Helsinki Energy Challenge: How can we decarbonize the heating of Helsinki, using as little biomass as possible?

22.1.2021

Abstract

Global climate change has created an environmental push to change heating technologies in Helsinki and elsewhere. Multi-party negotiations are needed to create a market pull for such technologies. We give examples of results that could appear in such negotiations, the top three of which form the backbone of our solution.

- A decision to electrify heating. We propose that technologies with the highest coefficient of performance (COP) should be prioritized when doing this. In practice, our technical solution consists of different kinds of heat pumps, use of excess heat, demand response utilizing different kinds of storage, and, if needed, electric boilers.
- A target size and timetable for creating a new heat procurement market. We propose new market instruments like a hybrid tariff for hybrid heaters and a feed-in tariff for heat providers. These are needed to change heat pump owners from competitors to collaborators in district heating.
- A new vision for the district heating network. We see district heating network as a digitalized platform for decentralized heat exchange, enabling optimization of energy efficiency from production to consumption.

Our solution replaces the coal used in Salmisaari, reducing Helen's CO_2 emissions generated in district heating from the planned 2024 level of 0,7 Mt to 0,2 Mt in 2030.

The biggest environmental impact is created by the electricity used in the technologies we suggest. We recommend that all electricity used in the heat production, traded on the new transparent heating market, be certified with a renewable energy certificate (REC). However, this condition is not a deal-breaker. Electrifying heating in the first place has a considerably bigger positive environmental impact than can be achieved by also using REC-certified electricity to power our solution.

The estimated total investment cost of our 300-MW coal-replacement solution is 400 million euros. Investments can be done either by Helen or, as in the market model we propose, by third parties.

If the investments are made by third parties following our model, Helen adds a new feed-in tariff to their current heat procurement price. We estimate the cumulative cost of this to be €150 M during the period that the tariff is needed. This would increase the end-user price of district heat by 2%.

Time-critical steps on our implementation timeline include the negotiations needed to spur the systemic change that we propose. To ensure engagement from all the parties necessary, it is important to agree on the new vision for the district heating network. The parties involved finalize the market instruments needed together. This way, they become widely accepted and sustainable in the long run.

Our solution aims at solving the current pain points of main actors; therefore, we expect our solution to be easy for most stakeholders to accept. Of course, there are trade-offs for each of them to make between existing and future benefits. We reserve time for those considerations right at the beginning of the process.

We use mature technologies and technologies in the commercialization phase. There is room for technological development that provides additional economic benefits, but our solution is not dependent on it.

Our new market rules improve the transparency, equality, and effectivity of the system. Decentralizing and electrifying district heating increases both the reliability of the system and its supply security.

Energy-efficiency measures lead to smaller needs for both peak and back-up capacity. They can be provided either by using the electricity resistors in heat pumps or by the electric boilers built for market back-up. In 2030, our solution will have added 800 MW to the total capacity, 300 MW of which can be categorized as coal-replacing base load capacity. The other 500 MW is short-term peak load capacity (demand response).

Preface

> *"The climate crisis is the most crucial challenge of our time, and cities have a key role to play in driving the transition to a low-carbon economy. Helsinki is one of the leading cities in the transition towards a sustainable future, with the goal of becoming carbon neutral by 2035. But there is an issue to overcome. Currently, more than half of the city's heat is produced with coal. To reach the carbon-neutrality goal, radically new solutions are needed to meet Helsinki's heat demand. To fight climate change, sustainable heating solutions are needed in cities all over the world.*
>
> *That is why Helsinki City launched the Helsinki Energy Challenge."*
>
> - *https://energychallenge.hel.fi*

This report describes how our team "Consumers to Heat Producers" tackles the Helsinki Energy Challenge.

We adopted that team name, because we think that turning consumers to heat producers is the most important of all changes that we suggest. We describe what kind of new market rules are needed to get new key players to the negotiation table: owners and managers of buildings and land. We need them onboard if we want to realize our vision about the district heating network as a digitalized platform for decentralized heat exchange.

We take part in this challenge because we feel that we have a contribution to make. At the time when we worked together at Helen, things were not possible that are possible now. We have also learned a lot since then, in the different roles that we have held in our working lives. We see this competition as a unique opportunity to design a solution that reaches for the best for not only one organization but for the whole local community.

We hope that this report helps to conceptualize new ideas. Of course, we would be glad if some of them even were implemented.

We admire the courage of the organizers, launching a competition like this, and we thank them for all support and good co-operation during the competition. Special thanks go to our families for their patience during our endless Zoom meetings and to all friends that commented our final solution.

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Table of Contents

Definitions and technology descriptions

AI is an abbreviation of artificial intelligence. It is used in this paper to describe the kind of automated monitoring and control of heat consumption that allows for the optimization of both production and consumption.

Air-to-water heat pump refers to a heat pump solution where the heat content of compressed outdoor air is transformed into hot water. During summer, the system can be used to produce cooling. This technology is widely used in single-family houses. District heating companies are piloting MW-scale solutions where heat is also used for district heating. The coefficient of performance (COP) for this technology decreases below 2 in -10^{o} C.

Ceiling price refers to the highest possible feed-in tariff price. Heat producers are granted support up to the ceiling price. In other words, when the price of electricity goes up, the amount of support does not increase after the ceiling price is achieved.

COP is an abbreviation for *"*coefficient of performance". It describes the ratio for how much heat can be produced with an amount of electricity (e.g. COP 3 means that with 1 MW of electricity, it is possible to produce 3 MW of heat).

Deep geothermal refers to a technology where two boreholes/wells approximately 6–8 kilometres deep are drilled into the ground. Through one of the holes, water is pumped down to the bedrock. That water is heated by the earth's crust. Hot water is pumped up via the other hole, and the additional heat is captured with a heat exchanger and fed into the district heating network. This technology is in its commercialization phase. https://www.st1.com/geothermal-heat

Demand response refers to a solution where the heat demand pattern is changed to benefit the system. Throughout the day, different buildings are heated in flexible ways without the users noticing a change in indoor temperatures or in the availability of hot water.

DH is an abbreviation for district heating.

Electric boilers are a technology where electricity is used to produce hot water directly to the district heating network. They are a mature technology already used in district heating in other Nordic countries, for example.

Excess heat from data centres and other industrial sources refers to a solution where the excess heat from an industrial process or similar (e.g. data centres) is used for district heating directly or after investments in heat recovery equipment and a heat pump plant. This technology is mature and widely used. https://www.sitra.fi/en/cases/district-heating-from-data-centre-waste-heat-mantsala/

Feed-in tariff is a tariff structure where heat producers are granted a guarantee price during a certain period. Feed-in tariffs have been widely used in the electricity sector to boost development of renewable electricity production.

Floor price refers to the lowest feed-in tariff price when the heat producer is granted additional support. The existing open district heat tariff is applied below the floor price.

GSHP and other integrated building solutions are solutions where the heat from a ground source heat pump (GSHP) or, for example, centralized exhaust air heat pumps, is used not only for the building where they are installed but also for district heating. Some technical development is still needed before these technologies can effectively supply heat to the district heating network.

HOB refers to heat only boiler.

Housing company is a form of limited company that has control over an apartment building. Owning shares in the company entitles one to possession of one or several apartments.

Hybrid tariff refers to a district heating tariff structure where the base fee is minimal and energy fee is higher than in the current district heating tariff. The tariff is aimed at end users who have a hybrid heating system (more than one energy source) and for whom district heating is a supplementary or a back-up source of energy.

Medium deep geothermal wells / other medium-sized heat sources refer to technologies where wells of around 1–3 kilometres deep are drilled into the ground. During the heating phase, the bedrock cools gradually. On the other hand, during the cooling phase, energy is brought down to the bottom of the well, recharging the bedrock and bridging the energy gap generated during the heating phase. This technology is in a commercialization phase. https://www.qheat.fi/concept/

Platform refers to the current district heating network used as an energy carrier and modelled digitally to enable automated optimization and control of heating.

REC is an abbreviation for renewable energy certificates, which are tradable, non-tangible commodities certifying that the traded electricity comes from a renewable source.

Sea water heat pump refers to a technology that utilizes mass volumes and large-scale heat pumps to capture the heat of sea water. This technology is in the development phase in the context of Helsinki. *https://www.helen.fi/helen-oy/vastuullisuus/ajankohtaista/blogi/2019/merivesilampopumput*

Smart heating control refers to a solution where AI-driven, continuous indoor temperature monitoring is combined with building-level heating control. It enables optimization of the district heating system as a whole.

Support corridor refers to the price area between the *ceiling price and floor price* when a feed-in tariff is applied.

1 Summary

1.1 Why is there a problem?

It looks as though heating Helsinki without burning anything is a *technical* challenge. Partly, it is.

It also looks as though the owners of the problem are Helen and its owner, the City of Helsinki. Partly, they are.

When you try to add new technical solutions and solution providers to the equation, however, it reveals its more complex nature.

Our team, Consumers to Heat Producers (CHP), takes as its starting point *a systemic view* of this remote capital in Northern Europe. In that view, heating Helsinki is a technical problem; however, we point out that it is a *social* problem to decide which technologies can be used and how. A core part of this social problem is comprised by the existing *market* rules. They, in turn, are results of *political* processes.

"Political" is here understood as citizens and companies negotiating with city officials and regulators on a national and EU level about how to live their lives so that their city really becomes the most functional in the world.

What makes the problem critical, bringing us all, for example, to this contest to find solutions, is the *environmental* nature of the problem. Past solutions to the problem are creating an urgent need to do something differently and now. Climate change is not only the problem of a remote capital in Northern Europe – the whole globe owns it, which means they might have an interest in how it is solved.

It is a daunting task to suggest a solution to a problem with so many potential layers and problem owners.

We approach the task by narrowing the question. Within this contest, it is not possible to engage all parties creating the current state of affairs and challenge them to change things – something of that nature is only possible after this contest. We emphasize that those parties need to be engaged, as they are the actors who can make the change. The only thing we can do within this contest is to sketch what the result could look like if a limited number of the main actors sat down and did what each of them can do to find a systemic solution to heating a city without coal or biomass.

We ask the reader to start with the understanding that even the actors that we define as most central to the problem are embedded in the wider context. Even parties from that wider context might need to be engaged in the real negotiations, in order to enable a change that is fast enough.

We also ask the reader to be open to several suggestions that may at first not sound realistic, because we're challenging an existing equilibrium that has worked very well for many parties for so long. Moving to a new, more sustainable equilibrium requires a new kind of thinking from all parties. New benefits need to be found by the actors themselves, as well as new interactions to be formed between them to motivate the change.

Our proposal is an attempt to make the main problem owners in Helsinki believe that the most functional city in the world will be warm, even in the winter, and even if more than heating technologies are changed.

1.2 What is the problem?

We identify a minimum of five problem owners that need to be taken into account in order to be able to change the dynamics of the system. In this proposal, we address one core concern for each of them.

The City of Helsinki's core concern is that they have set binding climate targets for the whole city, but their power over the heating question is limited, mainly to the new construction of buildings and heating systems. Decisions over existing buildings are made by free agents in the market. Unfortunately, they are the majority whose actions matter the most in reducing emissions.

Helen's core concern is that the timeline is short to replace coal. There are several technical solutions to choose from and no security as to which of them might prove to be "the winning horse" from the business perspective.

The energy-efficiency service providers' core concern is that the market for the full value of their services hasn't emerged yet in Helsinki. For example, if they have excess heat to sell, it is not valuated the same way as Helen's own production.

Building owners' / residents' core concern is to spend as little money as possible on heating. They support green values, but few of them can pay for such solutions.

Investors' core concern is that there are few bankable projects. The profitability of projects depends on revenues that investments are able to create. Today, revenues are defined so that they make new investments in district heating in Helsinki only possible for Helen.

