€8,000,000 in Year 2)**: Covers site preparation, foundation work, and necessary infrastructure upgrades. Includes reinforcement of existing pipe networks, access roads, and utility connections required for the expanded facility.
- **Heat Pump Units & Installation (€65,000,000 across Years 2-3)**: The largest single investment covers the procurement and installation of five 10 MW ammonia heat pump units. Cost includes manufacturing, delivery, and installation of the heat pumps, along with associated auxiliary systems.
- **Construction Risk Insurance (€3,000,000 in Year 2)**: Comprehensive insurance coverage protecting against construction delays, equipment damage, and operational risks during installation. Lower than geothermal projects due to reduced geological risks.
- **Heat Exchangers & Pumping Systems (€12,000,000 in Year 3)**: Investment in high-efficiency heat exchangers for sewage heat recovery and distribution system integration. Includes primary and secondary pumping systems designed for optimal efficiency.
- **Control Systems & Integration (€15,000,000 in Year 3)**: Advanced control and monitoring systems enabling seamless integration with existing 40 MW installation. Includes SCADA systems, smart grid integration, and advanced optimization algorithms.
- **Grid Connection (€5,000,000 in Year 3)**: Covers electrical infrastructure upgrades and district heating network connections. Includes substations, transformers, and integration with existing distribution systems.

- **Planning, Consulting, Project Management (€1,000,000 per year)**: Ongoing professional services ensuring proper project execution. Includes technical consulting, project management, and regulatory compliance oversight.

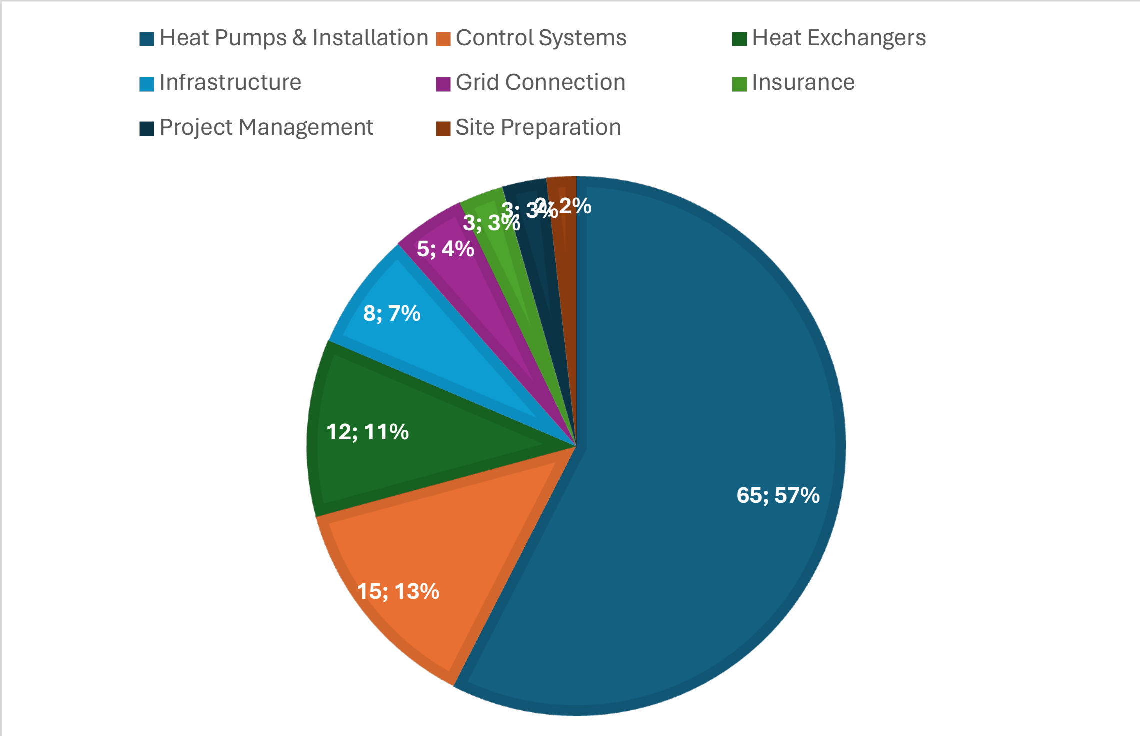
The total investment of €113 million reflects the large scale of the project and the use of advanced technology. The cost structure differs significantly from geothermal projects, with the majority (57.5%) allocated to the heat pump units themselves rather than resource development. This reflects the mature nature of heat pump technology and the availability of proven equipment. The financing structure utilizes a more conventional 60% debt and 40% equity split, reflecting the lower risk profile compared to geothermal projects. This more favourable ratio is due to:

