Helsinki Energy Challenge

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Contents

1. Summary of the proposed solution 3
1.1 Heat demand in Helsinki 3
1.2 District heating temperature program 5
1.3 The target picture for 2035 decarbonized solution 7
1.4 Deep-dive E-Fuels 8
1.5 Deep-dive Digitalisation 9
2. Climate Impact 11
2.1 Impact on CO_2 emissions 11
2.2 Impact on other emissions 12
2.3 Total impact on emissions per MWh of produced energy 13
2.4 Impact of Digitalisation 14
3. Impact on natural resources 14
4. Cost Impact 15
4.1 CAPEX 16
4.2 OPEX 16
4.3 Total cost of heat production 17
4.4 Digitalisation-based cost impact 18
4.5 Detailed assumptions 19
5. Implementation Schedule 20
6. Implementation Feasibility 22
6.1 Feasibility of the system components 22
6.2 Economic feasibility and potential risks associated with E-Fuels 23
6.3 Feasibility of the business model 24
7. Reliability and security of supply 25
8. Capacity 25

1. Summary of the proposed solution

As a society, we are today facing one of the most significant, urgent and complex challenges in our history. The challenge of providing a carbon free, reliable and secure energy future requires action at all levels, both locally and globally. Our proposed solution follows the megatrends of **urbanization**, **sustainability**, as well as enabling the **energy transition**. It is an ambitious, but achievable decarbonization journey which has the aim by the year 2035 to bring the Helsinki network to a zero local CO_2 emission from its district heating network and with "near zero" CO_2 emissions considering in-direct emissions from electricity.

The system will be transformed through a combination of innovative but proven technologies, digital control & steering components and a broad application of sector coupling with the hydrogen-derived synthetic fuels (E-Fuels). The proposed solution consists of:

- **Electric boilers** rapidly removing the need of large coal plants.
- Implementation of a **Local Energy System** using low temperatures and connecting to geothermal heat solutions and/or district heating.
- Introduction of **Enhanced Geothermal System (EGS)** complemented with shallow and mid-deep ground source heat pumps, including thermal storage capabilities.
- Construction of two large scale **seasonal storage systems** that will be charged with surplus heat from the E-Fuel production as well as electric boilers operating to deliver heat to the seasonal storage systems when the electricity price is very low, or even negative.
- Cooperation with multiple stakeholders to integrate excess heat from hydrogen based **E-Fuel production** used in the transport sector into district heating.
- **Digitalisation**, based on a holistic approach to the energy system, optimizing demand and distribution using flexibility across sectors, making the system more reliable and resilient and reducing cost.

The new energy world will increasingly rely on becoming more energy efficient, and the concept of the 'circular economy' will become increasingly prevalent. A circular economy - is one that has a key focus on the reuse and recycling of energy, such as integrating excess heat sources into the provision of heat supply. In modern cities, there is already adequate thermal energy generated by human activity to provide a base for both heating and cooling requirements. By connecting buildings with different thermal energy needs and balancing residual thermal energy flows between them, Local Energy System uses and then reuses all available thermal energy. This makes it possible to decrease both pollution and overall energy consumption by capturing otherwise lost energy. This is an innovation that will both help us fight climate change and in doing so transform the energy market.

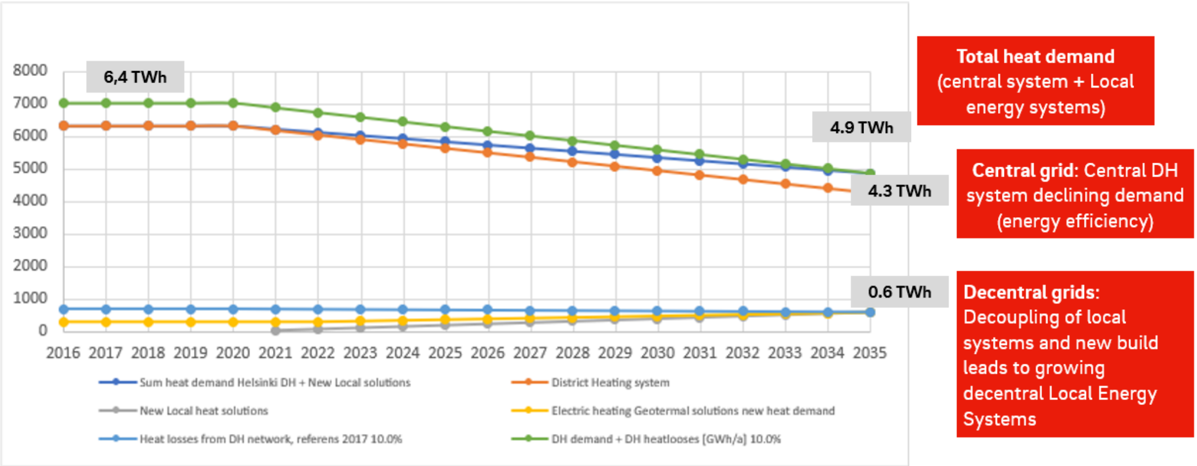
Our solution creates clear benefits for customers by offering a high security of supply and a heating network that lowers the impact urbanisation has on our environment. Our digitalisation offer has the capability to provide full carbon impact reporting, supporting customers in having a better transparency on their power and energy use, and empowering them to make individual choices about their own environmental impact and an active, rather than passive role in the energy transition. Sector coupling with the use of E-Fuels will further reduce emissions for both transport and district heating sectors.