As the common denominator of these five actors' core concerns seems to be the *economic* nature of the problem, the most detailed attention in our solution will be given to this aspect. Two other layers that we need to address are the *technological* investments needed and the *operational* solution for optimizing use of the city-wide heating system in the long run.

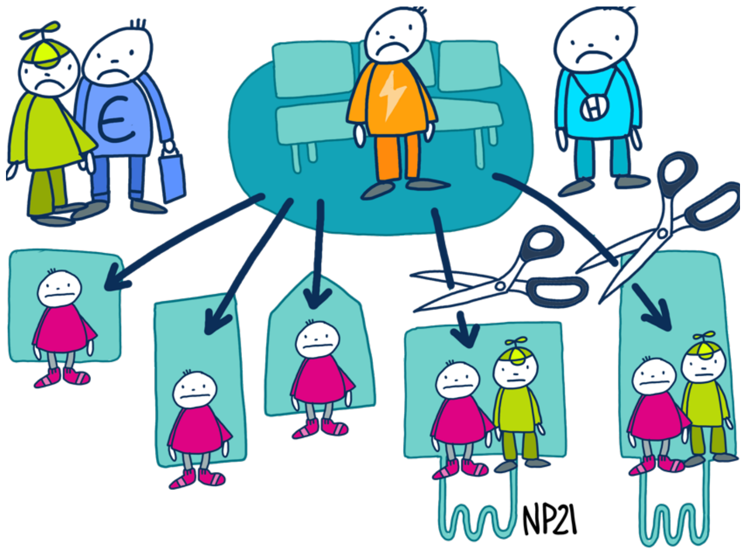


Figure 1. The current district heating market encourages housing companies to build ground source heat pump (GSHP) systems that are sufficient for their own energy needs and to disconnect from the district heating (DH) network after these investments.

It must be noted that these concerns are real and call for solutions, whether they are addressed or not. The current development is leading to a situation where in 2030 more and more of the households and commercial buildings will be heated with heat pumps that are not connected to the district heating network, as pointed out in Figure 1. This makes end-to-end operations of heat production and consumption impossible, resulting in less efficiency in the overall system. The costs of the common infrastructure are left to be covered by fewer customers, which puts pressure on the district heat price.

To turn this tide, we suggest that the core concerns of the five main actors be properly addressed.

The City of Helsinki needs a technical solution for replacing coal by 2029 that is 100% secure. Luckily, there is commercial technology available that could decarbonize heating in Helsinki within a year – it's just that the solution is not that effective. We have the luxury of 15 years, until the carbon neutrality target of 2035, to develop a market for more effective technologies. If nothing else works, electric boilers can be gradually put in place wherever they are needed.

From Helen's point of view, we need lots of investment in fossil-free heat production and soon, but we need cost-effective operation of those investments in order to be economically sustainable over time. Cost-effective operations require that we be able to optimize the energy chain from end-to-end, from production to consumption. Joining forces without losing control over the overall system – how can that be done?

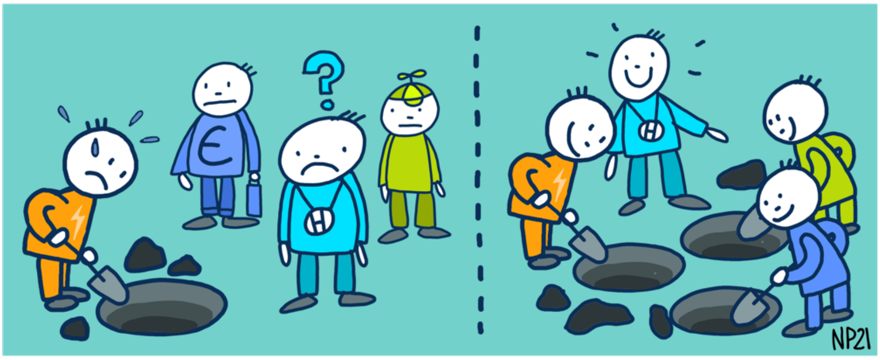


Figure 2. How we make the most of the time and money available

From the point of view of all actors, we need market rules that deliver investment to heat production faster than the current ones. We also need the market to deliver all the heating potential that there is in Helsinki, not just parts of it. With Figure 2 we want to point out that through co-operation with investors and service providers we can accelerate this development.

1.3 How we solve the problem

As most of the core concerns of the central actors seem to be market related, we make markets our core concern. We argue that the existing heating market in Helsinki isn't working as effectively as it could. To make it do so, some changes of thought are needed. These are listed below, illustrated in Figure 3, and summarized in Table 1.

1) *We redefine the subtext in "markets"*
   In our solution, investments and their operations are not expected to come only from one actor, Helen. We open the heating market in Helsinki to all that can deliver heating potential. That means real estate owners, from housing companies to private investors and public building owners. We also open it to institutional investors in heat production, as well as to energy-efficiency service providers.

2) *We redefine some market rules*
   You might argue that the market already *is* open. There's transparent pricing and detailed descriptions of the quality of heat that can be traded to Helen. Our solution challenges these agreements. We examine how small changes in pricing and contracts would affect the overall effectiveness of the market in order to make ends meet in the time frame available.

3) *We digitalize district heating to turn it into a platform for a new kind of heat exchange*
   We point to a difference between production and delivery of heat. Heat delivery in a true multi-actor market calls for new kinds of activities, such as internet of things (IoT) connectivity, open application programming interfaces (APIs), and two-way optimization. The physical heat delivery infrastructure, DH network, is a strategically important asset. It enables decentralized heat production and demand optimization, as soon all operations can be monitored and controlled digitally.

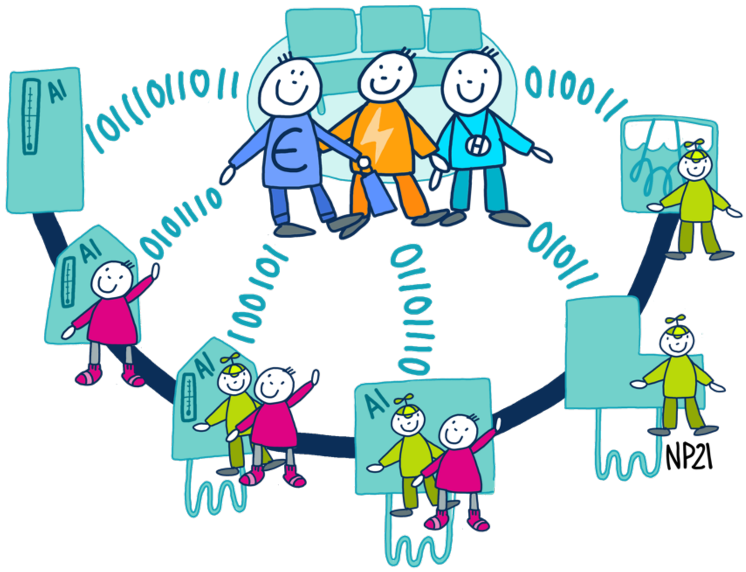


Figure 3. A new vision for the district heating network: a digitalized platform for decentralized heat exchange

1.3.1 Our economic solution: keeping customers in the heat pump era

Our economic solution is threefold. Firstly, we add value to the existing underground heat delivery and storage asset, the district heating network, by making it more attractive in the eyes of all customers – even heat pump users. Secondly, we apply experience from other markets in the emergence phase to make the market develop as quickly as needed. Thirdly, we address the notoriously difficult housing company market through a market design that makes life easy for consumer service companies.

1.3.1.1 New hybrid tariff for hybrid users to keep heat pump investors in the district heating network

A district heating invoice in Helsinki consists of a base fee and an energy fee. Currently, the base fee is so high that it makes it uneconomical for building owners to keep district heating as a backup, as illustrated in Figure 4. Building owners that want to switch to GSHPs or other new building-integrated heat sources are indirectly encouraged to disconnect from the DH network. Our solution is *a new hybrid tariff* for hybrid heaters who want to use district heat as a backup instead of electricity.

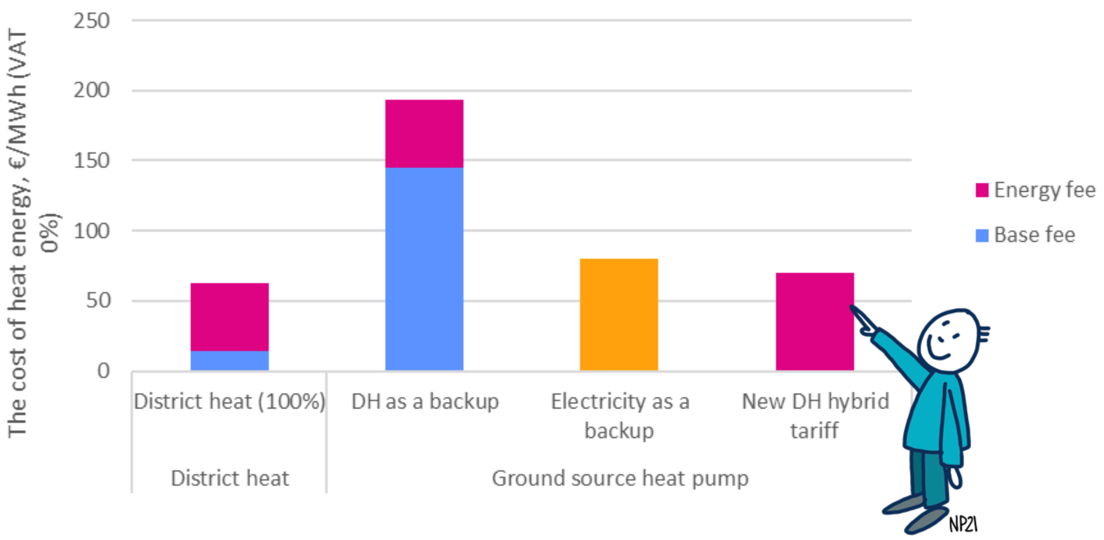


Figure 4. The new hybrid tariff keeps customers with their own heat pump production in the district heating network

Keeping customers who are in the heat pump era is not only important from the point of view of DH network operation and maintenance costs: it is also crucial from the point of view of coal-replacing energy production, as pointed out in Figure 5.

Figure 5. Our solution for the optimal utilization of ground source heating

In practice, the technologies available are mostly different kinds of heat pumps. To install them, ground and buildings are needed. They are owned by private parties. The full potential of the technologies cannot be realized without creating an interesting investment environment for those parties. The importance of this grows remarkably in the near future, when the City of Helsinki starts increasing the share of ground source heat pumps from 0,5% to 15%, which they've stated as their target in 2035.

This makes the new hybrid tariff a strategically important question.

1.3.1.2 New feed-in tariff for heat producers to make the market develop as fast as needed

Another strategically important instrument and a cornerstone for the first phase of implementing our economical solution is *a feed-in tariff* for district heat producers. For a limited period of time, a guarantee price should be paid for excess heat, in order to make heat pump investments more profitable. This can be done if investors in heat pumps are incentivized to dimension their solutions to make use of the whole heating potential available, instead of dimensioning them to provide heat only to the building block on the specific site, as is the case now.

The feed-in tariff aims at establishing at least 300 MWs of new, sustainable DH capacity by 2029 to replace the coal used in Salmisaari. It is an instrument for creating a market environment where new heat producers have an equal possibility with each other and with Helen to invest in new DH production capacity. It also leads to transparent and predictable pricing for all producers. With "sustainable capacity", we refer to different kinds of heat pumps and geothermal heating technologies that have a coefficient of performance (COP) greater than 1,5. That makes them more energy efficient than our backup solution, electric boilers (COP 1).

