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HIVE’s up to the **H**elsinki **E**nergy **C**hallenge

hive

Helsinki Innovative & Versatile Energies

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Table of Abbreviations

BTES	Borehole Thermal Energy Storage
CAPEX	Capital Expenditure
CHP	Combined Heat & Power
COH	Cost Of Heat
COP	Coefficient of Performance
DH	District Heating
DC	District Cooling
FSC	Forest Stewardship Council
GWP	Global Warming Potential
HEC	Helsinki Energy Challenge
HFO	Heavy Fuel Oil
HOB	Heat Only boiler
HP	Heat Pump
IRR	Internal Rate of Return
LFO	Light Fuel Oil
LTHW	Low Temperature Heating Water
NPL	Natural Language Processing
ODP	Ozone Depletion Potential
OPEX	OPerational EXpenditure
PEFC	Programme for the Endorsement of Forest Certification Schemes
PTES	Pit Thermal Energy Storage
SBP	Sustainable Biomass Partnership
SWHP	Sea Water Heat Pump
TES	Thermal Energy Storage

1. Summary of the proposed solution

The master plan brings the end of coal burning by 2028 and will decrease CO2 emissions by 78% between 2020 and 2035

HIVE offers a solution enabling to fully end coal burning in year 2028, and stop using other fossil fuels in year 2035. The solution betters Helsinki's expectations for the reduction of CO_2 emissions from heat production, as for instance expressed in The Carbon-Neutral Helsinki 2035 Action Plan. It enables a fall in the use of biomass over the implementation period.
It gradually substitutes fossil fuel free heat production and storage assets for Helen's fossil fuel assets. It makes use of Helen's fossil free assets (heat pumps, thermal storages, biomass boilers).

HIVE's solution does not rely on any technological breakthrough. However we intend to build for Helsinki the most advanced versions of the proven technologies we have selected, in some cases also making Helsinki the world's biggest user of these. The proposed optimizations to the district heating grid, enabling lower operating temperatures, were to date not implemented on such a large scale.

To harvest heat from the sea strikes us as an obvious choice for Helsinki, 70% of Helsinki Area consists of sea. At the doorstep of the City, sea provides a heat source that does not come with conditions; most others do.

The new heat production assets will be **sea water heat pumps** (SWHP), **electrical boilers** (EB) and **solar thermal fields** (ST). SWHPs have a track record in the Baltic sea, HIVE will expand it in Helsinki. With competitive prices, excellent availability and promising emission factor, the Finnish power mix offers further ground for using SWHPs. HIVE's solution will make Helsinki the user of SWHPs with the largest capacity in the world.

Solar thermal will be vastly expanded, with due consideration for Helsinki's land use plan. Solar fields are selected by HIVE for many reasons: grip over project development, local manufacturers, etc.
EBs will be installed beyond 2030 and serve as peaking capacity in winter-time. The choice is emission driven.
The total heat storage capacity serving the heating grid will be strongly expanded. The new heat storage assets will be of 2 types: **Pit Thermal Energy Storage** (PTES) and **Borehole Thermal Energy Storage** (BTES).

PTES is a fast response type of heat storage, used for balancing purposes in particular. It has proven track records at many sites in Scandinavia and elsewhere, Two 500,000 m^3 PTES – marginally larger than any PTES ever built - will be installed at Helsinki.

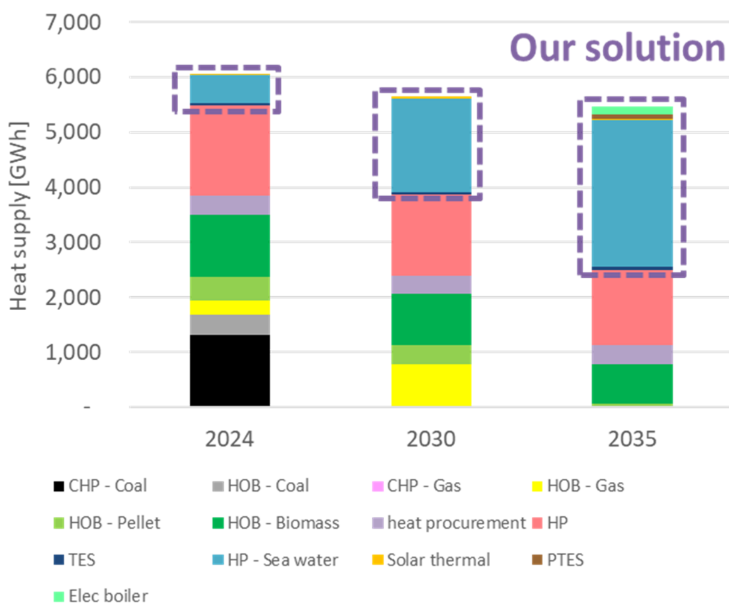
BTES is our large capacity storage, It will come in arrays of 2-300 m deep boreholes, enabling to store and retrieve up to 50 GWh of heat in the surrounding ground at a release power of up to 25 MW. HIVE intends to spread the arrays across various locations in the City where land is of lower value, such as patches of land trapped within road interchanges. In HIVE's solution BTES ensures strategic storage, securing heat that can be fed to the district heating grid in such conditions as extreme cold spells or forced outages of major production assets.

Furthermore, storages enhance the flexibility of the heating system by giving the operator the opportunity not to draw on expensive sources of commodities at times of very high prices.
HIVE's solution features steps towards operation of the heating grid at lower supply and return temperatures. The returns expected from these are a reduction in the need for higher enthalpy production assets (biomass boilers), and more optimal operating conditions for heat pumps.

Finally, the solution includes demand side management measures. HIVE will collaborate with the City to maximise the efficiency of measures in place and deploy additional ones.

The presented solution may be considered a "baseline scenario". Maybe one of the most ambitious baseline scenarios but still a "baseline": this is what we will do unless even more suitable elements emerge as time passes. The roadmap towards 2035 can be updated several times. Local stakeholders should play a role in this work. Helsinki could lead such a network considering the pooled resources together with the total demands. Industries' needs for raw materials and heat can be considered in such a collaboration platform. HIVE may assist Helsinki in setting up such a local network.

The following graph illustrates the contribution of our solution to the heat supply at 3 salient dates:



Year	Total heat supply GWh
2024	6060
2030	5650
2035	5450

HIVE's solution here is based on an in-house developed advanced simulation and optimization tool which designs the optimal configuration of the integrated value chain minimizing the total cost of ownership (TCO) of the system, including the optimal sizing (CAPEX) and dispatching (OPEX) of all physical assets. This results in an **hourly** merit order based optimization of the heat supply against the load requirements in the selected years, further challenged by our team of experts. Details of the modelling can be found in the Appendix Book, section 1 "HIVE Master Plan".

Overview of key technologies in HIVE's solution

Capacities to be built (see also preliminary site location maps in Appendix Book, section 2):

Time period	**Till 2024**	**2024-29**	**2029-35**
SWHP (MW_{th})	60	180	220
ST (MW_{th})	25	25	
BTES (MW_{th}/MWh)		100/200	50/100
PTES (MW_{th}/MWh)			275/45
EB (MW_{th})			280

Sea water heat pumps (SWHP):

SWHP is a proven technology. Implementation in Helsinki and in our solution requires to tackle several specific issues:

- Low sea water temperature in winter-time, and low salinity
- High feed and return temperatures in the heating grid (current, will be reduced)

HIVE's know-how tells that machines of suitable large unit size (15-20 MW) and capable of operating at economical COPs in the local conditions, are available on the market.

The design phase will dedicate special attention to the sea water intakes, such that water with high enough temperature can be fed to the SWHPs at all times. The number of intakes will be optimized to keep costs down, accordingly the SWHPs will be grouped in a limited number of locations on the shore.

Our implementation program also dictates a staged deployment, whereby return of local operational experience can be incorporated in most components of the SWHP fleet.

COPs were studied (cf. details in appendix, section 3). COP ranges (monthly averages) in our energy model are as follows:

- Before implementing grid temperature reduction: 2.71– 3.64
- After: 2.92 – 3.64

Solar thermal fields:

Two STs, each with a peak capacity of 25 MW, will be built. Initial review of the land use plan has shown adequate areas. At 15 ha, the total land requirement for ST remains modest. Emission factor is among the lowest. STs typically have a high acceptability.

STs will cover a significant part of the energy needed for supplying the City with hot water in summer. Solar panels can be sourced locally.

PTES:

PTES are large water reservoirs for the storage of thermal energy. Water temperature can be up to 90°C.

A PTES unit is essentially a hole in the ground with a water-proof membrane, filled with water and covered by a floating and insulating lid. The excavated soil may be used as banks surrounding the hole, thus increasing the water depth and reducing establishment costs.

Aerial view of a PTES in Denmark.

PTES are a proven storage technology, with a number of sites in operation. Existing sizes are typically smaller than what is proposed in the HIVE solution (up to approx. 200,000 m^3 but larger cases are upcoming. In Aalborg, Denmark a turn-key project of 2 x 500,000 m^3 is currently (January 2021) in the tendering phase). HIVE proposes to build similar sized units in Helsinki,

BTES:

The principle of BTES is to store heat in the underground by circulating through a closed loop a fluid in plastic u-tube pipes installed in a large number of closely spaced, interconnected boreholes or Borehole Heat Exchangers (BHE) and completed with a sealing grout (see figure below). The distance between the boreholes is typically in the range of 2-5 m and their depth can be up to 300m making these systems very compact with a reduced surface footprint (small area and non-visible) and limited thermal losses. NB : should the system need to be even more compact at the surface, there is the possibility to drill some lateral boreholes with a deviation (already done in several locations).