In addition to the advantages above, our solution would also significantly reduce the operational cost burden from the city of Helsinki. Implementing our proposed solution is expected to have a significant reduction on the operating costs for both the existing and proposed asset base (ca. 50 % reduction of the current costs by 2035) by making a reasonable and proportionate capital investment, in particular when viewed against the considerable operational expenditure savings. The key advantage of our solution is in its flexibility and scalability, which ensures that it can be extended flexibly (step-wise) in response to the growing or reducing demand – this flexibility can be used as a "balancing", addressing the inherent potential for errors in long-term forecasts.

1.1 Heat demand in Helsinki

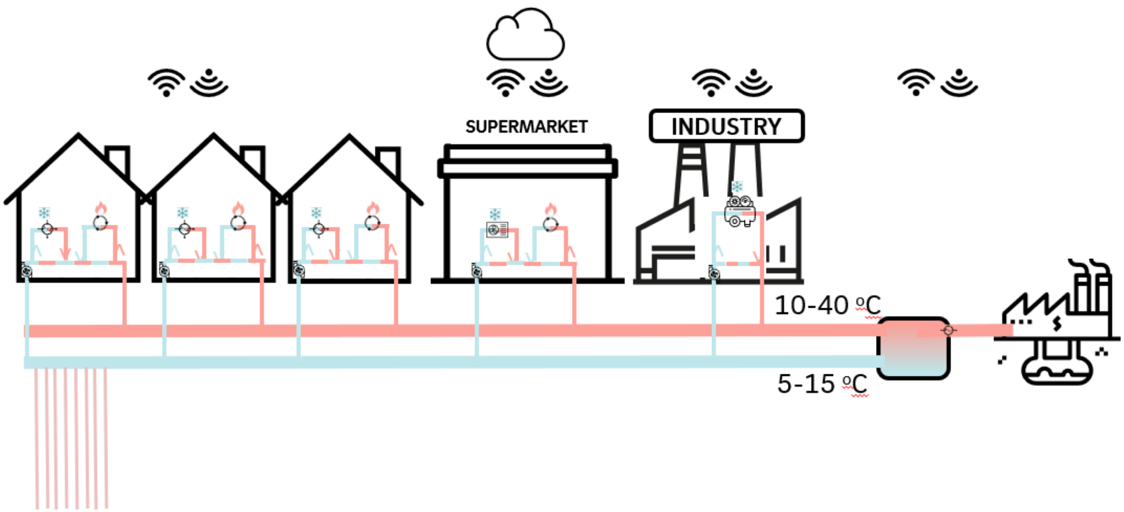
In our solution the figure from The Carbon-Neutral Helsinki 2035 Action Plan (Table 5, Assessment of the technical and economic potential of the energy efficiency actions and renewable energy in 2035 / Gala Consulting Ltd 2018) and the scenario that gives a district heating demand of 4,873 GWH/a and Electric heating of 594 GWh/a 2035 has been used as base assumption.