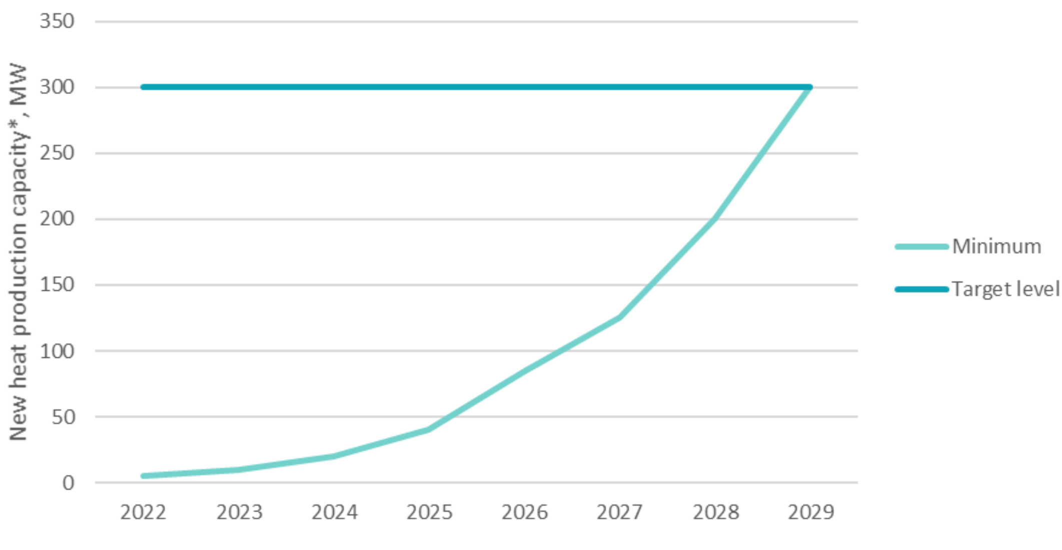


Figure 6. Size of the new, open, and transparent district heating market

Helen can make part of these investments by themselves, but they are obliged to *increase the size of the transparent heating market* yearly, according to the *target set by their owner, the City of Helsinki*. In other words, Helen will be making new heat capacity agreements with external actors until the target level of 300 MWs is achieved as illustrated in Figure 6. Later on, the target can be adjusted higher.

The new feed-in tariff is based on Helen's existing "open district heating" tariff structure, but it includes a guarantee price during the heating season (1.10.–30.4.). New heat producers make heat capacity agreements with Helen for ten years. Pricing is analogous to feed-in-tariffs used in the electricity sector, as illustrated in Figure 7**.**

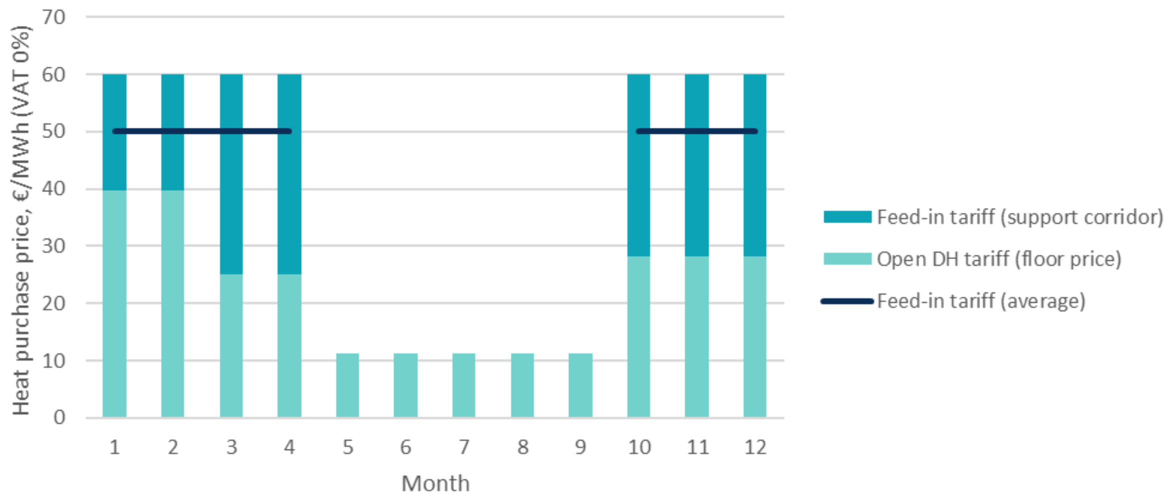


Figure 7. Helen buys heat at a fixed price that is based on electricity price

More specifically, Helen buys heat at a fixed price (Nordpool SPOT (fi) + €10/MWh). The current open DH tariff acts as a floor purchase price. A new ceiling price is set at 60€/MWh. This means that the new heating capacity is additionally subsidized when the electricity price varies between 30€ to 50€/MWh in winter (January to February, according to the open DH tariff), between 15€ to 50€/MWh during spring, and between 18€ to 50€/MWh in autumn. During summer, Helen already has enough sustainable heat production; therefore, the new capacity is not subsidized then. According to 2016 heat production data, the heat demand is above 500 MW more than 98% of the applied feed-in tariff time. This means that our coal-replacing 300 MW fit into the system.

Figure 8 below shows the relation between heat purchase price (current open DH tariff + feed-in tariff) and electricity price during one example day in spring. The figure also shows the heat production cost of a deep geothermal solution with and without capital costs (15 a, 3%). Figure 8 verifies the fact that the current open DH tariff is not sufficient to boost investments in new capacity without additional support.

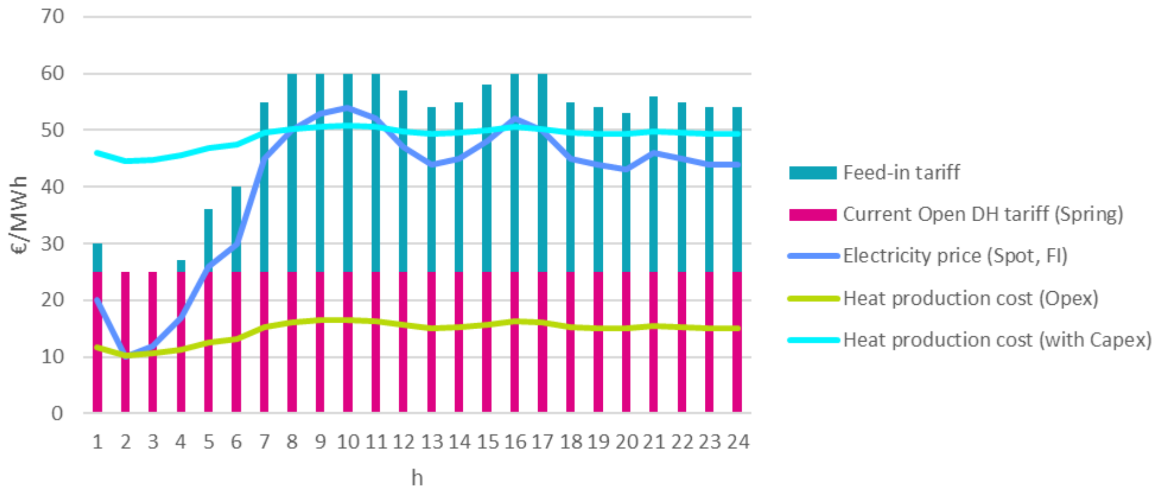


Figure 8. Heat and electricity price fluctuation during an example day in spring: how the feed-in tariff makes it profitable to sell heat produced with heat pumps

After 2029, when coal replacement is secured (or the 300-MW target is met) by adding several new heat production units to the network, it becomes vital to optimize the system as a whole.

There are at least two options for the implementation of our economic solution:

a) Helen remains the district heat market operator, but it has opened its district heating market to new players in a transparent way. Production and distribution of heat are still managed by one company.
b) A new district heating network operator is established to manage and optimize operations and trade in the network. The operator buys district heating energy from heat producers and prosumers, as it doesn't have its own production.

Option A, where Helen is doing the optimization, requires that Helen pay compensation to external heat capacity owners for maintaining capacity. Capacity is activated and optimized based on actual needs. The current open district heating tariff does not allow for this kind of optimization.

In option B, a common marketplace is established. The full design of the second option is beyond the scope of this study.

In both options the optimization method can be driven by the marketplace, as in current electricity reserve markets. It can also be based on connected capacity. In that case, the network operator controls the production through open interfaces, compensating the capacity owner for its use. These optimization-enabling elements (open interfaces, smart controls, etc.) should be required when building the new capacity using the feed-in tariff.

We have seen in cases of wind energy in B2B markets and electric vehicles in B2C markets how a rapid adoption of new technologies happens right after the correct incentives are put in place. The incentives described above are designed to stimulate the emergence of a truly open and transparent district heating market in Helsinki that will deliver the capacity needed for coal replacement within the time frame available. Primarily, the market is addressing the interests of new, Helen-external heat production companies.

Pilots, test beds, and living labs are another way of accelerating adoption of new technologies and supporting the emergence of new markets. Helsinki is even internationally known for its living labs, such as Kalasatama and Jätkäsaari, where new energy solutions are being piloted. Adjusting the district heating network and buildings to the requirements of *a low-temperature district heating network* in some new pilot area of the city would place Helen where it belongs at the forefront of realizing the national Energy Industries' strategy. It would multiply the amount of heat producers that can take part in the new district heating market, making it strategically as important a question as the transparent and fair pricing that our solution focuses on. Heat pumps and other low emission technologies would benefit from a low-temperature network.

1.3.1.3 A market design that makes life easy for consumer service companies

A smaller amount of the new heating capacity is expected to come from building owners, which in Helsinki are typically housing companies. They are something between B2B and B2C markets. They often lack technical knowledge and sometimes even interest in new technical solutions. Additionally, they usually lack money – at least they are very cost oriented in their decision making. Therefore, we address them through energy-efficiency service companies. There is evidence that when service is available, even interested and technically aware people prefer buying it to “doing it themselves”. In housing companies, DIY isn’t even easy, as it isn’t just “you” making the decisions.

There are cases where energy-efficiency service companies have been able to convert large amounts of housing companies to adopt the new technical solutions needed in a very short time. Their secret has been a service model where the factual economical profitability for the customer has been followed by a value promise that eliminates the risk embedded in the change of contract. In addition, they have been able to promise more living comfort (stable indoor temperatures and in some cases cooling in the summer) to the customer.

From the point of view of some service companies, public buildings and B2B customers are an easier entry point to the market than housing companies, as they provide larger volumes behind one customer account. They can be used as market accelerators, providing the reference stories that make the benefits of these new technologies understandable for all.

We make life easy for service companies by suggesting that the City of Helsinki provide the real-time indoor temperature data that service providers need to be able to offer smart heating control and that it be done over an open application programming interface (API). The city can even negotiate general agreements within which it is easy for service providers and housing companies to make service agreements.

The cornerstones of our economic solution are summarized in table 1 in the end of the summary section, along with key elements in our technical and operational solutions that will be presented next.

1.3.2 Our technical solution: highest COP rules

We build on Helen’s existing and planned energy production, using commercial technologies with the lowest overall emissions, particle emissions included.

District heat consumption in Helsinki is assumed to be 5 400 GWh in 2030. When taking distribution loss into account, the needed heat production is around 5 800 GWh in 2030. The year 2024 in Figure 9 below shows Helen’s existing plans to increase coal replacement technologies. Heat only boiler (HOB) production refers mainly to biomass boilers in Vuosaari and Salmisaari. The year 2030 shows how our solution is built on Helen’s plans. The remaining combined heat and power (CHP) is the gas-fired power plant in Vuosaari.