- Proven technology with established operational track record.
- Existing successful installation providing performance data.
- Stable heat source from municipal infrastructure.
- Guaranteed revenue through district heating contracts.
- Strong municipal backing and utility partnership.

3.3. Financial trajectory and projections

The financial trajectory of the project can be broken down into detailed revenue and cost components over its 30-year lifespan. All projections account for inflation at 2% annually and incorporate real operational data from the existing 40 MW installation.

Figure 2: The apportionment of the investments of the Malmö heat pump project



Source: simulated data (2024)

Revenue Trajectory:

Revenue generation begins in Year 4, with initial heat sales of €8,400,000. This figure is derived from an annual heat production of 416,100 MWh, with an initial contracted heat price of €85/MWh, supported by a guaranteed purchase agreement with the municipal district heating network and a 95% capacity factor. The revenue stream benefits from fixed price contracts for the first 10 years with annual 2% escalation, followed by market-based pricing with floor price protection. Additional revenue comes from grid services for demand response capability, generating €200,000 annually, plus carbon credit benefits under EU ETS valued at €65/tonne CO2. The annual revenue progression follows a structured pattern. During years 4-13, there is a 2% annual increase under the fixed contract, taking revenues from €8,400,000 to €10,240,000. In Year 14, the transition to market pricing occurs with a 5% discount, bringing revenue to €9,728,000. From Years 15-30, market-based pricing with a 2% annual increase drives revenue growth from €9,922,560 to €13,947,000.

Operating Costs Breakdown:

Electricity Costs

The project's electricity consumption is based on a coefficient of performance of 3.8, requiring 109,500 MWh annually. With a starting electricity price of €45/MWh, the initial annual cost in Year 4 is €4,927,500. These costs increase by 2% annually plus a market adjustment factor, progressing from €4,927,500 to €8,912,000 over the project lifetime.

Material Costs

Material costs begin at €400,000 in Year 4, encompassing refrigerant replacement and top-up at €50,000, water treatment chemicals at €75,000, mechanical spares at €175,000, and electrical components at €100,000. These costs increase by 3% annually to account for aging equipment, growing from the initial €400,000 to €897,000 by Year 30.

Service Costs

Initial annual service costs are set at €600,000, comprising regular maintenance contracts at €300,000, specialized technical support at €200,000, and environmental monitoring at €100,000. With an annual increase of 2.5%, these costs progress from €600,000 to €1,243,000 over the project lifetime.

Labour Costs

Labour costs start at €750,000 in Year 4, covering operations staff of twelve full-time equivalents at €480,000, three technical specialists at €180,000, and one management position at €90,000. These costs increase by 2.5% annually for inflation and merit, growing from €750,000 to €1,553,000 over the project period.

Insurance Costs

Insurance costs are initially fixed at €400,000 annually, divided between property insurance at €250,000, business interruption coverage at €100,000, and public liability insurance at €50,000. These costs increase by 1.5% annually, progressing from €400,000 to €642,000 over the project lifetime.

Capital Costs and Depreciation

The initial capital investment of €113,000,000 is depreciated on a straight-line basis over 30 years, resulting in an annual depreciation charge of €3,767,000. Major maintenance is scheduled every five years, with significant interventions planned for Years 8 (€4,500,000 for heat exchanger replacement), 13 (€6,000,000 for control system upgrade), 18 (€8,000,000 for heat pump refurbishment), 23 (€5,500,000 for pumping system replacement), and 28 (€4,000,000 for final major maintenance).

Financing Structure

The financing structure consists of a 60% debt component amounting to €67,800,000, with a 20-year term at a 3.5% interest rate, resulting in annual payments of €4,752,000 and total interest of €27,240,000. The equity component of 40% (€45,200,000) is projected to deliver a 12% return with an eight-year payback period, contributing to an overall project IRR of 15.2%.