Underlying demand curve of Helsinki until 2035 and relevant assumptions



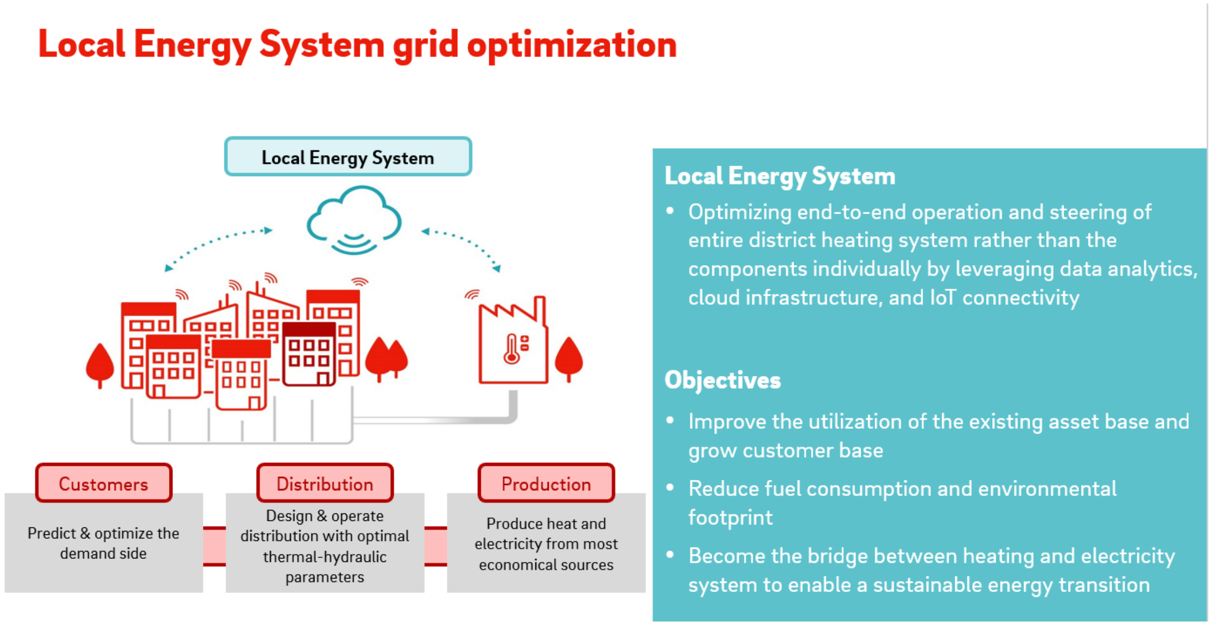
The Helsinki network operator is already planning a reduction in demand from a combination of planned energy efficiency and optimization improvement measures. Our solution will drive a stronger reduction in heat demand in addition to the already planned measures. We believe this is achievable through the implementation of the Local Energy System based on implementation of decentral solutions and by low temperature operation.

The Local Energy System connects each city with a flexible network that distributes thermal energy flows between neighbours allowing for operation at low temperatures. Each building connected to the system uses heat pumps and cooling machines. The buildings make energy “deposits” or “withdrawals” from the network to meet their own needs, balancing the energy demands of all the buildings against each other. Therefore, it is important for the system to have buildings with different energy profiles, e.g. buildings for industrial, commercial and residential use. The system is flexible and could be either connected and/or detached from the main network, depending on location and access to waste heat energy sources.



The Local Energy System technology is built on decades of experience from the design, construction and operation of energy systems across multiple countries. It takes the best characteristics of heat pumps and cooling machines and combines them with the best features of energy distribution networks in a new, innovative way.

When combined in this way, the performance of each system increases. The heat pumps and cooling machines can operate in low temperature ranges, and the efficiency of thermal energy distribution increases, removing losses and traditional large-scale production units. Only one network is needed, but it serves several purposes – thermal distribution for heating and cooling, as well as storage.



1.2 District heating temperature program

Operating at low temperature programs offers additional system benefits, such as:

- Increased opportunities to connect heat sources with low temperatures including flow gas condensation,
- Increased thermal storage opportunities,
- Reduced network heat losses,
- Increased lifetime of piping system and components.

To ensure the transition to the low temperature operation we suggest actions in three areas: technical guidelines, operating temperatures and price models.

Technical guidelines for district heating substations and buildings (District heating of buildings, Regulations and guidelines Publication K1/2013) need to be developed. As a starting point, the current technical guidelines would be assessed for a possibility to lower the district heating supply and return temperatures. By adjusting the technical guidelines toward low temperatures in the building systems for Heating, ventilation and domestic hot water the general temperatures can be lowered over time for the system as a whole.