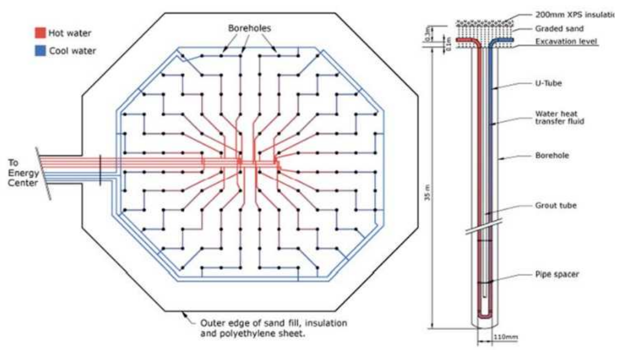
Heat retrieved from the storage is delivered to the heating grid at suitable temperature through an auxiliary heat pump.

BTES are a proven storage technology, with a number of sites in operation worldwide connected with variable sources (solar sources, CHP, incineration, district heating, etc.) and with variable sizes.

HIVE proposes to build several arrays comprising each 500 deep boreholes (300 m). Preferred locations have been identified because of:

- the vicinity of the heating grid (reduced connection costs)
- the availability of sufficient land with no other known usage (land encapsulated in road interchanges)

and in agreement with the Underground Master Plan.



Example of a BTES design, construction and surface low footprint once in operation (non-visible and land can be used for other purposes)

Grid temperature reduction:

Every heat grid is different. However, research shows that most grids can reduce temperatures using more advanced control methods. This is even more encouraged and facilitated when primary and secondary systems are hydronic as it seems to be the case in Helsinki. Temperature reduction leads to several economical, technical and environmental benefits. Also, production heat pumps can greatly benefit from dynamic supply temperatures functionality.

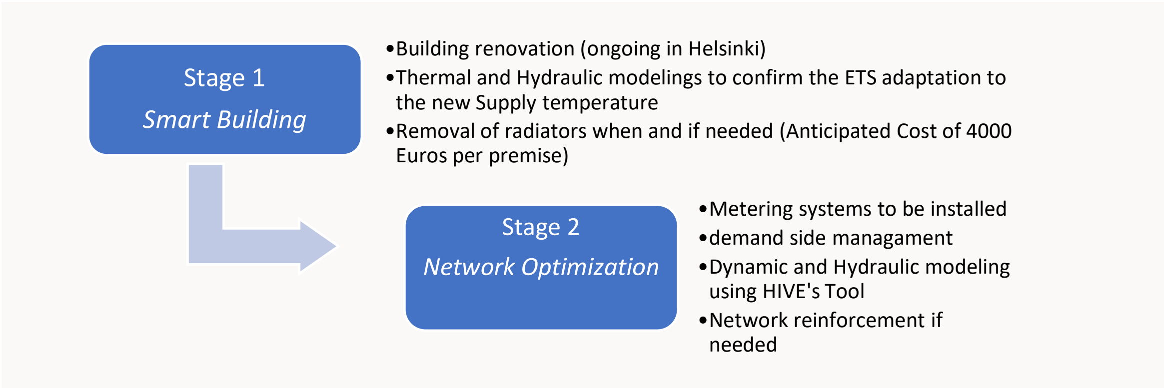
HIVE’s objective is to have all connected buildings supplied by Low Temperature Heating Water (LTHW), with operating temperatures gradually reduced as the Customer buildings undergo energy efficiency improvements. Most existing Customer buildings with hydronic systems were designed for Secondary hot water temperatures of 80°C supply and 60°C return, where some may have peak temperatures upwards of 85°C supply and 65°C return.

Based on a target 5°C return temperature approach across the Energy Transfer Stations (ETS), such buildings can connect to a district system having Primary supply water temperature of 85°C, and 65°C return water temperatures, which is the target maximum initial District Heating operating temperature profile for the optimized LTHW systems.

LTHW Temperature Profiles	Max. Primary Heating Temperatures (Supply/Return)	Max. Secondary Heating Temperatures (Supply/Return)
Initial Requirements	85°C / 65°C	80°C / 60°C

A long term objective would be to operate the ETSs at a lower Primary temperature supply of 70°C. Then, building Secondary systems would be operated at 65°C supply and 40°C or lower return temperatures. This feature is not needed by HIVE's solution nor considered in our entry.

Proposed optimization strategy:



Demand side management:

Helsinki appear to be well advanced in terms of demand side & load side management tools. However, HIVE also has an experience to share in that matter and collaborations as well as field return of experience could be shared on technologies & programs to help the City reduce global consumption. HIVE anticipates two work fronts :

- Primary loop optimization: reduction in fuel consumption (typically 3 to 5%) can be achieved with primary loop optimization using digital optimization tools which forecast with finesse the demand geographically & energetically. Optimization can then be run to engage units & distribution in the most effective way with live dashboard to ensure a good delivery to all clients
- Secondary loop optimization:
    - Reductions can be achieved with incentive programs aiming to involve the end user in the emission reduction process by individualizing consumption and communicating (and even supporting financially) on current emissions & ways to reduce them. Individual meters, & thermostats linked to apps can be a cheap & efficient way to achieve reduction targets.
    - To avoid peak load, buildings can used as storages, leveraging on their inertia by pre-heating some of them during low load phases. 4 to 8% global reduction could be achieved in field test cases.

HIVE support

Towards building new assets and upgrading existing ones

HIVE’s solution includes the support to the City of Helsinki in its role of project sponsor. Indeed one key challenge on the way towards 0 carbon heat will be to steer in all aspects (financial, project management & permitting, adapt to changing circumstances, etc.) the large turn-over of assets required in the relatively short time frame allowed.

HIVE will make available experts and tools to help the City make decisions and drive the project based on best information and pertinent analyses.

Towards deploying the solution

HIVE can also contribute considerable expertise in helping to engage the public and clients of the district heating grid into a global move towards more environment-friendly behaviours.

HIVE will be available for designing and taking part into information and training plans for the local public and will share experience gained in other cities.

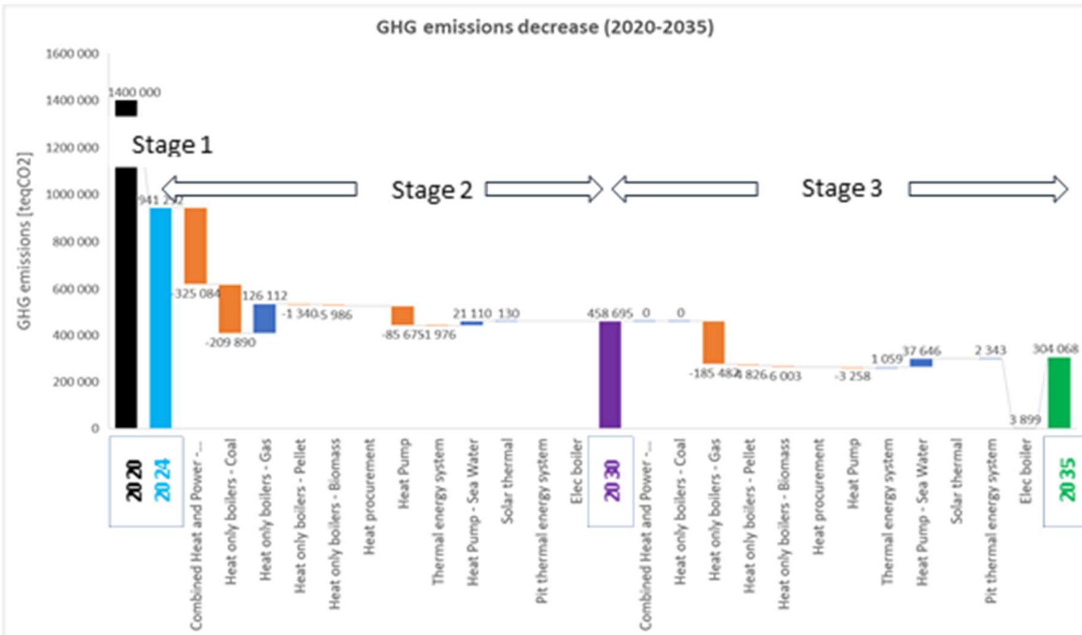
Tools developed for such actions can also be proposed.HIVE members have for example developed a unique digital tool that helps understand a city's ambitions and goals in various policies domain such as energy, environment, employment, etc. Utilizing our capabilities in automatic text analysis (Natural Language Processing (NLP)), the tool brings the policy objectives of a city into a diagrammatic representation and helps understand how HIVE solutions can help the public authority fulfill its roadmap. It allows users to explore and analyze the full picture of a city’s policy landscape and identify synergies between strategies. These insights can be used to design solutions tailored to the city’s needs and visualize their full impact across policy objectives.”

We believe in the power of 3D digital twins for planification, operation, and most of all for common work on complex territorial subjects that involve numerous stakeholders and infrastructures. Capitalizing on the 3D digital twin already initiated by the municipality (https://kartta.hel.fi/3d/atlas/#/), which already contains interesting information on energy and configuration of the buildings, we propose to enrich it with data related to the DH network (type and performance of the production units, type and consumption of the buildings connected, other infrastructures nearby …). All this data, aggregated in the same referential, can be used for example to simulate the impact of the network on air quality and greenhouse gas, help to understand mutual interaction between DH network and other infrastructures like bus, cycle lanes, or other underground utilities, or show the social impact of the network, like statistics on energy bills.

2. Climate impact

78% reduction of the life cycle GHG emissions

The solution proposed by HIVE conducts to a decarbonization of Helsinki's heating system of approximately **78% between 2020 and 2035** (See chart below). HIVE solution will bring the heating system life cycle GreenHouse Gas (GHG) emissions gradually and effectively from 0.94 MteqCO2 in 2024, to 0.46 MteqCO2 in 2030 and respectively to a value of **0.3 MteqCO2 in 2035**.