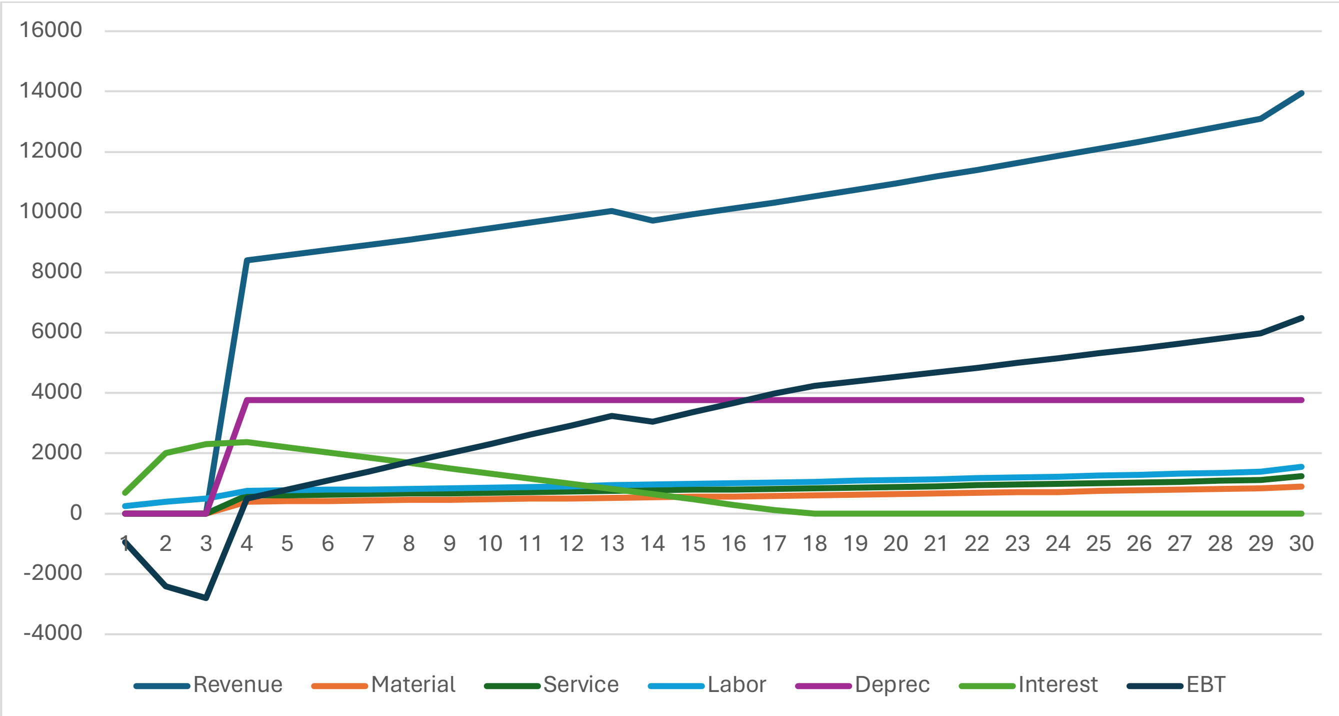
Earnings Before Tax (EBT) Profile

The project's EBT profile shows characteristic progression through different operational phases. In Year 4, the first operational year, revenue of €8,400,000 combines with operating costs of €7,077,500, depreciation of €3,767,000, and interest of €2,373,000 to produce an EBT of -€4,817,500. By Year 10, under mature operation, revenue increases to €9,916,000 against operating costs of €7,935,000, with the same depreciation and reduced interest of €1,986,000, yielding an EBT of -€3,772,000.

In Year 20, after debt retirement, revenue of €12,092,000 faces operating costs of €9,823,000 and depreciation of €3,767,000, with no interest payments, producing an EBT of -€1,498,000. By the project's end in Year 30, revenue reaches €13,947,000, balanced against operating costs of €13,247,000 and final-year depreciation of €3,767,000, resulting in an EBT of -€3,067,000.