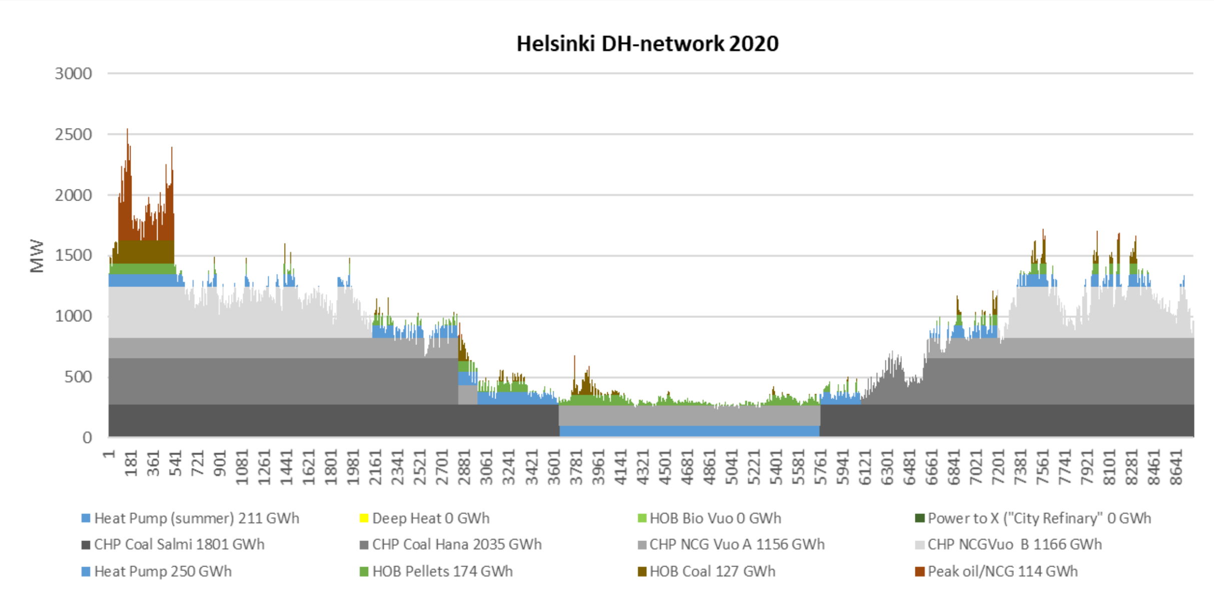
The existing **operating temperatures** in the district heating network of Helsinki are set on a traditional level for both system design and operations. If we assume a decrease of the district heating demand from an existing annual level of 6.3 TWh to 4.3 TWh, this would give a thermal relief in capacity that can be used to lower the supply temperatures in the district heating network. By changing the design and operating temperatures, the supply temperature can gradually reduce to a level 15 -20 °C lower compared to the current status. If the return temperature can be reduced, then the supply temperature can also be lowered without exceeding the hydraulic capacity of the district heating network. When reducing the system temperatures in the district heating system things like bypasses, bottlenecks, and other operating issues need to be considered. The improved temperature program will lead to lower energy losses and a higher utilization rate of the fuel, hence, less heat needs to be generated in the central energy plants and the gap between energy generated and energy sold will decline.

District heating **price models** include volume and flow components. Helsinki network has a flow element already included in the connecting price and an annual capacity price. The volume (district heating water volume in m^3) could be added to the price model so that the customers are stimulated to achieve lower return temperatures from their buildings and substations. Successful practices of adapting such price models can be observed in many countries and district heating systems.

The transformation journey starts in 2020 with a classic, cost-based merit order including:

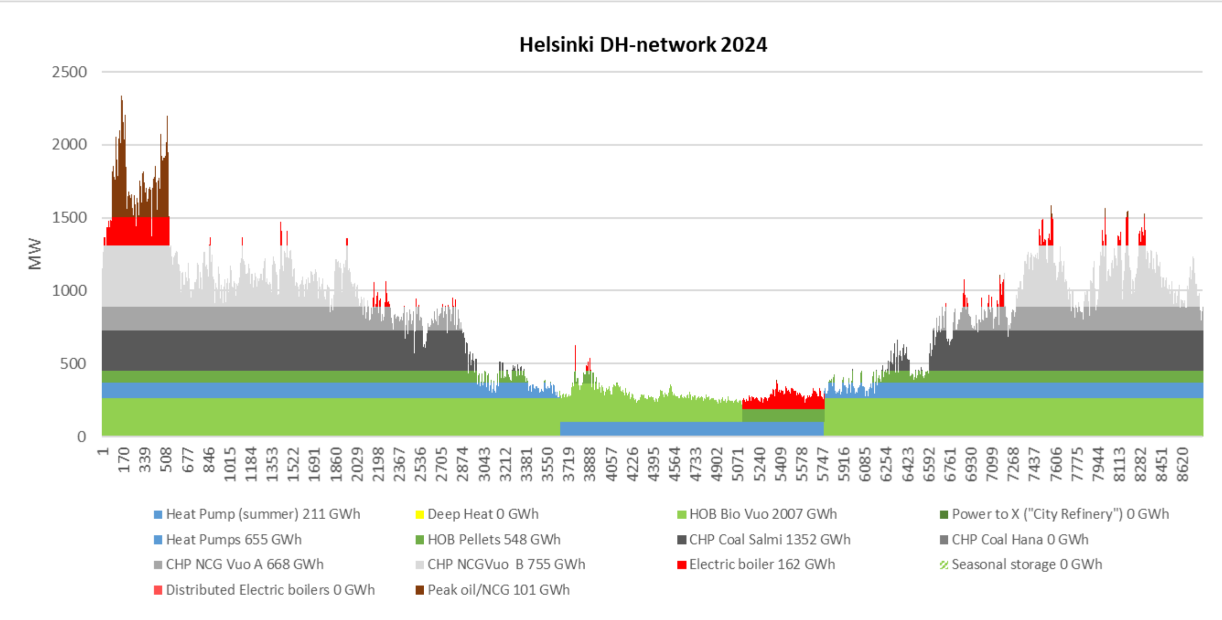
- CHP coal Hanasaari 430 MWth (decommissioning end of 2023) and CHP coal Salmisaari 300 MWth (decommissioning end of 2029)
- Heat Only Boiler (HOB) coal 190 MWth (decommissioning end of 2023)
- CHP natural gas Vuosaari A and B total 600 MWth ending 2034