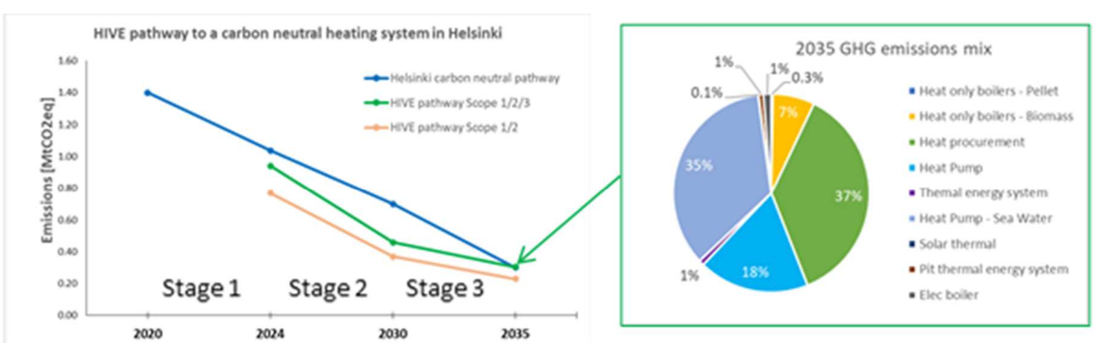
HIVE's pathway to a decarbonized heating system

HIVE's and Helsinki's pathways fully aligned

The 3 phases reduction proposed by our team will be enabled by the removal of all the fossil fuels and the adoption of a greener combination of technologies (heat pumps, thermal storages, etc.) and measures (decrease of the district heating supply temperatures, building renovation, demand side management, etc).

GHG emissions from only carbon neutral sources

The GHG emissions reduction provided by the HIVE solution, both in Scope 1/2 and with the life cycle scope (Scope 1/2/3 which is more restrictive), is fully aligned with the objectives of the Helsinki's heating system carbon neutral pathway (chart below).



HIVE pathway vs. Helsinki carbon neutral pathway (heating only)

Thus, in 2035, at full capacity and maturity of the HIVE solution, the GHG emissions will mainly come from low carbon sources such as Heat procurement from neutral carbon sources (37%, Vantaa), SHWP - sea water heat pump (35%, the calculations have been led using a R134a refrigerant and can be adapted to even lower-GWP ones, Table below), heat pump (18%) and other (10%).

Life cycle GHG emissions (scope 1/2/3) of the HIVE solution

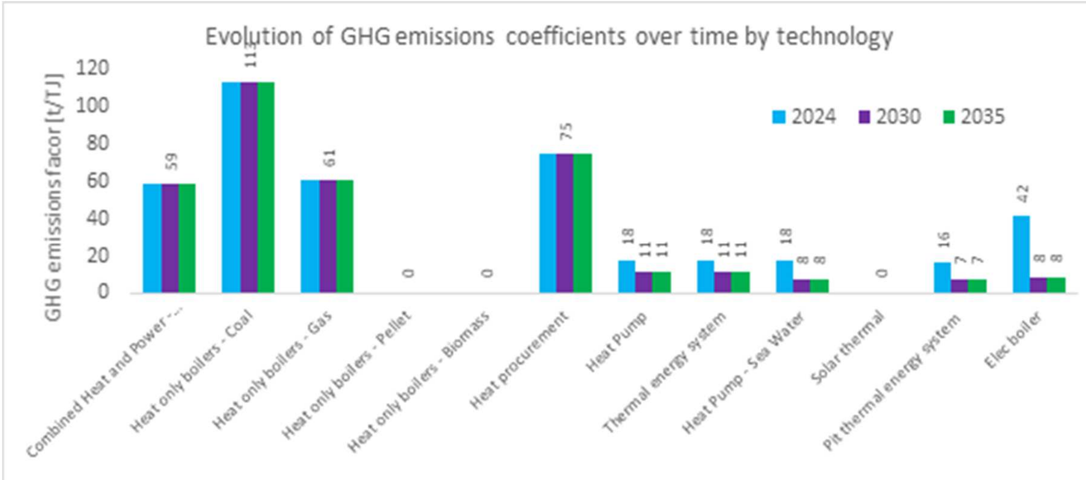
	GHG emissions [tCO2eq]			GHG emissions mix [%]		
Heat production mix	**2024**	**2030**	**2035**	**2024**	**2030**	**2035**
Combined Heat and Power - Coal	325 084	0	0	35%	0%	0%
Heat only boilers - Coal	209 890	0	0	22%	0%	0%
Heat only boilers - Gas	59 374	185 487	0	6%	40%	0%
Heat only boilers - Pellet	6 989	5 650	824	1%	1%	0%
Heat only boilers - Biomass	32 925	26 939	20 936	3%	6%	7%
Heat procurement	111 996	111 996	111 996	12%	24%	37%
Heat Pump	144 246	58 571	55 313	15%	13%	18%
Thermal energy system	3 515	1 540	2 598	0%	0%	1%
Heat Pump - Sea Water	47 143	68 253	105 899	5%	15%	35%
Solar thermal	130	260	260	0%	0%	0%
Pit thermal energy system	0	0	2 343	0%	0%	1%
Elec boiler	0	0	3 899	0%	0%	1%

HIVE's total life cycle emissions [tCO2eq]	941 292	458 695	304 068
HIVE's total life cycle emissions [MtCO2eq]	**0.94**	**0.46**	**0.30**

The GHG emissions calculated correspond to the emissions related to the heat produced by the HIVE solution. The calculation method is based on three steps:

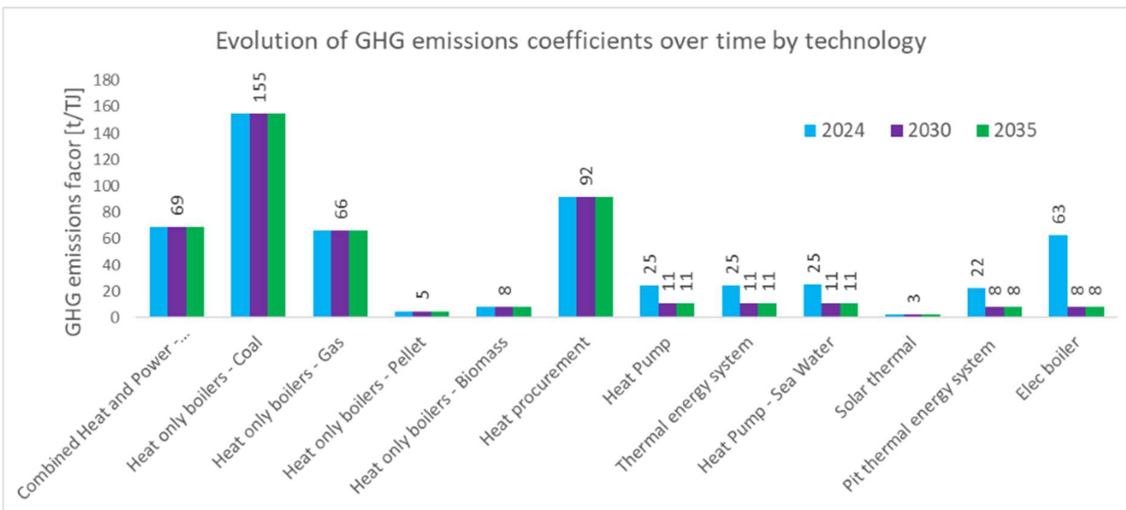
1. The first step is to **calculate the heat production** : this calculation was made in the Summary of the solution section. The heat production mixes calculation were established at different timeframes 2024, 2030, 2035.

2. The second step is to **determine GHG emissions factors** of the heat production with regard to the technologies used in the conversion process to obtain heat. In this context issues like system boundaries (e.g. life cycle analysis vs direct emissions) play a major role. Thus, the chosen GHG emissions factors of the conversion processes need to be explained. This is done for each technology and for the initial three time horizons 2024, 2030 and 2035 (See the 2 Charts below). The calculation has been led with two emission factors and biogenic CO_2 emissions are not reported within those emission factors in accordance with the GHG Protocol guidelines and recommendations :
   - The emissions factors of each heat production pathway for direct emissions (Scopes 1/2). The used electricity mix has been directly taken from the City trajectory (30 g CO_2 eq./kWh). Those Scopes 1/2 emission factors were in line with the competition methodology and the city trajectory to make sure the objectives were fulfilled. More information about the sources and the main assumptions are given in Appendix Book, section 4.



Scope 1/2 emissions coefficients used in the GHG evaluation

- The emissions factors of each heat production pathway were also analyzed under the life cycle scope (Scopes 1/2/3) to include all the emissions linked to the solution. The used electricity mix has however been directly taken from the City trajectory (30 g CO_2 eq./kWh). More information about the sources and the main assumptions are given in Appendix, section 4.



Scope 1/2/3 (life cycle emissions) coefficients used in the GHG evaluation

3. The third and final step in the calculation process is the **calculation of the GHG emissions** for heat and for the selected timeframes.

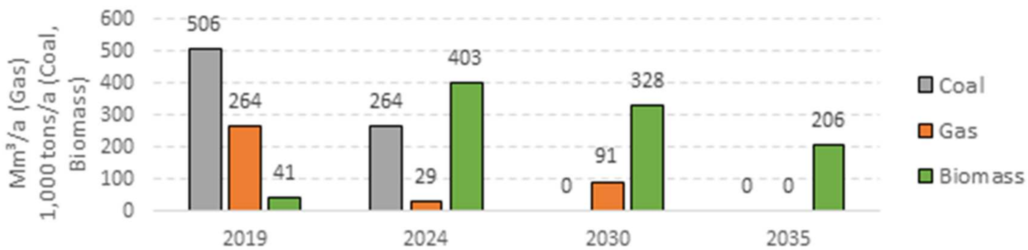
3. Impact on natural resources

The impact on natural resources of the solution proposed by HIVE is considered to be low and decreasing over time.

The proposed solution makes use of existing biomass heating plants, heat pumps and storages. The need for new infrastructure is limited to mainly the sea water heat pumps, large solar thermal installations and large-scale thermal energy storages (PTES and BTES). The main issue in regard of these new infrastructures is the use of land. The land availability for PTES and large solar thermal installation is considered a key aspect here and is later discussed in more detail.
The impact on natural resources during operation is considered to be low thanks mainly to the high share of renewables. However, the biomass supply (primarily till 2030) and necessary logistics are considered a challenge and a key aspect to be dealt with in order to minimize the impact on natural resources, and are discussed below.

Drastic reduction of the overall fuel consumption.