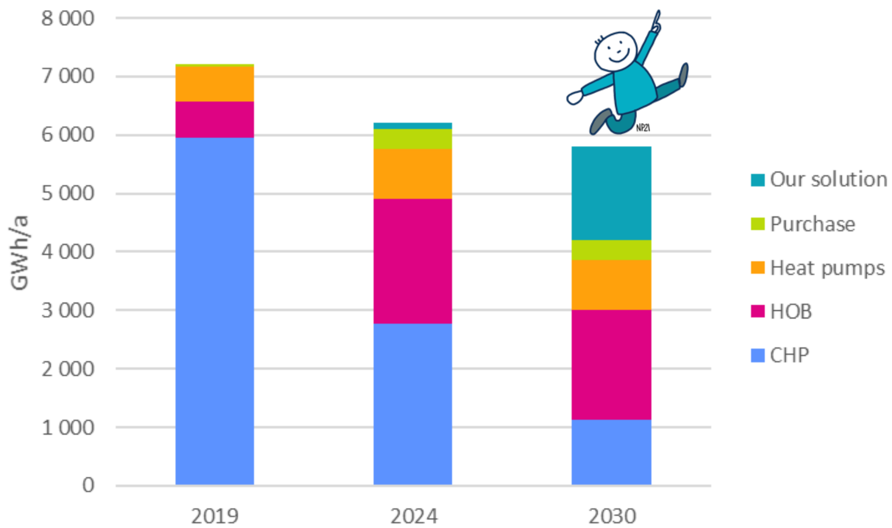


Figure 9. Energy Balance 2030

Our technical solution consists of different kinds of heat pumps, use of excess heat, demand response utilizing different kinds of storage, and, if needed, electric boilers. Because the new feed-in tariff is based on the price of electricity, the participants transforming power to heat using technologies with the highest possible coefficient of performance (COP) will reap the greatest benefits. We call this “the highest COP rule”. Figure 10 shows their potential for covering the need of new heat production capacity in the district heating network.

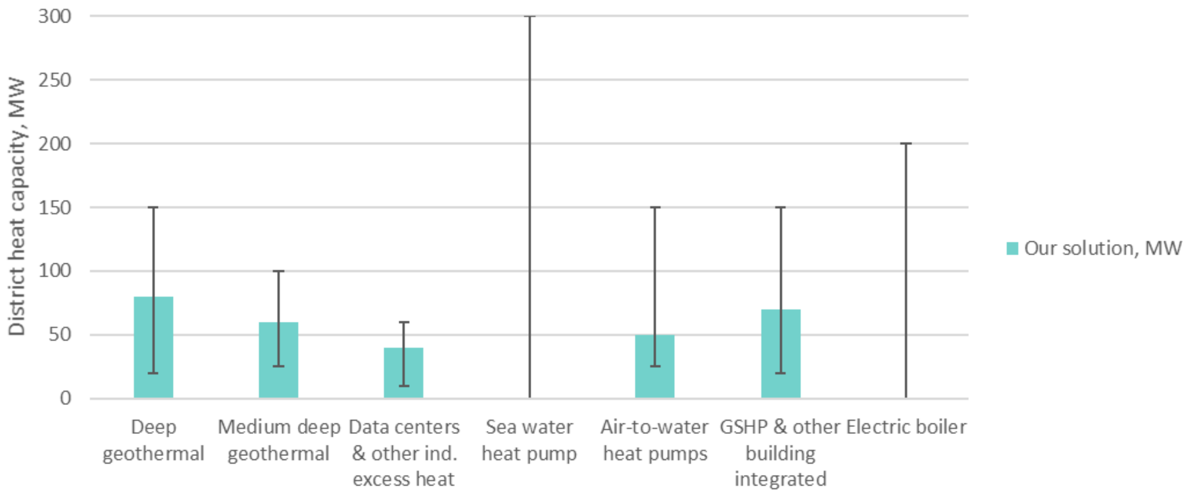


Figure 10. Expected types of heating capacity with estimated variation

The system will include some large-scale geothermal solutions (> 10 MW) as well as a high number of smaller building-level solutions (100 kW). Larger units produce the base load in the system, whereas smaller ones bring flexibility and control. If some of the technologies don’t perform or scale in the market, electric boilers still guarantee the electrification of the district heating system as a whole.

Figure 11 below describes the amount of heat that is produced by the new capacity by 2030. The estimated heat production is 1,6 TWh. Deep geothermal provides the highest share of new capacity and we also assume that its capacity will be utilized during the summer season. If the capacity is owned directly by Helen, they will run it due to the low marginal production cost. If that capacity is owned by some third party, we believe that they will agree with Helen on separate pricing to ensure the most economical production mix.

The potential of medium deep geothermal, air-to-water heat pumps and GSHPs can be limited during summer because they might provide cooling to the buildings to which they are connected. Medium deep geothermal can also act as seasonal heat storage, as already piloted by Vantaan Energia, a neighbouring energy company.

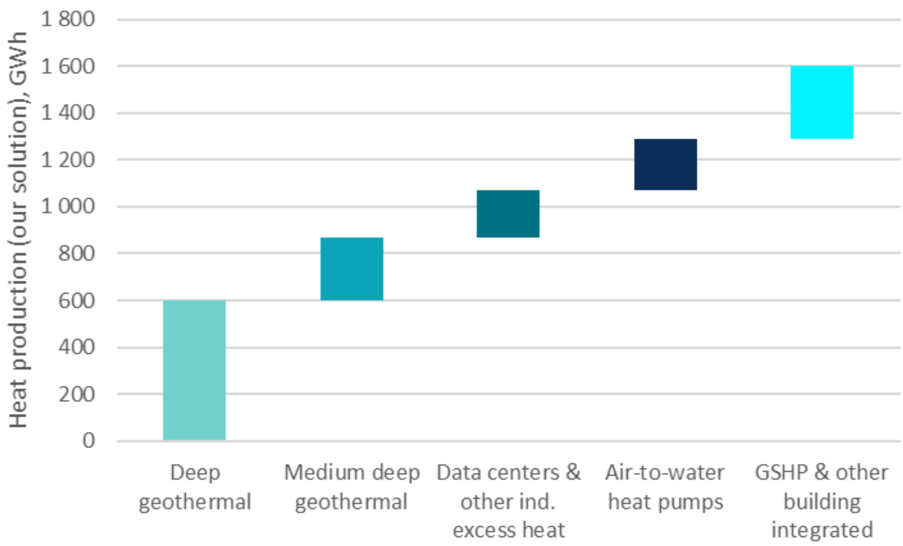


Figure 11 describes the amount of heating energy that is produced in 2029 by the new capacity.

As described above, the new capacity will be built partly by Helen and partly by third parties. In the beginning, Helen may be the main contributor, but the share of third parties will grow as the market develops.

1.3.3 Our operational solution: heat is produced to keep people warm

We present a plan for digitalizing the entire value chain in heating, from production to consumption. We need it to be able to operate the whole system efficiently during varying conditions. This can only be achieved by taking good care of the end customer.

Economic and technical planning for how to heat Helsinki without coal is inspiring. However, in order to be able to design a system that is functional, effective, and sustainable in the long run, we need to keep in mind the fundamental reason why we're doing it, and the reason is basically that nobody likes feeling cold.

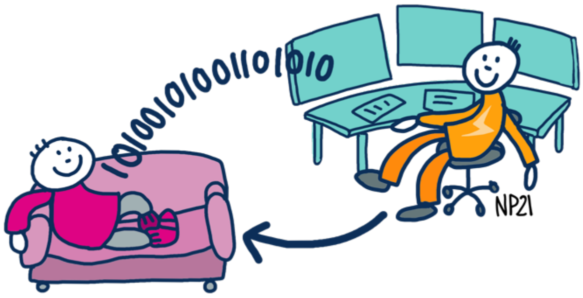


Figure 12. System-level optimization is not possible without visibility to end user living conditions

Understanding heating as a basic human need and making that need our first design principle emphasizes the importance of knowing what happens with all the produced energy. Is it warming people and important functions?

Indoor temperatures can be monitored. It is astonishing that this information isn't already a vital part of the energy-efficiency optimization of the system, as it provides so many system-level benefits. Better understanding of consumption gives us more possibilities regarding network temperatures, peak and reserve capacity building, flexibility functions, etc. Figure 12 above points out the importance. These are described a bit later in detail.

Our suggestion is that apartment temperature measurements be promoted in private households by the City of Helsinki. The city would even collect the data, aggregate it when necessary, for privacy reasons, and administer how data owners can give their consent to service providers to use it. This allows data to be used efficiently for improving the energy efficiency of the buildings. Piloting automated indoor temperature monitoring in public buildings would build up the competence of city officials, enabling them to support private housing market with advice, examples, and case studies.

Service providers can build heating control services on top of indoor temperature measurements. We would make the City of Helsinki the actor that publicly requests bids for data acquisition of indoor temperatures.

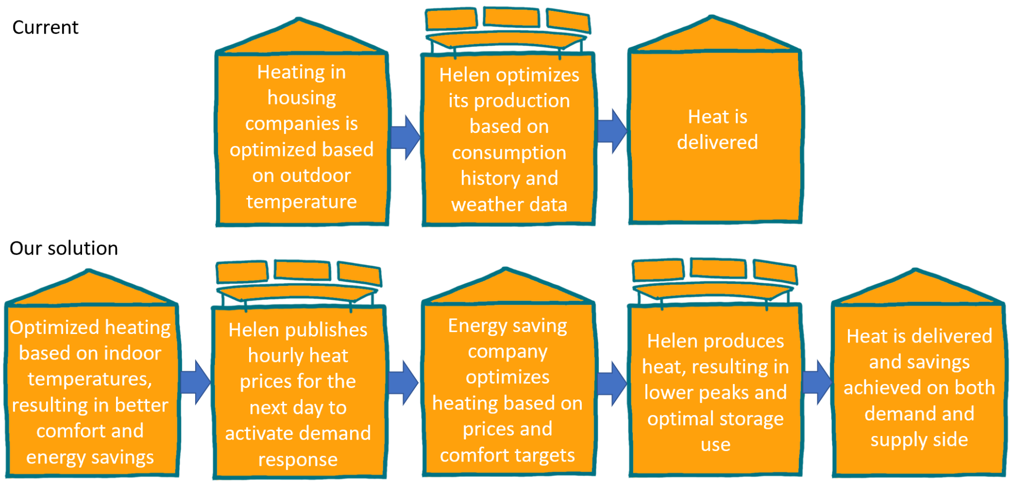


Figure 13. System-level optimization now and after implementation of our solution

The benefits of controlling heat demand in buildings are: 1) lower overall capacity requirement; 2) reduction of overall heat consumption; 3) more stable indoor temperatures; and 4) the possibility to optimize the energy chain from production to consumption. They are described in more detail below.

1) AI-driven continuous heating control typically results in about a 20% reduction in needed capacity. This is accomplished by preheating the building during non-peak hours and by reducing the space heating temporarily for peak consumption times. The City of Helsinki's Energy Renaissance programme provides additional support in this by ensuring that energy efficiency measures are taken in old buildings that improve their heat-storing capacity.
2) Continuous consumption is typically reduced by 7% without changing the indoor temperature target. This is possible by utilizing the apartment-level temperature data for control and correction of imbalances in the heating network. Other benefits include predictive heating based on weather forecasts, making full use of passive solar energy.
3) All of this is also beneficial for people living in the apartments. Indoor temperatures are more stable and uncontrolled overheating is reduced during springtime.
4) Automated and AI-driven heating control systems model how buildings store and radiate heat. They are capable of predicting what kind of flexibility there is in a specific building to store or radiate heat at a specific time, according to known weather forecasts and past heating history. As these flexibilities are aggregated, they can be used as short-term thermal storages in the district heat optimization system. This complements the normal operation which Helen has been doing for years with its own heat storages but not with buildings.