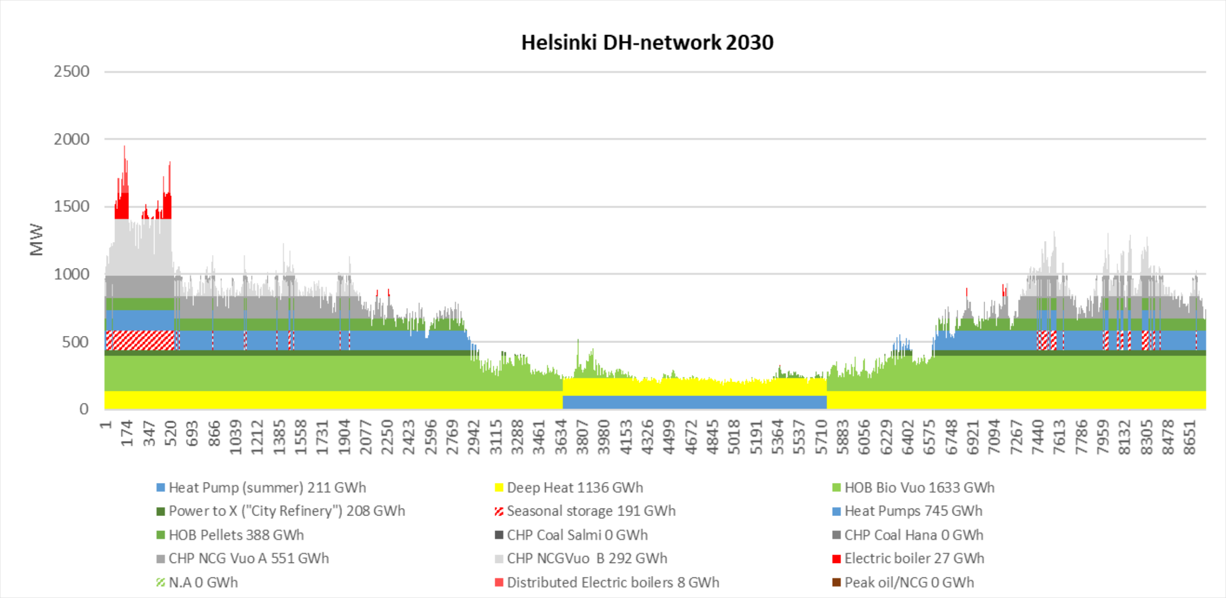
- HOB pellets 90 MWth
- Heat pumps 105 MWth
- Peak oil/natural gas boilers 1,910 MWth



HELEN has already planned to introduce a number of measures, including the operation of a new HOB. The merit order is proposed to be changed from cost-based to a CO_2-based in order to support the sustainability target. Large electric boilers will be introduced until 2024, which would decrease the carbon footprint of the peak load oil and gas boilers, in total 190 MWth. The commissioning time is relatively short, and the CO_2 reduction will be large introducing a well-known technology at a low cost. In addition, due to the Local Energy System starting in 2024 with 50 MW the heat losses will decrease. All that would additionally reduce the peak capacity of the network.

This solution will cover the phase out of the coal CHP in 2030 mostly with additional Local Energy Systems (in 2030 450 MW), shallow and middle deep geothermal heat (140 MW), heat pumps (150 MW), seasonal storage (150 MW), the local energy systems and waste heat from city refinery for E-Fuels (42 MW in 2030).The seasonal storage will cover the peak loads, that some of the existing peak production units will have less operating hours and will reduce in the years until 2035.