Based on the design of the technical solution and the calculations carried out, the fuel needs could be estimated, see figure hereafter:



Yearly fuel consumption. Data for 2019 based on heat production data from Helen Ltd. and assumption of yearly average efficiency for gas, coal and biomass heat production units of 85 % each. Data for 2024, 2030 and 2035 based on own calculations of the primary energy use and following conversion factors: 0.009166667 t/GWh for Coal, 1.01111E-05 m³/GWh for Gas, 0.0053 t/GWh for Biomass (pellets) and 0.0044 t/GWh for Biomass (non-pellets))

The **coal consumption will continuously decrease and be eliminated by 2029**. The gas consumption will fluctuate in the upcoming years. It will be drastically reduced down to 29 Mm³ by 2024, increase up to 91 Mm³ by 2030 and fade by 2035. A noticeable increase of biomass consumption is planned for the upcoming years, so that 403,000 tons biomass a year are to be consumed by 2024 when the new Vuosaari biomass boiler comes on stream. The biomass consumption will after 2024 slowly decrease till reach 206,000 tons a year by 2035.

Biomass supply is a challenge, though not critical, as gas supply can compensate in case of shortfall.

The reduction on gas and coal consumption is mainly achieved by an increase on heat from heat pumps and biomass heating plants, with contributions of other sources like solar thermal, direct electric boilers or large thermal energy storages.

The biomass consumption for heat production in 2019 is estimated[1] to be 41,000 tons / year. According to Helen Ltd.[2], most of the wood pellets were manufactured in Finland and a small portion was imported from Estonia. In any case, 81 % had sustainability certification (e.g. PEFC, FSC or SBP) and the rest came from certificate controlled sources or originated from certified suppliers.

The use of Vuosaari and Salmisaari biomass heating plants as base load will increase the biomass demand up to 403,000 tons per year, i.e. an increase of 981 %. The Finnish Forest Research Institute[3] estimated that if forests were to be felled according to the greatest sustainable felling capacity with respect to wood production and economy, the accrual of energy wood in the coming decades would be approximately 22 Mm³ (≈44 TWh primary energy) annually. By no major changes in the use of wood for residential use the increase is estimated to be 11 Mm³ (≈22 TWh). This is indeed a large potential, notice that based on wood flows in 2013, 36.7 Mm³ of wood output was used for energy in some way in Finland (being 79.2 Mm^3 the total drain). The natural resources institute Finland[4] (comprising the Finnish forest research institute) holds the estimation of high potential for biomass, stating that the annual growth of trees in Finland exceeds the volume of felling and natural loss by over 20 Mm^3 and that **annual sustainable removals of 60-65 Mm^3 can be increased above 85 Mm^3 in the next decades**. Thus, the main issue is the actual implementation in a short time frame, i.e. convince forest owners of energy wood potential and definition of necessary logistics after identification of source regions. Synergies with mechanical and specially pulp industry are known and need to be further endorsed.

Though the implementation of the necessary measures to ensure the steady and sustainable supply of biomass are considered to be a challenge, we do not consider this to be a critical aspect since delays on the implementation can be compensated with a lower reduction of gas consumption, which supply is considered to be ensured.

Land availability would require a dedicated upstream management with stakeholders only for PTES and solar thermal installations.

6 zones in East Helsinki and 4 zones in Vantaa with a total area of appr. 5.5 km^2 and 8 km^2 respectively have been identified as potential areas for the implementation of large solar thermal installation and pit thermal energy storages. Notice that the required area for **the planned two 500,000 m^3 PTES and the two 25 MW solar thermal installations requires no more than 350,000 m^2**.

Most of the defined zones are close to protected areas but do not include them. However, some of the current potential zones do include valuable nature areas, e.g. important for reptile and amphibian, important geological site or important bird areas. A list of figures showing the chosen areas in the Helsinki region and potential natural impact have been added in the appendix section 5 onwards.

Preservation of the zones have to be taken into account in the further planning. Examples on achieving such a synergy between land use for renewable energies and preservation of valuable areas can be found in Denmark, Germany and Austria among others.
Independently of the current ownership of these areas, these are of clear value for other stakeholders such as farmers and citizens so that reticence to dedicate such areas for energy use is to be expected.

This situation is known and based on experience, it can be only solved with a transparent communication and dialogue with the most affected communities, the endorsement of the local and regional authorities of such projects is key in finding consensual solutions.

The space requirements to install BTES is considered to be minor (3,500 m^2 surface area per BTES – 15 GW and 50 GWh each). Potential zones with space for up to 49 and 26 BTES units have been identified in Helsinki and Vantaa respectively (listed in the appendix section 5, from page 46). These selected areas are unused and unforested areas close to main roads and road interconnections with little or none interest for other uses. The implementation of the planned 6 BTES is considered achievable and uncritical.

The size requirements for SWHP are considered to be low, the main challenge is the location of suitable and available spots at this stage.

No impacts are expected on the sea temperature, water savings are expected, natural refrigerants will be used. According to Helen Ltd[5] in 2019, a total of 147 GWh of waste heat and cooling energy from power plants and cooling centres was released into the sea and so far, no major negative effects, e.g. eutrophication, have been detected. Though after the installation of sea water heat pumps a relatively large amount of heat will be extracted from the sea, the large heat capacity of the sea indicates that no major issues are to be expected. Furthermore, HIVE planned the use of natural refrigerants with zero ozone depletion potential (ODP) and global warning potential (GWP) such as Ammonia, thus reducing harmful impact on the environment due to leakages.

[1] Based on heat production data from Helen for 2019. https://www.helen.fi/en/company/responsibility/responsibility-report/environmental-responsibility/carbon-neutral-energy. Assuming an average yearly efficiency of 85 % and a conversion factor equal to 0.0053 t/GWh.
[2] https://www.helen.fi/en/company/responsibility/responsibility-report/environmental-responsibility/origin-and-sustainability
[3] Energy and Climate Roadmap 2050. Report of the parliamentary Committee on Energy and Climate Issues on 16 Oct. 2014.
[4] https://www.luke.fi/en/natural-resources/forest/forest-resources-and-forest-planning/
[5] https://www.helen.fi/en/company/responsibility/responsibility-report/environmental-responsibility/emissions

4. Cost impact

Objective

The present section provides the following determination of cost of heat production with the proposed portfolio :

- Separating the components investments, operating….
- Over the lifetime of the solution
- Presenting annual investments till 2035
- Including all costs, as detailed in the report
- Cost of heat production + levelized cost of heat for 2030 and 2035
- Taxes
- Interest rate 4%.

Notes:

- For explanation on the possible financing, please refer to section 6 'Implementation Feasibility'.
- HIVE's estimates exclude any subsidy. HIVE recommends that a detailed study should be conducted as soon as implementation of the solution is started, in order to appraise whether the estimated COHs could be improved with the help of subsidies. In particular the European Innovation Fund could be targeted. The solution will enable a massive reduction of CO2 emissions, which will put an application for subsidy under the scheme in a very favourable position. The level of "relevant costs" that may attract subsidy and the impact on COH will however require more detailed studies of the solution than available today.

Method

The **Cost of Heat ("COH")** is calculated for the portfolio of heat generating plants. The COH calculation is performed in any particular year (e.g. 2030, 2035), and based on the mix of generating assets and their respective productions in that year.

The **COH** (expressed in Euro per MWh of heat generated) for each plant is calculated as the sum of following contributions:

- **Capital recovery component**. This component is calculated as an annuity over an assumed economic life of asset, and generating a project IRR of 4% on the investment value.
- **Increment on the capital recovery component to account for corporation tax**. An increment of 10% on the above capital recovery component is applied [3].
- Fixed O&M costs component. The yearly amount (M€/year) of such costs is considered constant through the economic life of the project.
- **Variable cost contributions to COH**. These comprise: primary energy contribution (fuel for boilers; electricity for heat pumps); auxiliary electricity consumption; Tax on fuel; CO2 cost; other / various variable operating and maintenance costs.

The **COH of a mix of heat generating plants** is the weighted average of COH for the different plants, weighted by their respective heat productions in the mix.

To the COH of the mix of heat generating plants is then added a contribution of following cost elements, which are represented as common to the portfolio rather than specific to any one asset:

- Cost contributions from the heat storage assets: capital recovery contribution and Fixed O&M;
- Contributions from the yearly fixed operating and maintenance cost (personnel, insurance, land renting costs, …), allocatable to the portfolio.

No indexation / inflation is applied, COH values are to be considered expressed in real (2021) terms.

Inputs and assumptions

All input values to the COH calculations can be found in the printout of the calculation sheets, provided in section 6 of the Appendix Book.

Installed capacities and generation

Evolution over time of installed capacities of different technologies; yearly generation per asset.

Capital recovery on assets

Assumptions for capital recovery on investments are:

- Target IRR = 4% after tax;
- 20% corporation tax rate;
- Technical = economic life of respective assets : 20 or 25 years;

As an approximation, the capital recovery component for existing Helen assets is calculated similarly to capital recovery for new investment. The rationale is that the yearly capital recovery on an asset still in operation (= during its economic life) is calculated as an annuity (=constant yearly value) over the economic life of the asset, hence independent of the year in which the COH is calculated or the year in which it was built.

Parameters specific to heat generating assets

For each technology, estimated values for Capex, Opex and plant performance are applied. For specific values, please refer to the printout of the calculation sheet, provided in section 6 of the Appendix Book.

Network temperature reduction and efficiency increase

A Capex of 48 M€ is included corresponding to the adaptation for network temperature reduction and efficiency increase. It includes interventions on pump and pipes for the network, Energy Transfer Station adaptation and modification on end user side (radiators, etc.), as described in "implementation feasibility" section.

Extension/densification of the district

We consider that the network is continuing its current growth of 15 km / year, whether it be for extension or densification. We are therefore planning an envelope of 15M€/year.