The result is optimization of the whole energy chain. From production to distribution and consumption, energy can be used more effectively than today, as pointed out above in Figure 13.

Even more energy efficiency can be gained through sector integration. Our solution combines flexible, predictable heating capacity with low-cost electricity for heat pumps, minimizing heating costs and mitigating the volatility of the power market.

1.3.4 Cornerstones of the solution

To solve the technical challenges, we reveal the market challenges behind them and address the root causes of the problem. This is how we create a pull for commercially viable emission-free technologies, making sure that technologies with the highest coefficient of performance (COP) are applied first. We even make sure that all technical solutions and market incentives are in place for the overall cost and energy-effective optimization of the system as described in Table 1.

Table 1. Our solution to the identified technical and market challenges

Technical challenges	Market challenges behind the technical challenges	Our solution
Coal technology needs to be replaced.	Current district heating market discourages external actors' investments in coal replacement technologies and the use of external excess heat sources in DH network.	A new feed-in tariff for excess heat guarantees reasonable payback periods for coal replacement technology investments and opens the DH market to third parties. Integration of external heating energy sources to the production optimization system is made easy.
To replace coal, the city-wide system needs the full heating potential of geothermal, GSHP, and other heat pump technologies that exist in Helsinki.	The current district heating market encourages housing companies and other building owners to: 1) build heat pump systems that are only sufficient for their own energy needs; and 2) leave the DH network when investing in GSHPs or other new heat sources.	The new feed-in tariff along with a new hybrid tariff for hybrid district heaters (DH as a backup) make excess energy production and staying in the DH network profitable for housing companies and other building owners.

Production and consumption of DH needs to be effectively optimized on the system level.	System-level optimization is not possible without visibility to end-user living conditions. Current tariff models do not encourage consumer-side optimization.	Automated indoor temperature monitoring makes it possible to adjust heating effect based on real needs, saving energy and money. Hourly pricing of district heating or some other intra-day pricing instrument encourages building heaters to shave peaks, lowering the total peak capacity need and enabling the use of existing buildings as intra-day heat storages.

A summary of how heat is sold and bought based on our plan is presented in following tables: Table 2, Table 3 and Table 4. They describe it from different actors' points of view.

Table 2. District heat tariffs for business customers and housing companies

Heat tariff	Value proposition	Remarks
District Heat, Standard	• 100% district heat • Reliable and easy solution • Seasonal pricing • 24/7 service always available	• Helen's current price structure • https://www.helen.fi/en/companies/heating-for-companies • Cost elements behind energy and base fee should be opened to provide transparency and predictability.
Hybrid tariff for hybrid heaters	• District heat as a back-up 24/7 • Seasonal pricing with a minimal base fee • During high electricity prices, customers can optimize the use of different energy sources • Feed-in tariff can be used when selling excess heat	• Lower fixed fee is compensated by a higher energy fee • Costs less than using direct electricity heating as a backup • If customer is using 100% DH, hybrid tariff is more expensive than standard district heating
Flex heat, hourly pricing for flexibility providers	• Encourages demand side actions • Can be combined to all district heat tariffs • Transparent hourly indexed pricing • "Other users have saved up to x % with this" • Available only for Helen approved technologies (open interface to communicate demand response)	• Hourly pricing is published a day in advance through open API • Peak hours more expensive than others • Lower prices for customers that shift their demand within a day • Enables Helen to reflect electricity price variation in their heat prices

Table 3. District heat services for an end customer

Heat service	Value proposition	Remarks
Renewable District Heat	• By choosing Renewable District Heat for your home, you can reduce your carbon footprint easily for just a small extra fee. • You can order Renewable District Heat whether you live in an apartment block or a terraced house, or whether you are renting or own your home.	• https://www.helen.fi/en/heating-and-cooling/renewable-district-heating

Flexible District Heat	• By choosing Flexible District Heat for your home, you help Helsinki to reach its climate targets • You allow your living conditions to vary within +/- 1°C and even more when you're not at home • Available only for Flex heat contracts • Annual benefits for your flexibility	• Requires monitoring and smart control of living conditions, included in Flex heat contract • Other services can be added to the service

Table 4. District heat purchase tariffs for business customers and housing companies

Heat purhace tariff	Value proposition	Remarks
Open District Heat	• By selling surplus heat, you will increase the energy efficiency of your property and have a predictable income flow. • Seasonal pricing • Easy solution for existing customers	• https:/www.helen.fi/en/companies/heating-for-companies/open-district-heat
Feed-in tariff	• Additional support to Open District Heat tariff • Price guarantee for 10 years • Spot + 10 €/MWh is paid between 1.10-30.4 • In summer, a special price for the activated capacity • Requires systems with open interface and remote control	• Tariff level is checked against the 300 MW target annually • Technology needs to be compatible with Helen's production optimization system to allow summertime optimization and later system level optimization

2 Climate impacts

Electrifying heating in Helsinki results in zero greenhouse gas (GHG) emissions in the long run, as the emissions of electricity are decreasing over time. Even other emissions (SO_x, NO_x, particles) will decrease when more and more of the district heating production is electrified.

Our CO_2 emission analysis is based on general emission factors used in Finland (https://www.motiva.fi/files/16063/CO2-laskentaohje_-_Yhteenvedot.pdf) and capacity calculations presented in Chapter 8. We assume overall COP 3, which means 300% efficiency for the use of electricity. The planned heat procurement (from Vantaan Energia) by Helen (340 GWh) is assumed to be CO_2 free, because its emission factor was not available.

Helen's total CO_2 emissions for energy production were 3,3 Mt in 2019. In 2024, when the Hanasaari coal-fired power plant is replaced by the use of biomass, increased energy purchases, heat pumps, and other sources of energy, emissions will drop to the level of 1,5 Mt. In 2030, when even the Salmisaari coal-fired power plant is replaced by our electricity-based solution, emissions will drop to 0,5 Mt level. This development is presented in Figure 14 below.

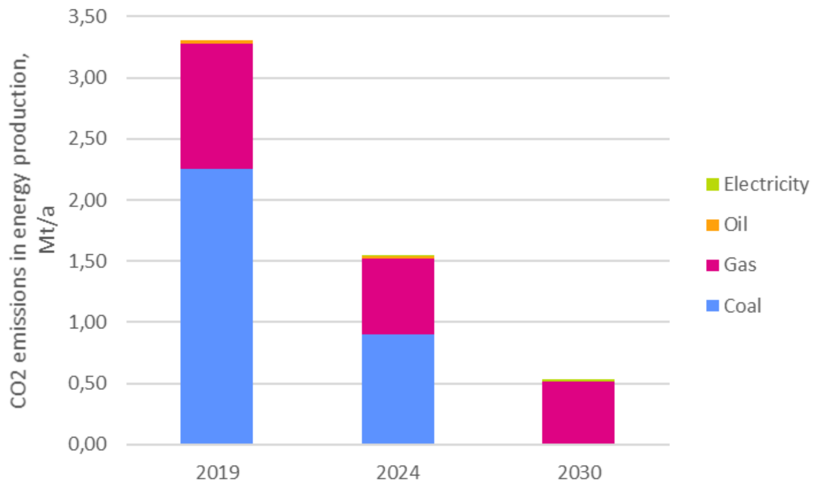


Figure 14. Helen's total CO_2 emissions decrease from 3,3 to 0,5 Mt/a

The coal replacement in Salmisaari requires 0,6 TWh of electricity (COP 3) in 2030. To maximize the emissions decrease, we recommend that all electricity used in heating come from renewable energy certificate (REC) certified sources.

In the greenhouse gas (GHG) emissions inventory of Helsinki, emissions related to the combined power and heat production are calculated using a benefit allocation method. The same method is used in our analysis, following the competition guidelines.

Helen's CO_2 emissions in heat production were 1,4 Mt in 2019. In 2024, emissions will drop to the 0,7 Mt level, and in 2030 they will be at a level of 0,2 Mt, as illustrated below in Figure 15. The emission factor of district heating was 198 g/kWh in 2019 (https://www.helen.fi/helenoy/vastuullisuus/ajankohtaista/blogi/2020/ominaisp%C3%A4%C3%A4st%C3%B6laskenta). It will change to 106 g/kWh in 2024 and 32 g/kWh in 2030.

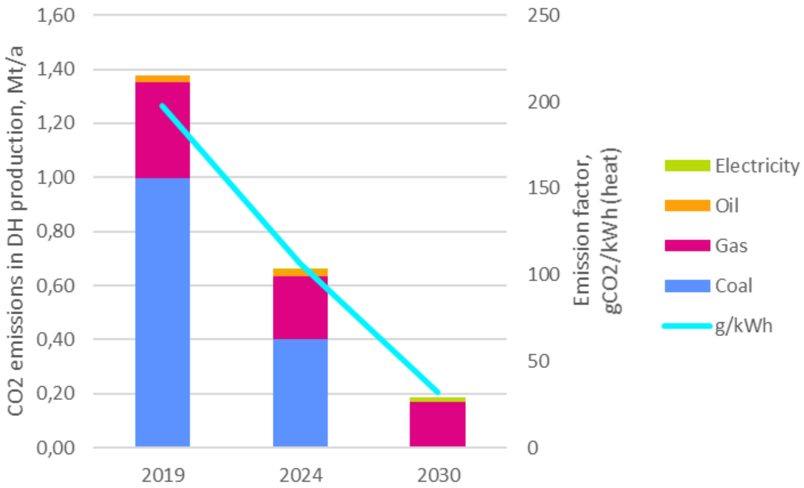


Figure 15. By 2030, our solution reduces the yearly CO_2 emissions of DH by 1,2 Mt from what it was in 2019.

In the new transparent heating market, the new excess capacity of heat pumps can be maximized during the cheapest hourly prices of electricity. At that same time, the emissions are lowest in the Nordic electricity market. The flexibility of the new heating capacity, along with the heat-storing capacity of buildings, heat storage in Mustikkamaa, heat-storing possibility of medium deep geothermal solutions and smart optimization of the whole system enables a wider adaptation of intermittent renewable electricity production (wind/solar). Thus, the sector coupling of heat and electricity benefits both.

Our solution replaces the coal used in Salmisaari, reducing Helen's CO_2 emissions for district heating from the planned 2024 level of 0,7 Mt to 0,2 Mt in 2030.

3 Impact on natural resources

To replace coal, we gradually electrify district heating, building on Helen's existing plans. The biomass used in heat production replacing Hanasaari is not included in our calculations. The same is true when it comes to use of natural gas before 2029. Our solution is to first replace the coal used in Salmisaari (300 MW) with technologies turning electricity into heat that can be traded on the new transparent heating market. To maximize emissions reductions, we recommend that all electricity used in this new heat production is required to be REC certified. However, it is no deal-breaker according to our calculations.

Because the new feed-in tariff is based on the price of electricity, the participants transforming power to heat using technologies with the highest possible coefficient of performance (COP) will reap the greatest benefits. This means that depending on the situation, geothermal energy (COP 7) or ground source heat pumps (GSHPs), other kinds of heat pumps (COP 2–4), excess heat or, if needed, electric boilers (COP 1) will be used. The amount of electricity needed is defined by the COP of the technology. Assuming that the average COP of these technologies is 3, the amount of electricity needed is about 0,53 TWh. If none of the more efficient technologies can be used, the solution would be based on electric boilers, and, in that case, the amount of electricity needed would be 1,6 TWh.