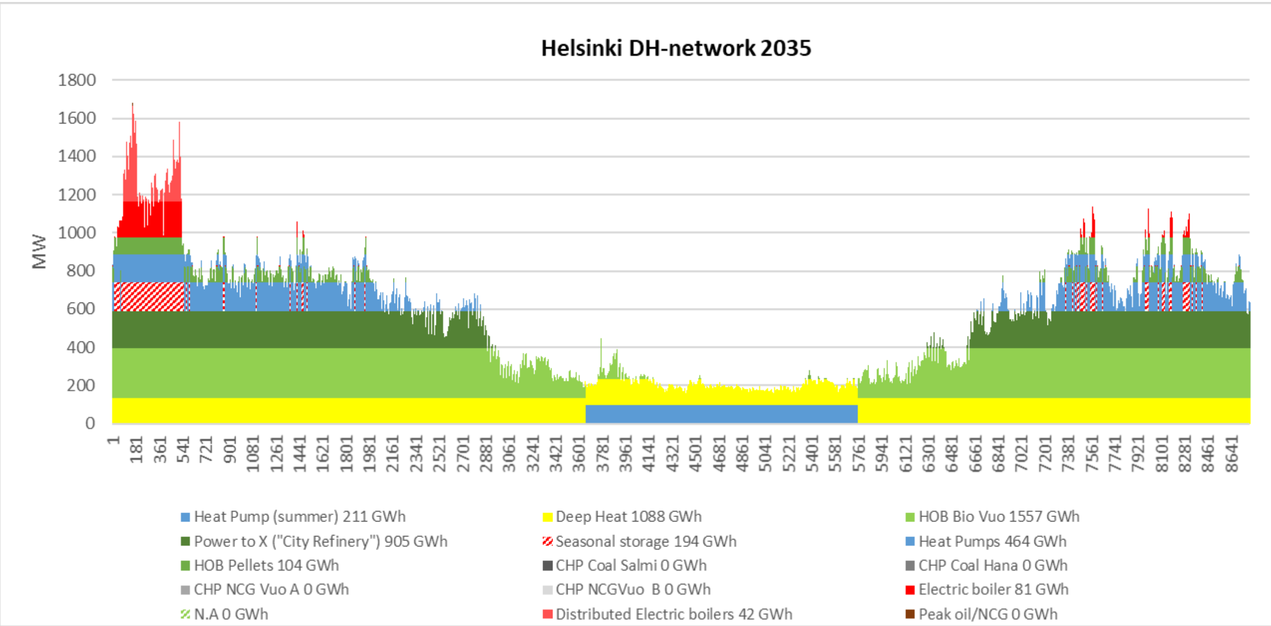
For more details please have a look at phasing in this chapter as well as in the 5. Implementation schedule.

1.3 The target picture for 2035 decarbonized solution

The Central system will be based on the following merit order:

- The base load is covered by Deep geothermal of 140 MWth
- In summer, the heat pump system that operates the cooling system in Katri Vala (105 MW) will serve as base load
- The upgraded HOB in Vuosaari of 276 MWth will be operating next
- Waste heat from E-Fuel refinery & hydrogen solutions 205 MWth (dependency on the operation of the HOB in Vuosaari)
- Heat pumps and seasonal storage will then operate, operation depending on the volume stored and the demand. The installed thermal capacities are 150 MWth each
- The HOB of 90 MWth using wood pellets
- Then the electric boilers central 190 MWth and decentral 450 MWth to cover the peak

The Local Energy System will operate on ca. 200 MWth installed heat pumps (not included in the duration chart).



Note: Phased out coal will not be replaced by additional biomass.