General operating costs

Cost elements, which are represented as common to the portfolio rather than specific to any one asset, included in the calculation of COH, are the following:

- Personnel costs : we have included 100% of the personnel (old and new assets, heat distribution grid, commercial, projects), with a total salary cost assumed equal to 80% of the current value (obtained by subtracting from the total Helen Parent Co salary cost, the part allocated to the electrical production in the 2019 financial accounts).
- Rents: we have assumed 100% of the cost of land leases as found in the 2019 Helen financial accounts. The underlying assumption is that additional land required for solar, PTES, etc., will be compensated by reduction in surface on the sites of the cola plants.
- Insurance policies : we have assumed 0.5% of the investment value of the installed assets.
- General O&M cost for the grid and global performance monitoring : 18M€/year.
- Other, based on the Helen 2019 financial accounts:
    - Other leases : 10 M€/year
    - Other information technology and expert services : 10 M€/year
    - Vehicle and equipment expenses: 3 M€/year
    - Representation and marketing : 8 M€/year

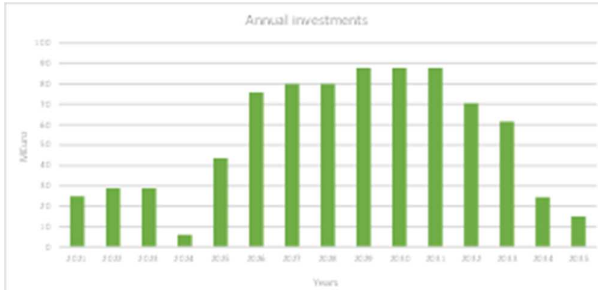
The total general operating cost amounts to 86 M€/year. **It will be noted from the results of COH calculation, that these general operating cost represent a significant part (of the order of 30%) of the COH.**

Background figures and material

Figures as indicated in the Evaluation Criteria, have been applied.

Annual investments

The total investment amount over the period 2021 to 2035 is 803 M€. The distribution of the total amount over the years is shown in the graph below.



Results

The calculated COH figures, calculated w/o VAT are:

- 58 €/MWh (2030); 59 €/MWh (2035)
- Note : excluding the general operating costs, the values are 40 €/MWh (both 2030 and 2035)

The average heat price in 2019, from the 2019 HELEN financial statement, was 446 717/6 523 = 68,5€/MWh w/o VAT.

Following main conclusions can be noted:

- COH is essentially identical between 2030 and 2035;
- COH comparison between 2030 and 2035 is somewhat affected by the difference in overall quantity of heat produced, the 2035 quantity being approximately 5% lower than the 2030 quantity;
- From 2030 to 2035, the graph shows transfer of COH build-up mainly from HOB (Gas, Pellets) to additional HP-seawater and to a lesser extent the electric boiler and the PTES.
- The average heat price proposed by HIVE, as calculated, is in the same order of magnitude, or even cheaper than the 2019 price. Of course, the economic study is to be deepened.

A breakdown of COH is represented in section 6 of the Appendix Book.

Sensitivities

Sensitivities of COH to increase in the constituent components are presented in the table below.

Sensitivities	% increase over base case 2030	% increase over base case 2035
COH : capex +20%	+ 4%	+ 6%
COH : Fixed O&M +20%	+ 6%	+ 7%
COH : Variable costs (fuel, electricity, CO2) +20%	+ 9%	+ 7%

Sensitivities illustrate the respective weights of the different components (investment, fixed O&M, variable costs) in the COH. As weights are balanced, the COH figures are rather robust.

5. Implementation schedule

This section details the implementation schedule for the technologies portfolio proposed as described in the following figure:

The implementation schedule is a high-level one and presents for each asset the major activities to be performed from feasibility until construction phase:

1. Feasibility Study, Basic Design of the project including land negotiation, measurement campaign, geotechnical survey;
2. Permitting track (permit submission, evaluation by authorities, permit granted);
3. Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM);
4. Project execution (EPC or EPCM to be defined later);
5. Commercial Operating date.

The table on next page illustrates the high level planning. As can be observed, three major phases will take place:

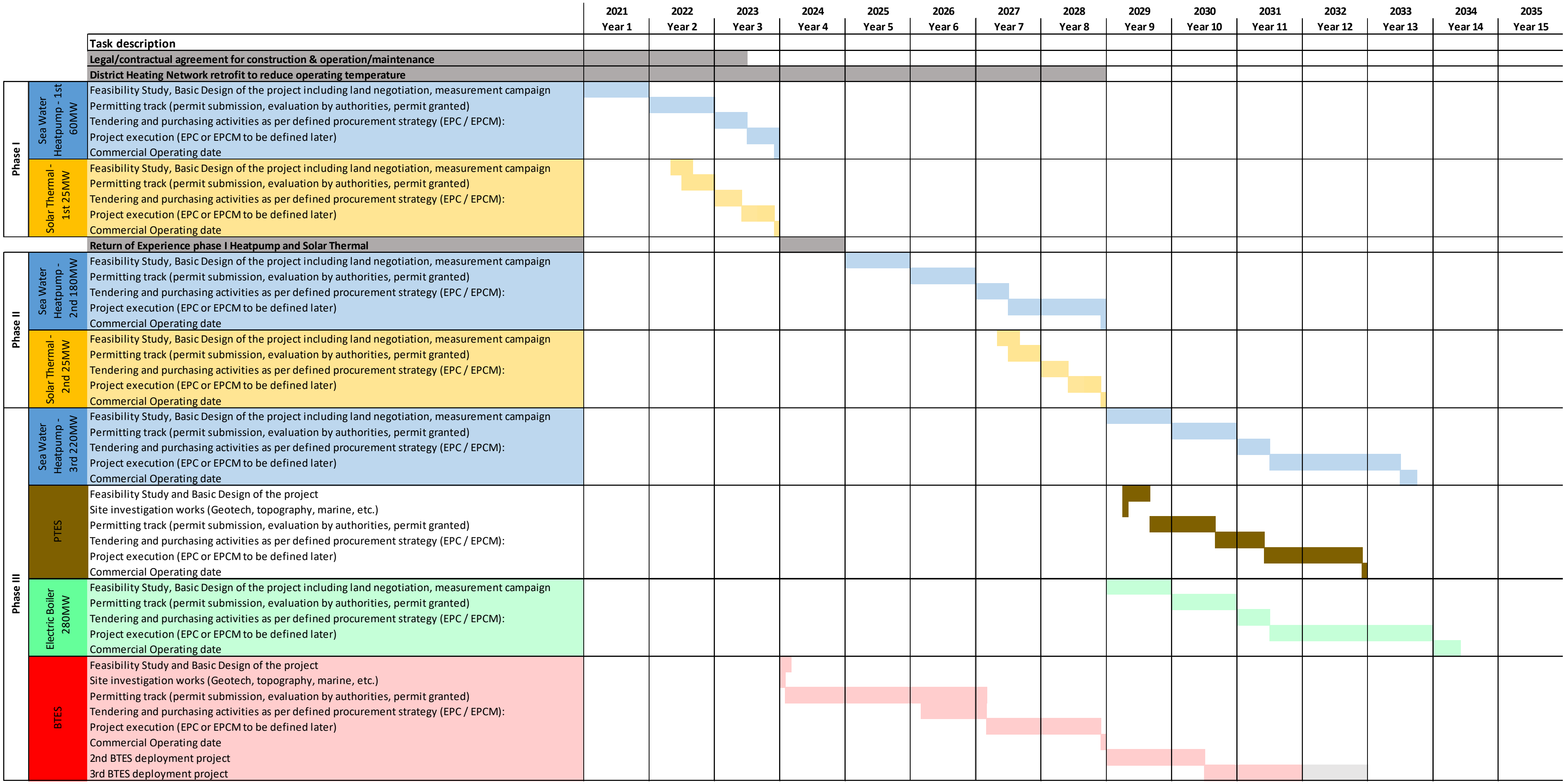
1. A first phase to address the **closure of the coal CHP plant** in Hanasaari by 2024 which will be compensated through 60 MW of sea water heat pumps and solar thermal plants, on top of the foreseen and planned investments of the city (e.g. (1) Vuosaari biomass plant (2) increased heat procurement from the adjacent district heating networks in Espoo and Vantaa).

2. A second phase to address the phase-out of coal by 2029. A period of 1 year in 2024 will be leveraged to perform a deep Return on Experience (REX) on the sea water heat pump and for the solar thermal panels:
   a. Proper working of the seawater heat pump especially during winter month when external temperature are very low;
   b. Assessment of the real production and comparison with the assessed one taking into account external weather conditions (including irradiation for solar asset).

If during the winter season of the period of REX, we observe that production of these assets is as expected, we can accelerate the implementation of the second phase and continue to increase the volume of CO2 avoided emissions even if the coal power plant are still operated.

3. A third phase to foster stronger decarbonization of the district heating network and enable a full independency towards fossil fuels. Implementation of the third phase will start after the second phase of investment. The aim to have a continuity in terms of construction is to ensure a resilient and well proved energy system. This planning also has the benefit to leave 2 years of margin before final due date by 2035. This will enable to gain Return On Experience for BTES and PTES. Beyond these 3 major phases, three additional elements should be taken into account in the planning:

- Legal/contractual agreement for construction & operation/maintenance: discussions should take place from the early phase of the project to setup the legal framework required for large scale deployment suggested in HIVE's solution.
- HIVE proposes to pursue investigations that aims to lower the supply temperature which is a first and thoroughly important step on Helsinki's journey toward Carbon Neutrality. As of 2029, the District Heating Network will be operated at a lower temperature to foster the decarbonization through efficient electrification technologies (i.e. sea water heat pump). The modification of the network will be started as soon as possible and should be ready by end of 2028.