Materials and energy used for manufacturing the heat pumps of different kinds are not estimated in this proposition. In rough terms, those factors are estimated to create 10–20% of the life cycle emissions of these technologies. The majority of the environmental impact of heat pumps is created by the electricity used, which is estimated in the previous section. We even assume that hydrofluorocarbons (HFCs) used in heat pump manufacturing are replaced with more climate-friendly compounds, like CO_2. Other environmental impacts that need to be taken into consideration, such as the potential impacts of heat pumps on ground water, are very site specific and need to be carefully assessed in each case.

Most of these new technologies are using the ground heat potential from 300 to 7 000 metres. As the solutions being built can be dimensioned to serve more than the specific site where they are located, fewer wells need to be drilled. Making sales of heat profitable thus reduces the pressure for land use. Geothermal wells can be utilized as long-term heat storages in summer, which counteracts exhausting the wells, securing heat supply for the coming decades. It also reduces the risk of seasonal heat oversupply.

Some of the heat comes from data centres and other building-integrated solutions where additional land is not needed. In case electric boilers are needed, they can be installed at the premises of existing power plants where the infrastructure is already in place.

Electricity consumption in the Helsinki metropolitan area was 8,5 TWh in 2019. In the whole of Finland, 86 TWh of electricity was consumed. Using COP 3, the additional amount of electricity that our solution needs would be a bit more than 5% of the consumption in the metropolitan area. This does not cause any trouble for the electricity procurement system. Estimates of how much new renewable electricity production capacity would be needed and what the environmental impacts of those construction projects are lie beyond the scope of this proposition.

Our solution utilizes different kinds of heat pump technologies. Their biggest environmental impact is created by the electricity they use. We recommend that all electricity used in the heat production traded on the new transparent heating market should be required to be REC certified. However, electrifying heating has a considerably bigger positive environmental impact compared with today's heating than using specifically REC-certified electricity to power our solution, so RECs are not a must.

4 Cost impact

The cost of coal-replacing capacity

In our solution, building the new coal-replacing capacity is market-based. We assume that when the right market conditions are in place, the best and the most suitable technologies will be scaled. To be able to estimate the overall costs of this development, we need to assume first the nominal investment costs of different technologies. These are listed in Table 5.

Table 5. Investment and operating costs of different heat sources

	Capex, M€/MW	Our Solution, MW
Deep geothermal	2,0	80
Medium deep geothermal	2,5	60
Excess heat from data centres and other*	0,5	40
Air-to-water heat pumps	1,0	50
GSHP and other building integrated*	0,2	70
Total	1,3	300

*In case of GSHPs, data centres, and other potential excess heat sources, the cost covers only the additional investment needed to meet the requirements of DH connection and supply.

In deep and medium deep geothermal solutions, as well in air-to-water heat pumps, the investment cost covers all costs of the new heating capacity.

It must be noted that technology development will lower the nominal costs for all solutions over time, as soon as attractive market conditions are in place.

The estimated total investment cost of our 300-MW coal-replacement solution is 400 million euros. The annual investment cost grows as new capacity is installed. This growth is presented in Figure 16 below. Investments can be made either by Helen or, as in the presented market model, by third parties.

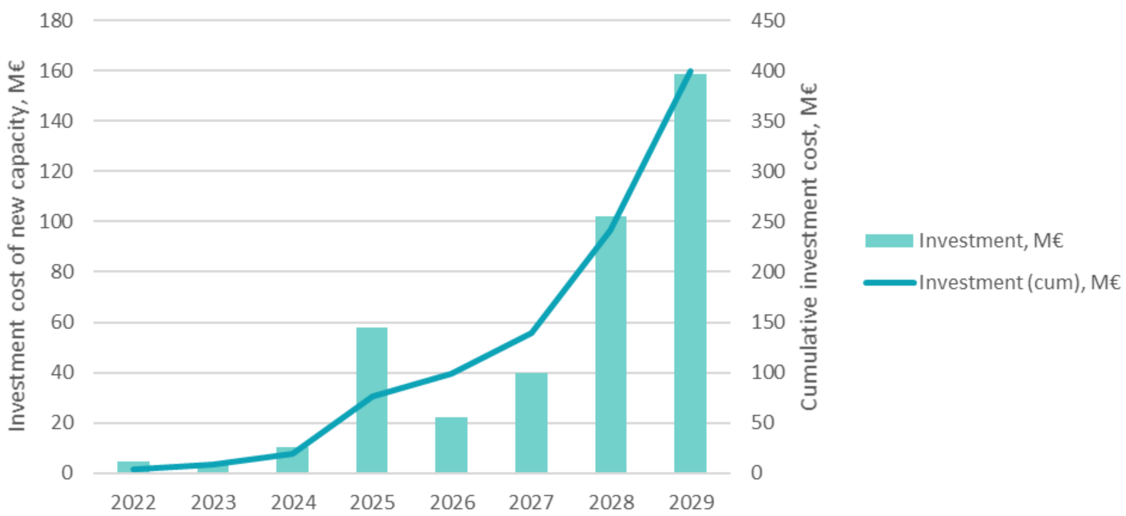


Figure 16. Market growth needed from 2022 to 2029 to meet the target of 300 MW

There will be several actors taking responsibility for building this new capacity. Bills will be paid not only by Helen or the City of Helsinki, as its owner, but also by third parties.

The average heat production cost of new technologies, presented in the next figure, varies around the average feed-in tariff price of 50€/MWh. The capital cost is based on the investment costs of Table 2, amortization period of 15 years, interest rate of 3%, and 5000 operating hours. Possible investment support is not included. The operational costs are based on the electricity price of 40€/MWh.

To give a comparable number for the cost of our solution, we use two methods. Our first method is to calculate the difference between our new feed-in tariff and the coal-fired heat production cost, using 2030 price levels. Our second method is to calculate the difference between the feed-in tariff and Helen's existing open district heating tariff.

The cost difference between the feed-in tariff and coal-fired heat is 6€/MWh in Figure 17 below. The supported heat amount is around 1,5 TWh (300 MW * 5000 h/a), which results in an additional annual cost of of €9 M for the feed-in tariff in 2030.

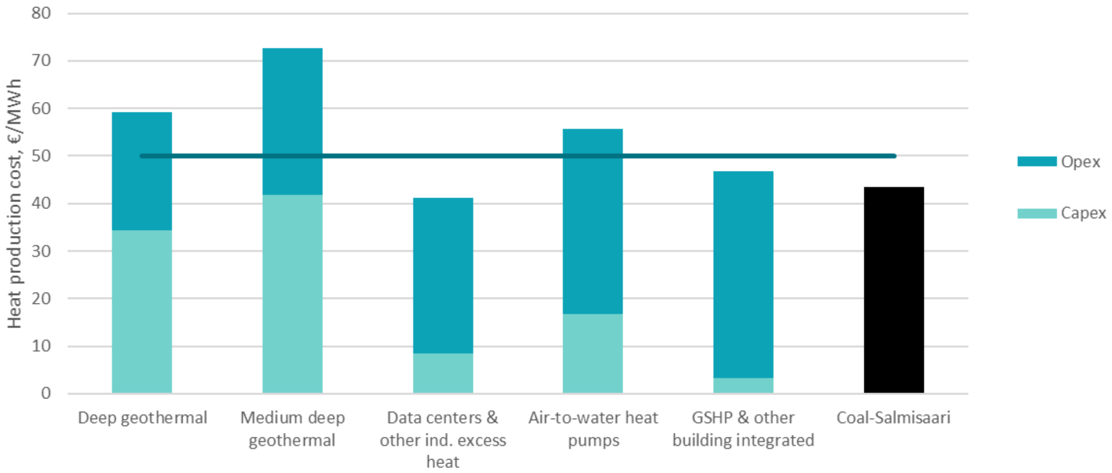


Figure 17. Investment and operating cost of different new technologies compared to coal-fired production following the 2030 price level

Following our second method, calculating the difference between our new feed-in tariff and Helen's existing open district heating tariff results in an average price difference of 19,5€/MWh in the beginning of 2021. This is based on an average price of electricity at 40€/MWh.

It can be assumed that the current production structure that still includes fossil fuels will become more expensive in the long run because of rising CO_2 costs, for example. The price of Helen's existing open district heating tariff would thus gradually go up. This would decrease the price difference to our new feed-in tariff. In our base scenario, we expect this difference to decrease by 1€/MWh every year. The difference is 12,5€/MWh in 2030, which is twice as high as when comparing the feed-in tariff to coal-fired heat production (6€/MWh). The supported heat amount is around 1,5 TWh (300 MW * 5000 h/a), which results in an additional annual cost of €19 M for the feed-in tariff in 2030.

In the high scenario the price difference remains constant, which results in a higher estimate for the overall costs. Should the price difference decrease, but investments lag behind, the margin could be used to raise the feed-in tariff in order to make markets move as fast as needed.

The cumulative cost of the feed-in tariff for Helen, during the whole period that it is in use, can be calculated following our second method. Unfortunately, a comparable result is not possible to calculate following the first method, because of too many price assumptions (coal, emission allowance, electricity, etc.) *Following our second method, the estimated cumulative cost of the feed-in tariff is €150 M (base scenario).* In other words, this is the cost of coal replacement. If there is no increase in the costs of other district heat production, the total cost is €300 M. The annual and cumulative cost of the feed-In tariff is illustrated below in Figure 18.

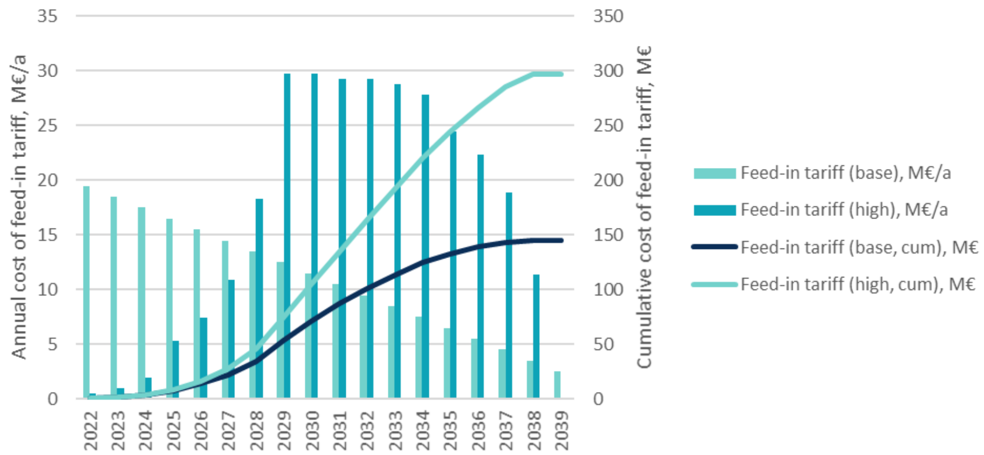


Figure 18. The feed-in tariff is a cost-effective way to support a new market

Expressed as the end-user price of district heat, the total cost of coal replacement (€150 M) is 1,4€/MWh per year divided to the whole tariff period. This represents an increase of 2% in the end-user price for district heating.

Cost of intelligent operations of the system and for creating a demand response capacity of 500 MW:

The estimated total investment cost of the smart heating control system, creating a demand response capacity of 500 MW, is 90 million euros. The cost of automated heating control in residential buildings consists partly of investments to needed appliances on the apartment and building level, and partly of operating costs for monitoring and control of living conditions.

Roughly 1250 apartments provide the demand response potential of 1 MW. The investment cost of creating this 1 MW is assumed to be about 180 000 euros. It is assumed to be divided equally between monitoring equipment, controlling equipment and software implementation. In commercial buildings, the existing automation may already support demand response and, for example, one shopping centre may provide a potential of several MWs.