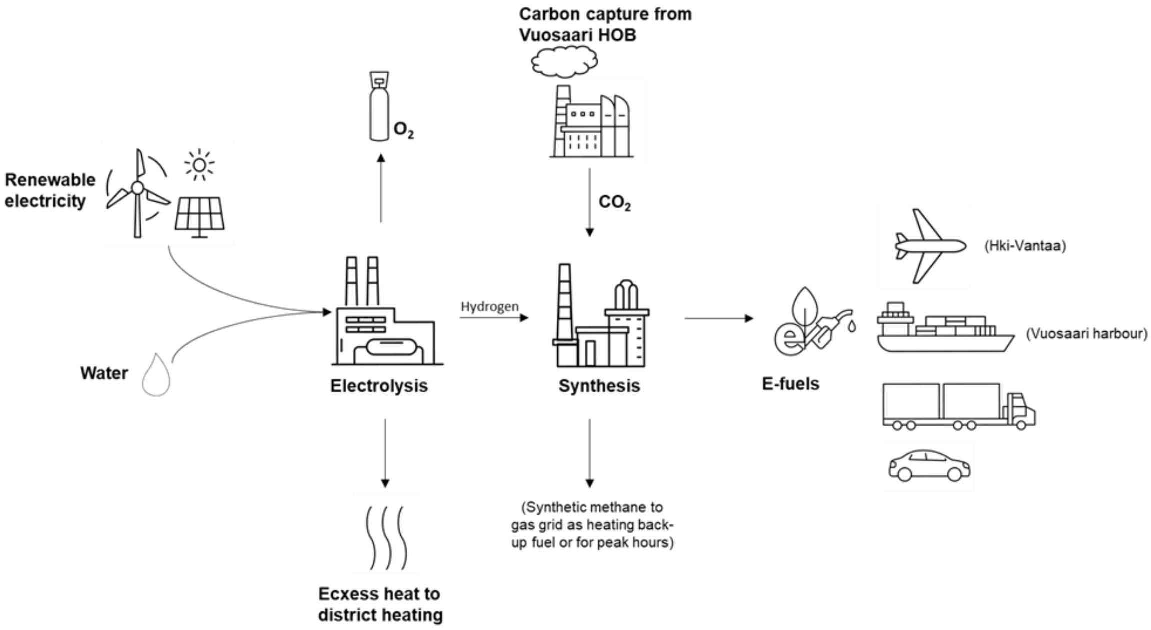
1.4 Deep-dive E-Fuels

The proposed solution also considers the effects on the energy system integration. Energy system integration refers to the planning and operating of the energy system "as a whole", across multiple infrastructures and energy sectors like power, heating and cooling, industry and transport. It will provide additional flexibility to the overall energy system management and help to integrate increased shares of variable renewable energy production and therefore is of crucial importance for Europe.

Hydrogen will become an intrinsic part of this integrated system. Based on EU's **Hydrogen strategy**, a strategic objective is to install at least 40 GW of renewable hydrogen electrolysers by 2030. Renewable hydrogen will balance renewables-based electricity system and provide daily or long-term seasonal storage. Hydrogen and hydrogen-derived synthetic fuels (E-Fuels), based on CO_2 from combustion products of biomass or biobased materials, can be used in sectors which are difficult to electrify directly like heavy-duty transport, aviation and shipping as well as chemical and steel industry. Hydrogen and synthetic fuels can be produced in local clusters or regional ecosystems with power-to-x facilities.

Finland's as well as Helsinki's target is to become Carbon-Neutral by 2035. This cannot be achieved unless the share of renewable energy is increased substantially in the whole energy system. Currently fossil fuels dominate being as primary energy source. Apart from geothermal energy, the only large-scale option in Nordic for replacing fossil fuels is renewable electricity complemented by advanced biofuels which can only be used to a limited extent. As a consequence, there is a **need for a substantial increase in renewable electricity production** such as onshore and offshore wind power. This is already in progress based on Finnish Wind Power Association's statistics. While some sectors can be electrified directly, others can be electrified indirectly by power-to-x technologies.

Power-to-x refers to the process where electricity is transformed to other form of energy like hydrogen or synthetic fuels. Main inputs are renewable electricity, water and carbon dioxide. In electrolysis water is split into hydrogen and oxygen by using renewable electricity. At the same time large amount of heat is released. When hydrogen is combined with carbon dioxide, captured from point sources or air, the end product can be synthetic gas (methane) or liquid fuel like synthetic methanol, kerosene, diesel or gasoline.