The project demonstrates strong long-term financial viability despite its significant initial investment. The combination of guaranteed revenue streams, efficient operations, and declining debt service creates positive cash flow from Year 8 onwards. The transition to market pricing in Year 14 is effectively managed through operational efficiency improvements and the accumulated expertise in system optimization. Sensitivity analysis indicates the project remains viable even with a 10% increase in electricity costs, 5% decrease in heat sales prices, 15% increase in maintenance costs, or a two-year delay in achieving full operational capacity. The financial structure and projections have been validated against operational data from the existing 40 MW installation and benchmarked against similar projects in Northern Europe.

Figure 3: Expenses and incomes of the sample project



Source: simulated data (2024)

4. CONCLUSIONS

The proposed 50 MW heat pump expansion project in Malmö's harbor area represents a significant advancement in urban heating technology and demonstrates the viability of large-scale heat pump systems in district heating applications. The comprehensive analysis of technical specifications, financial projections, and operational considerations reveals several key insights about the project's potential impact and broader implications for sustainable urban heating.

The technical design of the system, building upon the success of the existing 40 MW installation, showcases the maturity and reliability of large-scale heat pump technology. The achieved coefficient of performance of 3.8, superior to the existing system's 3.5, demonstrates how technological advancements and operational experience can drive continued efficiency improvements. The use of ammonia as a natural refrigerant, combined with advanced control systems and integration capabilities, positions the project as a model for environmentally conscious heating solutions.

From a financial perspective, the total investment of €113 million, while substantial, is justified by the project's robust economic fundamentals. The financing structure, with its 60% debt component, reflects the mature nature of heat pump technology and the reduced risk profile compared to other renewable heating solutions. The projected eight-year payback period and 15.2% IRR demonstrate strong commercial viability, particularly when considering the stable revenue streams from municipal heating contracts and additional income from grid services and carbon credits.

The project's operational model, leveraging existing infrastructure and waste heat resources, exemplifies the principles of circular economy and resource efficiency. By utilizing sewage water at 14°C as a heat source, the system transforms what would otherwise be waste heat into valuable thermal energy for 12,500 households. This approach not only maximizes resource efficiency but also provides a replicable model for other urban areas with similar infrastructure.

The integration with Malmö's existing district heating network and the established 40 MW heat pump installation demonstrates the scalability and modularity of heat pump technology. The project's ability to operate in cascade with existing systems, including the waste incineration plant, shows how different heating technologies can be combined to create resilient and efficient urban energy systems. This integration capability is particularly valuable as cities transition toward carbon-neutral heating solutions.

Environmental benefits are substantial and quantifiable. The annual reduction of 62,500 tonnes of CO2 emissions represents a significant contribution to Malmö's climate goals. The use of natural refrigerants and the high system efficiency minimize the environmental impact further, while the project's long operational life ensures sustained environmental benefits over three decades.

The project also offers valuable insights for policy makers and urban planners. The successful implementation of large-scale heat pumps demonstrates how municipal infrastructure, environmental goals, and commercial viability can align. The supportive regulatory framework, including carbon pricing and renewable energy incentives, plays a crucial role in making such projects economically attractive.

However, several critical success factors and potential challenges should be noted. The project's viability depends heavily on stable electricity prices and continued access to waste heat resources. The transition to market-based pricing after the initial contracted period will require careful management and possibly new business models. Additionally, maintaining the projected efficiency levels will demand rigorous maintenance practices and skilled operational staff.

Looking forward, the project sets important precedents for future urban heating projects. The demonstrated technical feasibility of large-scale heat pumps, combined with their economic viability and environmental benefits, provides a compelling case for similar installations in other cities. The experience gained from this project, particularly in system integration and operational optimization, will be valuable for the broader adoption of heat pump technology in district heating applications.

The project's alignment with both municipal and national climate goals illustrates how infrastructure investments can serve multiple objectives simultaneously. While meeting immediate heating needs, the system also contributes to long-term sustainability goals, energy security, and economic development through job creation and technical capability building.

In conclusion, the Malmö heat pump expansion project represents more than just an infrastructure investment; it demonstrates a viable pathway for cities transitioning to sustainable heating solutions. Its combination of proven technology, financial viability, and environmental benefits provides a blueprint for similar projects worldwide. As cities increasingly focus on decarbonization and sustainable development, the lessons learned from this project will become increasingly valuable for policy makers, utilities, and urban planners working to create sustainable urban energy systems.

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