2021 Year 1
2022 Year 2
2023 Year 3
2024 Year 4
2025 Year 5
2026 Year 6
2027 Year 7
2028 Year 8
2029 Year 9
2030 Year 10
2031 Year 11
2032 Year 12
2033 Year 13
2034 Year 14
2035 Year 15
Task description
Legal/contractual agreement for construction & operation/maintenance
District Heating Network retrofit to reduce operating temperature
Phase I
Sea Water Heatpump - 1st 60MW
Feasibility Study, Basic Design of the project including land negotiation, measurement campaign
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
Solar Thermal - 1st 25MW
Feasibility Study, Basic Design of the project including land negotiation, measurement campaign
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
Return of Experience phase I Heatpump and Solar Thermal
Phase II
Sea Water Heatpump - 2nd 180MW
Feasibility Study, Basic Design of the project including land negotiation, measurement campaign
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
Solar Thermal - 2nd 25MW
Feasibility Study, Basic Design of the project including land negotiation, measurement campaign
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
Phase III
Sea Water Heatpump - 3rd 220MW
Feasibility Study, Basic Design of the project including land negotiation, measurement campaign
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
PTES
Feasibility Study and Basic Design of the project
Site investigation works (Geotech, topography, marine, etc.)
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
Electric Boiler 280MW
Feasibility Study, Basic Design of the project including land negotiation, measurement campaign
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
BTES
Feasibility Study and Basic Design of the project
Site investigation works (Geotech, topography, marine, etc.)
Permitting track (permit submission, evaluation by authorities, permit granted)
Tendering and purchasing activities as per defined procurement strategy (EPC / EPCM):
Project execution (EPC or EPCM to be defined later)
Commercial Operating date
2nd BTES deployment project
3rd BTES deployment project

- In parallel to these implementations aiming to fulfill Helsinki energy balance, additional investments in geothermal energy, through Borehole Thermal Energy Storages, are recommended by HIVE to serve security of supply purposes and act as strategic reserves (see section 7 "*Reliability and security of supply*"). The suggested implementation is also depicted on the below figure.

After the decommissioning of the coal power plant, the current gas assets should be kept in the energy mix, be it for peak capacity or as back-up units if some implementing issues appear as described in the section implementation feasibility criteria.

The hereunder table provides an overview of major risks that can have a significant impact on the implementation schedule, together with the suggested mitigation measures. The main risks are related to:

- Delay in setting up a contract agreement / legal structure
- Delay in deploying HIVE's assets by 2029 due to permitting phase and other factors
- Delay in deploying HIVE's assets by 2035 due to permitting phase and other factors

Other major risks are already covered by section 6 "*Implementation feasibility*" .

Risk	Initial Risk			Mitigation measures	Residual Risk		
	Likelihood	Impact	Criticity		Likelihood	Impact	Criticity
Delay in Contract agreement / Legal structure for construction and operation and maintenance phase (shared risks, third party investor…)	3	4		Setting-up the 2 pilot projects (60MW heat pump and 25MW solar thermal) from Phase I (before 2024) will help to frame such a legal scheme and to clarify the different interfaces to be managed.	2	2	
Phase II: Delay in deploying assets in 2029 (permitting delays, environmental or human accidents/incidents during construction, any force majeur like pandemic	3	4		- The implementation of 2 pilot projects (sea water heat pump and solar thermal from Phase I) combined with one year of operation and associated REX will reduce the risk for the construction of the other identical assets for Phase II (before 2029). - Implementation of the additional sea water heat pumps foreseen from 2025 to 2028 will also occur in small individual plants and likehood than several intermediate plants were already commissioned is high. - Moreover, the proposed solution go beyond the CO2 avoided emissions targeted by the City of Helsinki (see Climate impact criteria) in Phase II. Assets like gas CHP and HOB, HFO and LFO HOB could still be operated to compensate the missing future green assets while still meeting the city objectives. - In HIVE solution, heat procurement from Vantaa and Espoo is assumed to be leveraged only in summer period (from May to Septembre). The existing heat exchanger capacities (250 MW) could be further leveraged on during critical periods would the deployement of our solution be delayed. - Health and Safety measures put in place during the whole project (environmental impact assessment, constuction) could highly reduce the risk to have environmental or human incidents.	2	2	
Phase III: Delay in deploying assets in 2035 (permitting delays, environmental or human accidents/incidents during construction, any force majeur like pandemic	2	3		- The commissioning period of HIVE's assets is planned to occur between 1 and 2 years up front of the full phase-out of conventional carbon-based fuels (i.e. gas, HFO, LFO), namely 2035. This margin could clearly help to anticipate and resolve any delay taken during the implementation Phase II. - Moreover a same duration for feasibility and construction phase as for the Phases I and II (2024 and 2029) is foreseen. However, securing the different suppliers trough a framework agreement and working with the same partners will enable to gain in efficiency and to take into account any previous REX. The risks for the phase III is much lower than for phase I and II. - Last but not least if for any reason, delays are still not resorbed, gas energy vector could still be used.	1	1	

Likehood level	Meaning
1	Unlikely <5%
2	Rather unlikely 5%< <25%
3	Rather likely 25%< <50%
4	Likely >50%

Impact level	Meaning
1	Low
2	Moderate
3	Severe
4	Catastrophic

6. Implementation feasibility

HIVE is a mix between the massification of mature technological solutions and a the lowering of the operating temperature of the network. The innovation lies mainly in the size effect: size of the heat pumps installed, size of the PTES, and above all size of the network for which the temperature is lowered. HIVE team is very confident in the solutions proposed. The feasibility factors are described in this table :

Feasibility factor	Detail	Comment reference
Technological	Mature technologies.	A
Financial	Marginal impact on final price to end-user. Project finance can be structured	B
Legal	No change needed in legislation.	
Administrative	Precaution with permitting, important role of the City	
Cultural and ethical	Our solution is culturally and ethically feasible. HIVE offers to support the change of energy consumption habits and the acceptance of changes among users.	C
Operational	Focus in this section on temperature decrease. Other aspects are described in "reliability and security of supply" section.	D

Some comments related to this table :

A (technological) : Concerning the following technologies HIVE plans to develop on Helsinki's DH :

The different Thermal Energy Storage : Pit TES and Borehole TES are mature and complementary solutions.

- BTES : Favorable thermal conductivity in the underground (≈ 3 W/(m.K)) but low geothermal gradient making shallow BTES solution more adapted than deeper, more expensive, opened or closed loop wells. Each BTES is large scale (500 boreholes) but compact which limits land area needed, reduces the underground thermal losses and improves efficiency.
- PTES : Enables stratification (layering according to different temperature levels); optimizing system utilization of low temperature heat sources and heat pumps. PTES needs a large surface (65 0000 m²) but HIVE has identified some available lands as shown in section 5 of the Appendix Book. The visual impact is low, so accepted by the population so far. If no PTES location can be found within the city area options may be available in the outskirts or neighbouring regions. For safety, heat losses are in the modelling set somewhat higher than what can be expected in practice with state-of-the-art.

Thermal solar production : Proven technology with solid track record (>30 years). Scale of Helsinki and optimization with heat storages and other renewable sources will also be innovative and aligned with current R&D projects. High acceptability : no emissions of CO2 or particles in the city, very low electricity consumption.

Sea Water Heat Pumps : 460 MWth of SWHP will be installed. HIVE's team has been operating several SWHP and a lot of sea water pumping in many countries for more than 15 years. HIVE is very confident in this mature technology. As an example Nordic countries (Sweden, Norway) where such installations are in large scale with several megawatt capacity are well adapted to DH.

HIVE proposes to continue the work carried out by HELEN so far concerning the installation of SWHP, to increase tenfold the installed heat power from it, and above all to use it all year round thanks to high temperature HP.

Sea water temperatures along the shores and salinity of the Baltic Sea are a challenge. Information gathered validates the feasibility of accessing at all times water above 2°C. This enables to operate SWHPs at economical COPs (cf. details of our study in section 3 of the Appendix Book)

Sea water intakes will have to be more carefully studied. Besides access to water at suitable temperature, the location and type of intake will have to ensure operational reliability of the heating plants.

The CHP sites at Salmisaari, Hanasaari and Vuosaari appear to be convenient locations for SWHPs. Located at the seaside, they have powerful connections to the electrical and district heating grids. SWHPs will only take a fraction of these sites. Thus the Hanasaari and Salmisaari sites can be to a large extent redeveloped for other uses when the coal fired CHP plants are decommissioned.

B (financial) : the rehabilitation project (with heating technologies using electricity and renewable energy sources) is planned with a decarbonization plan complying with the definition of an efficient system within the meaning of the EU Energy Efficiency Directive. Therefore, as such, the project is eligible for loans from the European Investment Bank (EIB), its characteristics being in line with the new lending policy of the Bank (which wants to be the climate bank within the EU). HIVE has a good working knowledge of the negotiations to be conducted with the banks and will be able to advise the City of Helsinki.

By decarbonizing the entire heating system of the city of Helsinki, the project is also eligible for grants from the EU Innovation Fund. If it is selected as part of a call for projects from this fund, the project could benefit from EU financial support to cover part of the CAPEX, but also OPEX for a period of 10 years. Due to the features of the call, the project can be competitive on all the different selection criteria : (i) GHG emission avoidance (ii) degree of innovation (iii) degree of maturity (iv) scalability and (v) cost efficiency.

The Levelized Cost of Heat will be similar to the current one, without grants, thanks to HIVE solution. Indeed the main solutions implemented, mainly SWHP are cheaper than coal and gas combustion.

C (cultural and ethical) : HIVE doesn't see any cultural or ethical risk in his solutions. Nevertheless the involvement of end users, and the reinforced involvement of all stakeholders is essential. In this respect HIVE offers support all along the deployment of the solution. What's more HIVE proposes to develop production sites (SWHP, ST, TES) by adding a public visitor center.

Our proposed technologies are silent, barely visible, non-polluting and accepted solutions.

From the end user's point of view, improving the DH means a better efficiency, a better air quality (end of coal, biomass use limited) and cheaper heat. But he's still free to disconnect from the DH, so the municipality and the DH operator still need to communicate about the advantages of the DH. HIVE proposes to highlight the social value from this solution thanks to the existing collection of information and the 3D model of Helsinki, as shown in section 7 of the Appendix Book. Of course personal data will be protected.

D (operational) : The **drop of supply temperature in winter** is key in HIVE solution. For us, no network of this size has done this before so although the operation is not innovative in itself, it is by the size of the network on which it is applied.