Yearly operating costs are estimated to be about 30 000 €/MW for data collection, control connection to the heat exchanger and apartment level optimization. However, these costs can be covered by the energy savings created by this energy optimization system. For example, by connecting city-owned buildings to the smart heating controls first, the City of Helsinki would not only encourage others in implementation of the plan but also save on heating costs. Shaving peaks would be the other economic benefit that these systems provide for the system-level operator.

In public buildings, the costs of intelligent heating control vary more than in residential buildings. Several building automation systems can control heat consumption based on external signals.

To motivate the use of this potential and to make heating control feasible, it's crucial to establish an hourly based heating tariff or another kind of intra-day pricing mechanism, as described in the summary section.

Software development costs arise from building the database and API to indoor temperature measurements, and for integrating consumption control to production control. The cost estimates for these are to be given by development service providers, some of which might already be employed by the City of Helsinki or Helen.

Operational costs for the software that will be doing the end-to-end optimization of district heating are included in our overall estimation of 30 000 €/MW.

The estimated total investment cost of our 300-MW coal-replacement solution is 400 million euros. Investments can be made either by Helen or, as in the market model we propose, by third parties.

If the investments are made by third parties following our model, Helen would add a new feed-in tariff to their current heat procurement price. We estimate the cumulative cost of this to be €150 M during the period that the tariff is needed.

For the end user, this would mean an increase of 2% in the price of district heating.

5 Implementation schedule

2021
2022

Introducing the new market model
Central actors negotiate and make decisions concerning the new market model.

- The City of Helsinki sets a goal for Helen to annually increase the share of emission-free heat production capacity in the DH network (**market size and timetable targets**).
- Helen takes into use a new **hybrid tariff for hybrid heaters**: a base fee that is almost zero and a higher-than-current energy fee, always cheaper than the price of electrical heating, in order to keep district heating as a backup energy in buildings that are primarily using their own heat pump solution for heating.
- Helen takes into use a new **feed-in tariff for heat producers**. The tariff is based on the electricity price and works as a guarantee price for heat producers during the heating season.

The City of Helsinki introduces **automated indoor temperature monitoring** in all **public buildings** in Helsinki. Temperature control begins with public buildings, creating energy savings for the city.
The City of Helsinki starts the distribution of free **indoor temperature sensors to all apartments**.
The City of Helsinki's officials ask housing companies, energy service companies, Helen, and other potential third-party heat providers for feedback in **mapping obstacles** like land use, permits, or technical connectivity issues that are **blocking the use of excess heat** in Helsinki. An action plan for clearing the obstacles is made.
Helen and third-party energy producers sign the **first market agreements on larger-scale energy production**.

2023
2028

Growing the market to a 300-MW capacity

City officials support energy production and energy-efficiency service providers in carrying out the **permit processes**.
Helen and the City of Helsinki **develop and adjust the market instruments** in order to reach the targets.

- For example, Helen can launch an intra-day pricing structure like **hourly pricing** to incentivize service providers to peak load shaving in buildings that aren't heat producers.
- The City of Helsinki can launch an **investment support** instrument for housing companies.

The City of Helsinki builds a **database of indoor temperatures for service providers** to use in heat optimization, for example, by adding aggregated indoor temperatures to the Helsinki Energy and Climate Atlas: https://kartta.hel.fi/3d/atlas/#/
The City of Helsinki makes a **general agreement about heating control** with service companies within which it is easy for them to make specific agreements with housing companies and other building owners.
Helen combines the data from smart control of consumption with the data from production optimization and DH network monitoring and builds a **predictive system to optimize energy use** in the city as a whole.
Helen opens the district heating network even to the warm heat sources **lower than 80 degrees** to make DH production even more attractive for heat pump investors.
Helen makes an investment in **electric boilers**, if they are still needed.

2029

Replacing coal
Coal-based DH production in Salmisaari ends.
The City of Helsinki **sets the next target** for replacing remaining fossil fuels.

2030
2035

Growing the market to replace other fossil energy production

Time-critical steps in our implementation timeline include the negotiations needed to spark the systemic change that we propose. To ensure engagement from all needed parties, it is important to agree on the new vision for the district heating network. The market instruments needed find their best final form if they are co-created between involved parties. It is possible to invest time in the beginning to find a market model that all parties can live with in the long run, as our proposal includes a fool-proof technological solution for replacing coal even if everything else fails.

The changes to heating infrastructure that we propose mostly occur in new places. New key players appear at the negotiation table: owners and managers of buildings and land. In our view, this is the most important of all the changes that we suggest. That's why we have even adopted as our team name "Consumers to Heat Producers (CHP)". We have done our best to describe what kinds of changes in market rules might help to get them on board, to become realizers of the new vision of district heating as a heat exchange platform.

Apart from fair and transparent market rules, it is imperative to make the permit processes as smooth as possible. Time and resources need to be allocated in the beginning of the process to clear any existing obstacles.

As a risk-mitigation plan regarding permit issues, the biggest new facilities should be negotiated first. This should be quite straightforward, after putting in place the new incentives, as actors capable of taking care of these kinds of projects are professionals already active on the market and keen to proceed with their solutions. Identified risks and mitigation plans are described below in Table 6.

Table 6. Identified and mitigated risks attached to our implementation schedule

Risk factor	Impact on schedule	Likelihood 1–5	Mitigation
Decisions about the vision and target for the new emission-free DH market take time	Delays every other action	4	Exploiting the publicity provided by Helsinki Energy Challenge to start immediate negotiations on the needed political consensus
Decisions about the new market incentives take time	Delays all third-party investments	4	Co-creation of the final versions of market incentives between Helen and third parties
Permits for deep and medium-depth geothermal heat pumps take time	Delays execution of the biggest new heating capacity	2	Early announcement of the target market and incentives, systematic removal of obstacles in the permit process, installation of electric boilers instead if everything else fails
Decision making in housing companies takes time	One-third of the market lags behind	5	New concepts from energy service companies facilitate decision making in housing companies. The City of Helsinki advisors support them as well.
There isn't enough drilling equipment for the massive geothermal deployment	Delays implementation of the new heating capacity	3	The more the actors are included in creation of the new heating capacity, the more resources become available
Building an easy connection process (digital & physical) for GSHPs, data centres and other sources for excess heat & storages takes time	Delays execution of "lowest hanging fruit" solutions	3	Developing technologies, lowering temperatures in DH network. Installation of electric boilers, if the time frame for market development becomes too short before 2029.
Deploying consumption monitoring and heating control in housing companies takes time	Keeps overall system less energy efficient than it has potential to be, additional production needed	2	Installation of more production capacity instead, if needed

6 Implementation feasibility

Technological feasibility (tech maturity and availability)
Some of the proposed technologies come with identified uncertainties, like water fracking in case of deep geothermal wells or achieving required temperatures in case of GSHPs. Risks too expensive to mitigate or uncertainties turning into certain no-go's will be ruled out by the markets. If some of the technologies aren't performing or scaling, electric boilers still guarantee the electrification of the DH system as a whole.

Some technical development is still needed before the excess heat from GSHPs and other smaller solutions integrated to buildings can effectively supply heat to the DH network. Lowering the temperature of the DH network mitigates the problem. The new market model will boost the development of these technologies and we may also see new innovations, thanks to favourable market conditions.

Financial feasibility (tech cost, impact on heat price, financial impact on other actors and the city)
The estimated investment cost for the technology needed is €400 M. In our open market approach, it's divided between several actors, which reduces the capital needed from Helen and eventually from the city.

The additional cost of the feed-in tariff is €150 M. It increases the heat price by 2%. New technologies are based on electricity which creates a risk in electricity price development. However, the assumed level of 40€/MWh is realistic, because it is possible to fix electricity purchases even at a lower price in Nordic electricity markets until 2030. The annual variation is also limited, based on data provided by the organizers: less than 14% of all hours in the year 2030 are above the ceiling price of our feed-in tariff (equal to electricity price of 50€/MWh). In other words, the risk created by electricity price fluctuation is small. Ultimately, the risk can be described by noting that the price was more than 70€/MWh during less than 220 hours per year (2,5%).

Other actors benefit from this emerging market, as they can sell their services for their full value and develop technologies that are sought after even in other markets.

Legal feasibility (e.g. changes needed to current legislation)
The current legislation does not need to be altered. The target size and timetable for a new DH market that the City of Helsinki requires of Helen follow the current legislation for limited companies, as did previous targets set within "Helsingin Energian kehitysohjelma" (a previous development programme aiming at CO_2 reductions in energy production).

If obstacles are found in permit processes, they most likely have to do with regulations connected to city planning. Thus, it is possible for the city to alter them, if found appropriate. As all of the technologies mentioned in this proposal are already in commercial use, they have been developed to fill the requirements of existing legislation.

Most changes needed have to do with market rules. Changing them requires no legal processes, just new agreements that Helen can make with district heating customers.

There might be a need to ensure that our planned internal feed-in tariff in Helsinki does not conflict with other supporting instruments for coal replacement technologies, like the national investment support.

Administrative feasibility (e.g. permit process, city's control over implementation)
City planners needs to study further and support the building of geothermal energy and GSHPs. The City of Helsinki defines the requirements for implementation, while Helen and third parties come with the initiatives and investments. The city strategy doesn't need to be changed and neither do any administrative roles.

Cultural and ethical feasibility (general acceptability, freedom to choose, privacy, GDPR)
General acceptability of our solution builds on the predictable, fair, and transparent rules for activation of renewable heating potential. They are created by the city-owned district heating operator, based on our market model that increases equality between heat producers and service providers. The result is increased freedom of choice, e.g. for housing companies.

City planners conduct the deliberative, regulative processes required, along with the investors in new heating capacity. They have a solid history and experience in participatory negotiations.

General acceptability is expected to be high among landowners, as they become new strategic partners in the common endeavour to heat Helsinki without coal. They get the support they need from service companies and the city, and they even win economically. Nobody is forced to go to the new heating market and benefit from it: there is freedom to choose the same district heating as now. In that case, the end price will go up 2%. We expect that this will be considered a reasonable price for mitigating climate change, as it requires doing nothing.

Data privacy issues and GDPR are taken seriously. This shows in our strategic decision to make the city, no commercial player, the operator of indoor temperature data. Still, even taking part in data gathering is voluntary for households. Agreements on heating control are made like other agreements that housing companies decide on, but only facilitated by the general agreements made by the city.

The Mayor of Helsinki and other prominent spokespersons can support acceptance and adoption of the equipment needed in buildings by advocating for the smart control systems. Arguments to use them include, e.g. that the new heat pump capacity also provides cooling when needed. Along with more stable indoor conditions provided by smart heating control, it maximizes comfortable living conditions in the buildings.

Our solution addresses the main actors' core concerns and provides solutions to them. It fundamentally improves the current situation in several ways and for several actors. Of course, there are trade-offs for each of the actors to be made between existing and coming benefits.

Our solution allows for technological development that decreases the overall costs of the change. At the same time, our solution is ultimately not dependent on technology development.

We find the financial impact acceptable when compared with alternatives. Legal and administrative frameworks, processes, and roles don't need to be changed to produce the changes required. We've done our best to design new rules and procedures that improve the transparency, equality, and security of the system. To ensure that they are considered as such, the final version of our solution is to be drafted by the parties themselves after this contest.

7 Reliability and security of supply

Our solution is based on several hundred sources supplying heat to the district heating network. In this case, the failure of one unit is not as critical as in the current system, where production is mainly based on a couple of large production units. The importance of this increases as extreme weather events caused by climate change become more frequent. Moving heat production from a few remote central units closer to consumption, even to the city centre, diminishes heat transfer losses. Ultimately, less production capacity is needed.

Our solution also relies more on the electricity network than the current solution. The reliability of electricity distribution is very high in Helsinki. More than 97% of the network is underground, protected from weather-related blackouts. In Helsinki, a typical consumer experiences only half an hour of power outage every ten years.