A system rated >100°C does not need to operate at a temperature above 100°C all hours, however it allows the system to run at higher temperatures to accommodate extreme loads. For most hours of a year, the system can run at 95°C or lower. In the case of the Helsinki district heating system, this is confirmed in the documentation we have been provided which tend to confirm that all systems (primary and in-Buildings secondary loop) are **hydronic systems** (with hot water) limiting the work to be done to convert the network to a Low Temperature Network (>100°C).

The important feasibility factors when dropping the supply temperature to 85°C are:

1. **Primary side** : While the intent is to operate at or below 85°C, the design temperature will provide some flexibility to operate above 85°C during the initial years of operation, as well as

the ability to more easily handle outdoor air temperature conditions. Supply temp already reaches 80°C in summer, so HIVE suppose plants are already equipped with superheated water/Hot water exchangers. It's possible that some plants need to increase the flow rates, meaning increasing the power of the pumps and increase pipe diameters beyond the DN1000 at the plant outlet. HIVE proposes some detailed hydraulic simulation to confirm potential work to be done and already plans a budget of 10M€.

2. **Secondary side** : Energy Transfer Station and Customer side thermal transmitters (radiators). The heat exchangers are one of the most critical components of the ETS; both in terms of performance and reliability, and several factors should be analyzed for optimum selection of each heat exchanger, such as:

    - Sizing each unit's capacity to match the load and turn-down capabilities
    - Critical nature of the load/operation
    - Temperature and pressure conditions
    - Available space in mechanical room
    - Allowable pressure drop across the heat exchanger

Customer side thermal transmitters (radiators) : some radiators may need to be changed as the pressure or the lower temperature does not procure the power needed for the final users. HIVE targets 5% of the apartments connected to the DH, built before 1970, need to change their heat exchanger and their radiators. 18M€ are budgeted for heat exchangers and 20M€ for radiators.

The total budget related to the drop temperature adaptation of the DH is 48M€, meaning only 0,6€ per MWh of heat injected in the DH, which is a marginal cost.

The realization of temperature reductions needs to be monitored carefully to ensure progress as the timeframe can be long. However, the lower levels are targeted several years before it becomes important for the HIVE solution to have the reduced DH supply temperatures.

To go further, we consider that a long-term objective (after 2035) could be to operate the District Energy System at a lower Primary temperature of 70°C supply. Therefore, the future target would be to operate building Secondary systems at 65°C supply and 40°C or lower return operating temperatures. This step is not mandatory to make HIVE proposal feasible.

<u>Top risks matrix</u>

On the following page is HIVE's matrix of the top implementation risks. Likelihood and impact levels shown in the table are explained below.

Likehood level	Meaning
1	**Unlikely <5%**
2	**Rather unlikely 5%< <25%**
3	**Rather likely 25%< <50%**
4	**Likely >50%**

Impact level	Meaning
1	**Low**
2	**Moderate**
3	**Severe**
4	**Catastrophic**

Feasibility factor						Category	Risk	Initial			Mitigation measures	Residual Risk			Comment
Technological	Financial	Legal	Administrative	Cultural and ethical	Operationnal			Likelihood	Impact	Criticity		Likelihood	Impact	Criticity	
	x			x	x	Demand	Drop in heat demand/customers switching to individual or local supply.	3	2		Solution implemented in steps, adaptable schedule ; social indicators and communication reinforced about the numerous benefits of DH to avoid disconnection.	2	2		
					x	Hydraulic balance of the DH	The drop of supply temperature from 115°C to 85°C in winter will lead to a lower delta T and could lead to massive hydraulic modifications on the primary and secondary side of the DH. The return temperature could be higher than expected, with impact on HP efficiencies.	3	2		HIVE plans to commission the new assets at the location of the existing ones so the max power to be injected in the pipes do not vary much and the electric power needed, espacially for HP and electric boilers, is available. A budget of 48M€ is planned to adapt the primary and the seconday side of the DH to the drop of temperature. HIVE propose to more deeply study the dynamic hydraulic balance of the DH thanks to proven tools. HIVE propose to include in the heat delivery contract with the users a bonus/malus system : if the flow is reduced (increased deltaT) the client gets bonus, if excessive flow he pays for it. This would first be a volontary option and it would be associated with a pedagogic approach of the clients relative to energy efficiency benefits for them.	2	1		D
					x	SWHP	Offshore risks : sea water quality (planctons in the water, leading to heavy cost of electricity to filter the water or bacteria treatment above Environmental permit) ; head and temperature losses in sea water pipe ; sea water pipe damaged/broken due to fishers or natural conditions	3	4		Run an annual survey on salinity in different locations. Work with the pipe manufacturer to take into consideration friction parameters after 20 years. Properly monitor water quality and run a maintenance cleaning of the HEX. Our planning proposes implementation by phases, REX is taken into account after each phase.	1	2		
	x					All new assets	CAPEX more important than expected : impact on heat price	2	3		Deeper feasibility studies to be lead by HIVE, but capex estimation takes into account the real operationnal conditions. A very good knowledge and experience of the technologies is provided by HIVE to limit the risk.	1	2		
			x	x		PTES, thermal solar	Land resources (priority target) broadly labelled "recreational use" not granted to the project	2	4		Several areas identified (10x the need for thermal solar) and more could potentially be added. Identified locations analysed for best suitability in a parallel process i.e. not one at a time.	1	3		
			x	x		All new assets	Public acceptability of the project : permitting refused ; Appeal by third party against project in permitting process.	2	3		Stakeholder management strategy in place upfront (1 employee dedicated to this mission) so the City of Helsinki can anticipated communication about the project ; systematic analysis of all stakeholders (matrix and tool proposed by HIVE) before the validation of the solution and collaboration with them ; quality of permits, get a fully documented file to submit ; propose a visit center of the different production sites ; approach to engage citizens in the process toward a fossil fuel free heat supply.	1	3		E
					x	Climate	Exceptionnal climatic events, sea level elevation particularly.	3	4		The activity continuation plan of the DH will include resiliency to the anticipated impacts of climate change. This will need a strong partnership with the city and the operator. HIVE could share his experience in operating plants close to rivers or sea.	2	2		
					x	Biomass	Failure of the most powerfull asset - Vuosaari biomass plant - during the winter peak demand. Could be due to wood delivery problem lasting more than 3 days.	1	3		Storage units proposed by HIVE to cover the heat power (270 MW available); gas units and electric boilers will be kept as back-up ; covering the SWHP heating power.	2	1		E
	x			x	x	Electricity price	HIVE solution is quite dependant to electricity consumption. Risk if electricity price increase dramatically. Impact on heat price.	3	3		Flexible mix with available capacity of non electric production ; negotiate long term PPAs with stable prices for renewable local power production (wind, solar, etc.),	1	2		

E : detailed in the “reliability and security of supply” section.

7. Reliability and security of supply

The HIVE solution involves a high degree of stability as the basic elements of the heat supply mix are directly dispatchable. The technologies are proven, reliable and can be implemented directly and initiated immediately thus reducing the risk "can the plan in fact be realized?". In fact, the plan and the associated emission reductions can be accelerated if there is a will to accept the additional costs compared to the presented timeframe e.g. in order to reduce natural gas use also before 2035. In the following, the reliability and security of supply is linked to associated risk categories.
A risk mitigation plan overview is seen in the "implementation feasibility" section.

Technical risks/ Performance of applied technologies

Since the HIVE solution is a mix of a wide range of distributed units it is very resilient. Even a 60 MW SWHP element consist of several HP units thus reducing the risk that in case of outages all 60 MW is unavailable. In case of lower COP levels of the SWHP than expected e.g. due to temperature of the sea being lower in winter, the power delivered by SWHP could be less than planned. On the other hand, a synergy option (sector coupling) is represented by the option of providing direct seawater-based district cooling and then extract heat from the return water thus enabling a combined use of the water stream for both cooling and heating.

With regard to the temperature levels of the network, the network temperature reduction action plan is described in the "implementation feasibility" section.
The solution is robust and does not rely on a single technology. Hence the overall feasibility of the plan is not relying on a single risk element. In addition, potentially more excess heat could be identified and feasible to utilise, technological improvements can increase efficiencies and/or investment costs in the period before investments are needed, etc.

Risks associated with the supply fuels and electricity

The described phase-out of a fossil fuel demand will make Helsinki not dependent on import of such fuels thus less geopolitically vulnerable (e.g. from imported natural gas). However, care must be taken that one type of fuel import dependency is not substituted with another. As biomass is a limited resource and global demands are expected to increase, it is especially important to consider the future demands in Finland in a system perspective. HIVE's solution drives the biomass use down (cf. natural resources section).

The HIVE solution relies on power supply from the national grid. This has strong reliability (with transmission reliability rate in 2020 of 99.99995% according to Fingrid). Large existing gas based capacity could be kept and serve as more backup. (See also "Operational risks" below.)

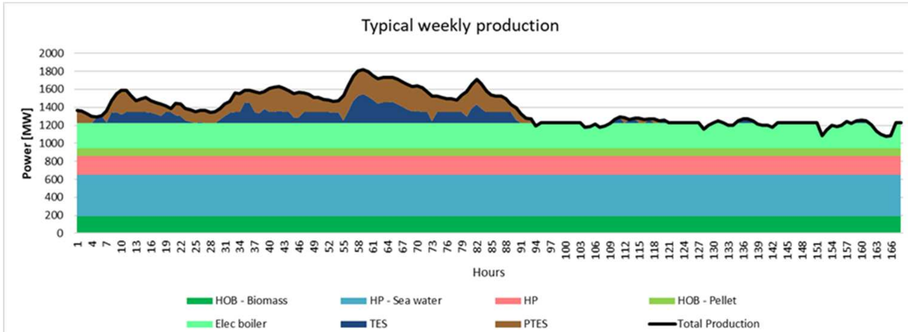
System-level risks (system flexibility, system complexity)

Flexibility of the system design

As it can be seen in the following graph, more than 400 MW are delivered by TES (existing or planned TES + PTES + BTES) during the peak in 2035, which makes it possible to avoid gas boiler operation.
By applying the storages, operation strategies will be more flexible in terms of a) maximizing/minimizing use from specific capacities (applying the storages as short-term flexibility providers) e.g. to reduce fuel use, and to optimize HP/electric boiler operation for lowest possible electricity price levels, and b) enabling non-fossil fuel peak load capacity.

Regarding fuel and electricity use, the ambition should always be to minimize emissions in an overall system perspective. This requires a continuously reviewed and revised long-term strategy which is both robust and realizable if (when) circumstances change, and avoiding stranded assets. Alternative options than what is described in the proposed solution may very well arise and sources such as locally available excess heat sources should be implemented where relevant. The same applies if higher costs are accepted or if boundary conditions change (e.g. changes in taxes/CO_2 price levels).
The decentralised structure of the solution makes it easier to adjust part of the plan without big impacts on the remaining elements. One example could be to engage potential future synthetic fuel production

stakeholders, since the utilisation of excess heat can improve the feasibility of such production capacities and thus facilitate the energy transition not only for the heating sector. Such presently unknown options should be investigated on a continuously to ensure that favourable alternatives are taken into account.



Graph of typical winter weekly production in 2035.

With the stepwise and decentralised approach combined with the chosen technologies, lock-in effects can be avoided, and adjustments can be applied if necessary.

When the decision is made that fossil fuels are not an option, the presented solution may be considered a "baseline scenario". Maybe one of the most ambitious baseline scenarios but still a "baseline". The term should not indicate "if we do nothing" but rather "this is what we will do unless even more suitable elements emerge". The process towards 2035 can be updated several times. Local stakeholders should play a role in this work. Helsinki could lead such a network considering the pooled resources together with the total demands. Industries' needs for raw materials and heat can be considered in such a joint collaboration platform. Besides this the forum can be used to ensure sustainability certification of all biomass needs in the city. HIVE may assist Helsinki in setting up such a local network.

Complexity

Though the solution consists of a lot of separate units, the system itself does not rely on a single or few units to operate thus making it quite reliable. The distribution of capacities which are able to operate independently across the city supports the robustness of the solution. It is obviously relevant to consider the optimisation of the overall efficiency e.g. by mixing lower temperature supply from heat pumps with high temperature from boilers where possible, in order to maximize COP of the heat pumps.

Connections to neighbouring regions

While interaction with neighbouring DH networks is included to take a holistic approach on the optimisation of the energy system, the solution is not dependent on such connections to maintain the high degree of security of supply. Benefits of selling heat using surplus capacity (not taken into account) will represent an additional value both economically and environmentally if fossil fuel heat supply can be displaced also outside Helsinki. In addition, joint investments e.g. in storages, may also improve the overall feasibility.

Flexibility of the implementation schedule

The proposed implementation schedule comes with a risk analysis and in-built mitigations for the main risks of delay. Please cf. to relevant section of our final entry.

Capacity risks

Depending on the economic context (e.g. revenues from electricity generated through CHP, etc.), an arbitrage could be made between gas CHP and HOB operation. In the modelled solution for 2030 gas boilers are used in peak conditions when non-fossil fuel capacity is not sufficient. Gas CHP units are not used anymore from 2024 and could be kept as a back-up. Hence, the proposed solution presents no interruptions in the heat supply even in the coldest winter days and can handle outages even at more key components at once.

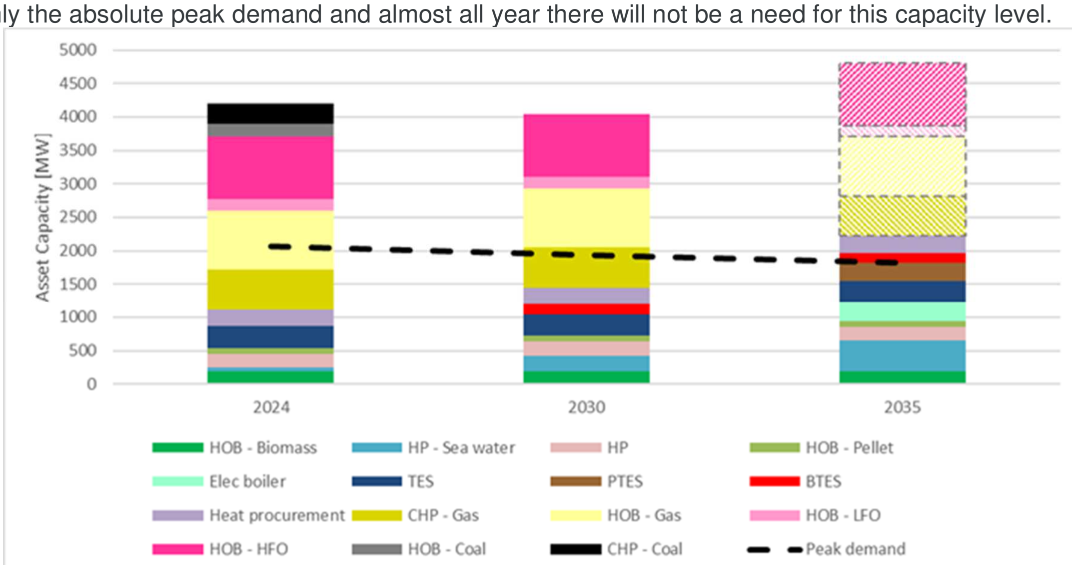
By 2035, gas boilers and gas CHP could be kept as backup. The need for backup in the *electricity grid* may result in a demand for CHP units, thus potentially also being available as DH backup. Even without any fossil fuels the combined installed capacity is 22% more than the peak demand. In case of an outage of the biggest single unit, the Vuosaari biomass plant, the combined remaining installed non-fossil capacity represents 112% of the peak demand.

At all times the system can handle interruptions even in the largest units. In 2024 the capacity represents 191 % of the peak demand. In 2030 this number is 196 %.

Though the production mix is predominantly electricity-based, non-electric and non-fossil capacity still represents 70% of the peak demand in 2035. One of the elements is BTES installed as a strategic reserve thus forming the "first line of defence" in case of extreme peaks or a demand for backup capacity. While a main role of PTES is to enable the avoidance of gas for peak loads by discharging mainly in January, they can also act as backup capacity if they are kept with some degree of energy content.

The connections to neighbour grids could be used as 2-way backup options (if agreed with such utilities) Such (potentially extended) collaboration could reduce the regions' total backup and peak demands.

An overview of installed capacities can be seen in the figure below. Note that the dashed line represents only the absolute peak demand and almost all year there will not be a need for this capacity level.



Operational risks

Electricity grid connections

Electric boilers are expected to be located where the electric grid capacity is strong enough to handle the large consumptions without endangering security of supply of the electricity grid. This is ensured by distributing the electric boiler capacity across the city and by placing boilers where existing power plants presently make use of strong grid connections. It should be mentioned that in fact, electric boilers can be used to provide electricity grid services (e.g. frequency regulation, balancing markets etc.).

Ownership and operating the assets

Though production is decentralised, the control and optimisation of the operation is centralised and can stay with Helsinki/HELEN. A system of local "green bonds" could be applied enabling citizens of Helsinki and other stakeholders to invest in Helsinki's "heating transition". The benefits of such a setup could be a) for the stakeholders to get a (small) interest rate of their investment while b) supporting the raise of capital for the upfront investments and c) creating a common understanding that the transition towards a sustainable heat supply is not "something someone else takes care of" but rather something in which the citizens play an active role. Such engagement of the inhabitants may also cause less complaints and more support in the local communities when the planning/construction phases start.

8. Capacity

The proposed solution fully complies with the Helsinki's goal to cease the use of coal for the heat production by 2028 including for back-up use.

After this date, there will be no coming back and no coal will be consumed by the city for its heat production anymore. The decrease of coal use will be implemented in two major steps: in 2024 and in 2029.

First, in 2023, the construction of the new assets as illustrated on page 4 of the Appendix Book and an optimized use of the other energy sources (pellet, biomass, gas CCGT, gas HOB,HP, heat procurement…) will drive the contribution of the Coal CHP down to 22% and of the Coal HOB down to 6% in 2023 (cf. page 6 of the Appendix Book). The combined production of the new renewable asset will be equal to 540 GWh (see page 5 of the Appendix Book) and this will avoid a similar amount of heat produced by coal. The remaining coal district heating production will be equal to 1 685 GWh per year for the two coal-fired units from 2024 to 2029.

Then, in 2028, an additional capacity of 180 MW SWHP will be brought to the asset portfolio of the city as illustrated on page 4 of the Appendix Book. As a result, in 2029, an increase of 1 182 GWh will be produced by sea water heat pump (see p 6 of Appendix Book), enabling the two coal fired units to be completely phased out, and eliminating the use of coal for heating production once for all, including for back-up purpose (see also graph on page 15 of the Appendix Book).

In 2034, additional SWHP, PTES storage and electrical boiler will be added to the production asset list as explained in p 4 of Appendix Book, and the solution will be fully implemented. At this stage, the use of coal will have been already fully stopped for 6 years (see pages 5 & 6 of Appendix Book) but this deployment will allow the city to minimize the use of biomass as of 2035 down to 14% of the total heat production as shown on page 6 of the appendix Book.

The energy mix of 2040 and forward has not been described in a graph as it will be very similar to the one in 2035 (the assets portfolio will stay the same and the production of each unit will be adjusted to the demand, the commodities' prices and the taxes).

The implementation plan includes some time buffer for the investments dated in 2028. Therefore, in case Helsinki city would like to accelerate, the permitting procedures are advanced, and the finance resources are available, some assets installation of this group could be anticipated, and the decrease of coal use explain for 2029 can be carried out earlier by additional steps.

9. Appendix Book (separate file)

Section 1 : HIVE Master plan
Section 2 : Deployment schedule
Section 3 : SWHP COP calculations
Section 4 : Assumptions and methodology for the carbon footprint calculation
Section 5 : Impact on natural resources
Section 6 : COH calculation
Section 7 : Social value indicators to be integrated in the City 3D model