All heat producers and users are monitored on a digitalized heat exchange platform, which makes it possible to identify potential problems proactively. In many cases, this means that the problems are fixed even before the heat users notice them at all.

The use of buildings as heat storages, combined with Helen's current and planned heat storage facilities, provides flexibility in exceptional electricity market situations. It also improves the energy efficiency of the heating system.

Under exceptional circumstances, lowering indoor temperatures to 17° C would make it possible to always guarantee heating of important buildings. It would also halve the overall energy use in Helsinki. Apartment temperature monitoring combined with smart building-level heating control makes this possible.

Overall, the city-wide optimization based on apartment level measurements means building the future system on more data than the current one. This increases the transparency as well as the reliability of the system.

Our model turns the existing district heating network into a platform for heat exchange. Responsibility for maintenance of this platform (pipes, centralized production and storages, digitalization and control of the operations, pricing, financial incentives and trading) is planned to remain at Helen, at least in the beginning.

Funding for the centralized part of the system comes from the same source as today: through a profitable business model from the customers. These customers can buy district heating as they do today, but they can even take on the role of delivering it. There is room for third parties that act only as producers of energy to the district heating network, parties that take care of aggregating small excess heat loads to bigger ones and parties that have the role of flexibility providers as they manage different kinds of storage. These ways of producing and using energy more efficiently than today limit pressure to raise the price of district heating. In section 4, “Cost impact”, we estimate the additional cost to district heating customers to be 2% above the current price.

In other words, the new incentives and market rules we’ve presented are designed to cover the costs of building and running the whole system. Compared with the current situation, investments in energy production and energy efficiency are expected to be made by several actors, not just by the network operator.

The incentive to provide peak capacity is the same as it is today for Helen – being the operator of the heat exchange platform is a profitable business that is strategically important to the capital of Finland. In addition to that, the task becomes easier: compared with the current situation, our solution decreases the need of peak load capacity by 300-500 MW by mitigating daily peaks through pre-heating of the buildings and more optimized use of the whole system.

When it comes to back-up capacity, less of it is needed, as energy efficiency reduces the total demand of heat. In addition to that, a part of the back-up capacity can be replaced by binding agreements to reduce heat consumption in situations when back-up is needed.

If there are interruptions in heat delivery from the main heat sources, they can be covered from the GSHPs and other heat pump solutions that are connected to the district heating network. This improves the reliability of the heating system. Heat can be produced on site or delivered through the network, depending on where and what kind the interruption is.

During a power shortage, for example, indoor temperatures can be lowered, strategic buildings can be prioritized, and only high COP production used. Only a total black-out of the city would prevent all heat delivery to apartments. The same would happen in the current situation.

In our model, the back-up solution in case of market failure is comprised of the electric boilers added to the centralized system. If they are installed, they can even be used for back-up heat production. Otherwise, the decentralized investments in heat pump production also act as a back-up, as they can be turned into direct electricity heaters.

The biggest risks of the plan have to do with the timetable and with the technological maturity of the most efficient solutions, such as geothermal wells and sea water heat pumps. These risks are mitigated by the market model, which boosts more secure technologies whenever the less mature solutions aren’t being realized. In the end, the feasibility of our solution is ensured by electric boilers.

To mitigate the risk that the actors disapprove of the new market model, careful negotiations are taking place before launching the model, making sure that the concerns of all parties are addressed.

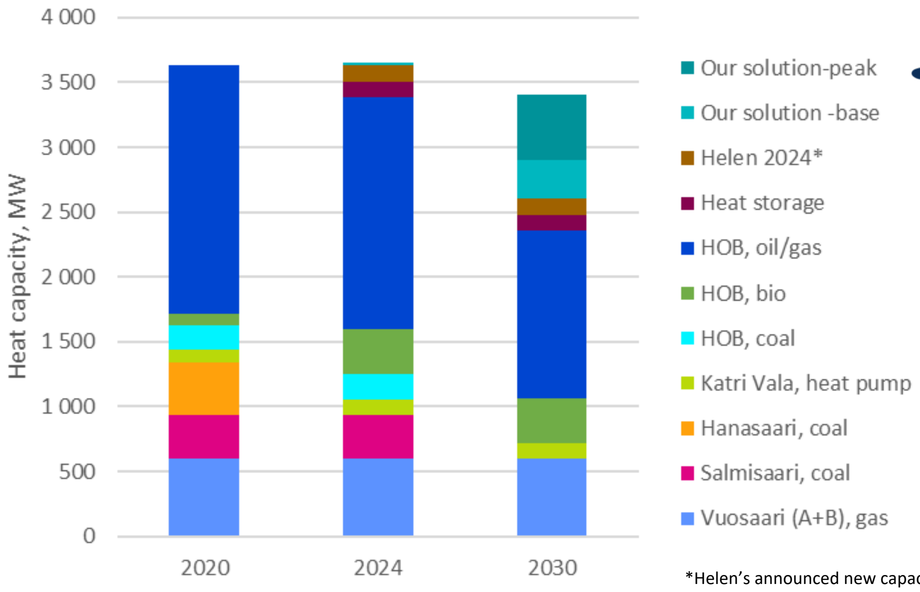
> Decentralizing and electrifying district heating improves both reliability of the system and security of supply. Energy-efficiency measures lead to smaller needs of both peak and back-up capacity. They can be provided either by using the electricity resistors in heat pumps or by the electric boilers built for market back-up.

8 Capacity

Capacity to replace coal

The steps up to 2024 are mostly taken by Helen. There is a plan to replace the coal used in Hanasaari with use of biomass, heat purchases, heat pumps, and other technologies. Only a small amount of the new capacity in

2024 comes from our solution (20 MW), as shown in Figure 19 below. In 2030, our solution represents 800 MW of the total capacity. 300 MW of it can be categorized as coal-replacing base load capacity and 500 MW as short-term peak load capacity (demand response).



*Helen's announced new capacity investments

Figure 19. Our solution to replace the use of coal by 2030

Our solution makes it possible to phase out coal-fired heat production in Helsinki within a year. This would be handled by implementing enough electric boilers, which have a low investment cost. However, the solution can be made more economic and energy efficient using our market model. Our solution for coal replacement includes:

- Deep geothermal: 80 MW. Range from 20 to 150 MW (1–5 installations). Deep geothermal will provide the base load with more than 7500 operational hours annually. Its potential is limited to 100–300 MW because of low demand in summertime.
- Medium deep geothermal wells / other medium-sized heat sources: 60 MW. Range from 25 to 100 MW (50–150 installations).
- Excess heat from data centres and other industrial sources: 40 MW. Range from 10 to 60 MW (3–10 installations).
- Sea water heat pumps are not assumed to be feasible in Helsinki. Even their COP is low. Therefore, they are not included in our basic assumption. However, we estimate that their technological potential would go up to 300 MW in Helsinki.
- Air-to-water heat pumps: 50 MW. Range from 25 to 150 MW (20–150 installations).
- GSHPs and building integrated solutions: 70 MW. Range from 20 to 150 MW (200–1000 installations).
- Electric boilers will secure the capacity replacement if some of the above-mentioned technologies are not scaling.

In total, these solutions add up to a minimum of 300 MW by 2029. Their breakdown is presented in Figure 20 below. It must be noted that the figure is only illustrative, because the actual markets will decide the development. If some of the technologies are not performing or scaling, electrical boilers still guarantee the electrification of the district heating system.

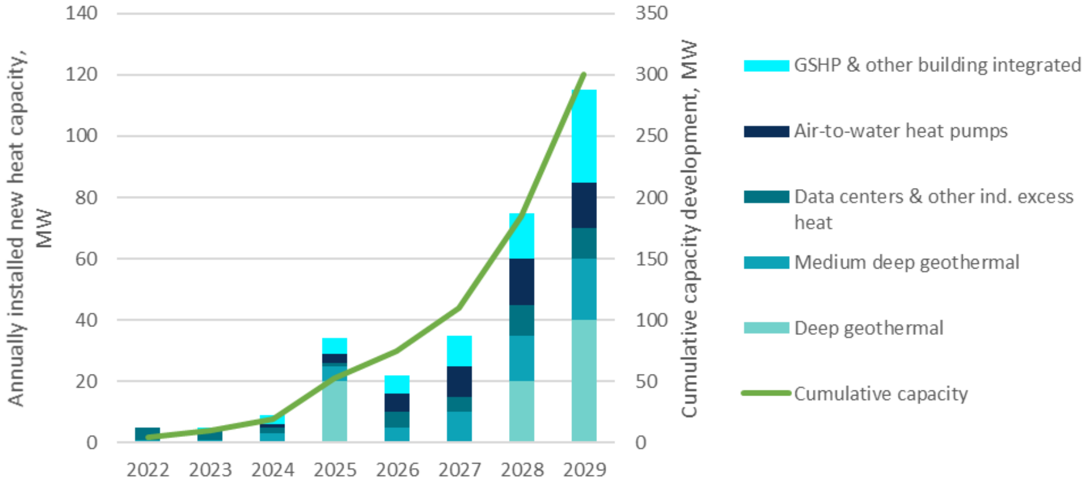


Figure 20. Yearly capacity additions on the new district heating market

Peak and back-up capacity

According to the provided heating data from 2016, the peak demand for heat in Helsinki is 2 600 MW. The current heat production capacity is more than 3 600 MW. Helen is implementing a 120-MW heat storage in Mustikkamaa which can be used continuously up to 4 days. District-heated buildings represent a short-time storage potential that can be loaded and unloaded within a day (the exact time is heavily dependent on the outdoor temperature). In our solution, heating control systems model how buildings store and radiate heat. As these flexibilities are aggregated, they can be used as short-term thermal storages in the district heat optimization system.

Our solution creates 500 MW of new capacity that can be used in demand response. The next figure (Figure 21) depicts a cold winter day. It shows how the storage in Mustikkamaa first reduces the need for peak capacity by 120 MW and then the demand response balances 250 MW from the morning peak to earlier hours.

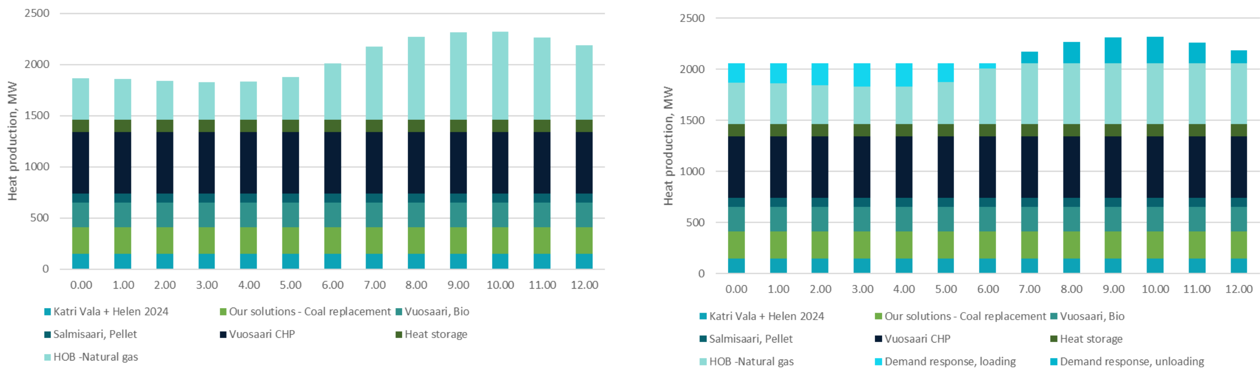


Figure 21. Example of demand response in heating during a cold winter day

In 2030, our solution has added 800 MW to the total capacity. 300 MW of it can be categorized as coal-replacing base load capacity. The other 500 MW is short-term peak load capacity (demand response).