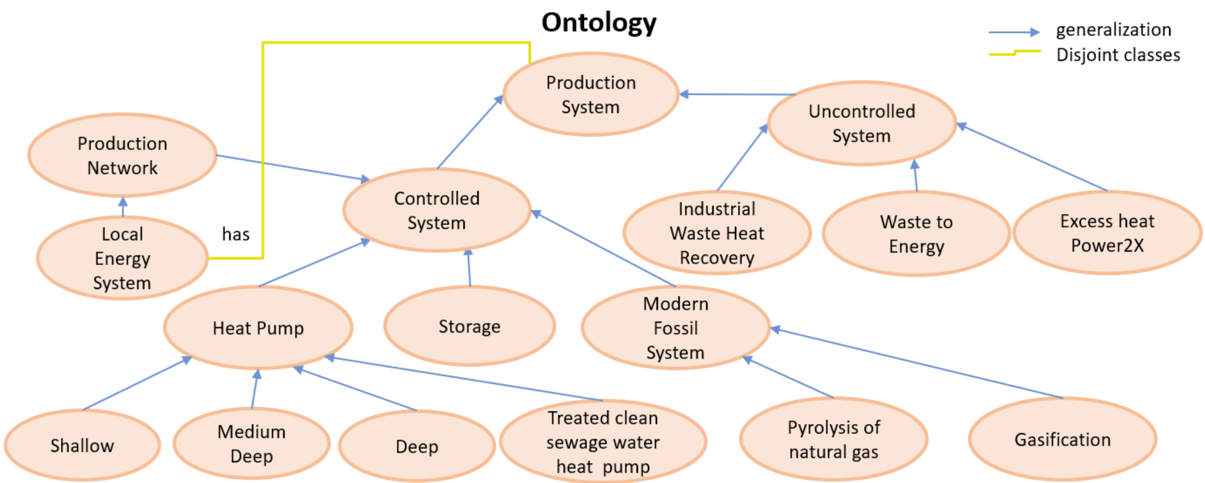
Eastern metropolitan area could be suitable location for power-to-x ecosystem. The main idea in Helsinki Energy Challenge is to capture the CO_2 from HELEN's new HOB and utilise the excess heat from electrolyser in district heating. There are already some pilot projects in the area like the City Refinery project in Vuosaari and joint project with Vantaa Energy and Wärtsilä roughly 10 km's from Vuosaari, which might have synergies. In Vuosaari the electricity network is strong and there's also existing natural gas pipeline network. Gas network could be used as buffer and storage for synthetic methane. It could also be used for back-up in heating, transport fuel (compressed synthetic gas) or liquified at certain location for synthetic LNG to transport sector, like marine and other energy uses. Vuosaari Harbour and Helsinki-Vantaa airport might be examples of potential locations for the end use of E-Fuels. Helsinki's sea area could potentially be used for offshore wind power production where this does not present a conflict of interest. Wind power could also be achieved through renewable power purchase agreements (PPA) which give the possibility to locate the wind mills in locations outside Helsinki.

1.5 Deep-dive Digitalisation

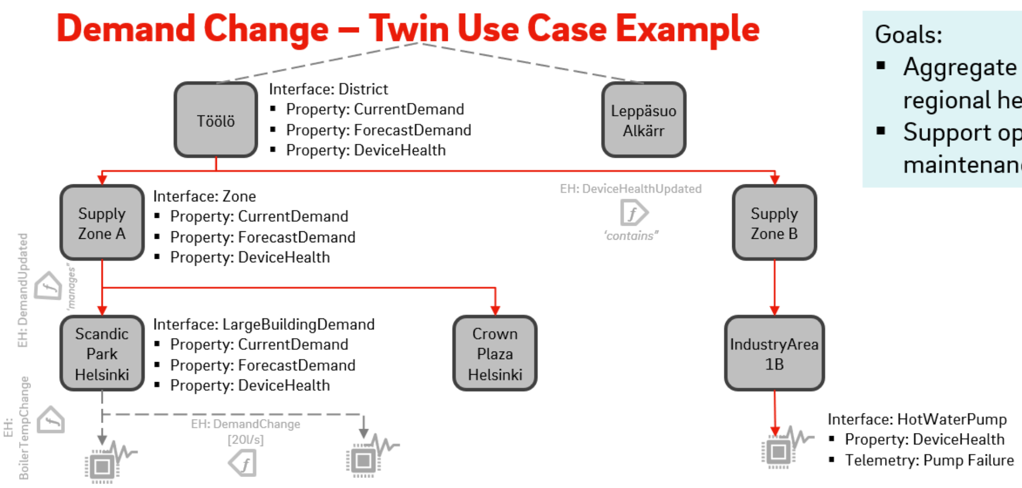
Our proposed solution is also backed up by a strong monitoring and steering digital solution from one of the leading industry players. Putting a strong focus on security and compliance, our digital solution is aimed to ensure the highest attributes to address a broad range of requirements. The attributes include:

Optimized Operations	Near real-time event handling	Prediction	Carbon reporting
High reliability	Open and future readiness	Peak shaving capability	Scalability

For our approach, we are using a Digital Twin technology, which significantly reduces the effort to design and build IoT solutions. This reduces cost, has broad industry adoption and can integrate legacy systems. In addition, the solution enables near-real-time event handling, is based on open standards and is in our view a perfect fit for the carbon-free Helsinki Energy System.



The Digital Twin technology is used to describe and build digital twins of real "things", locations, people/organizations and more and connect the digital twins instances in a "graph". It can be portrayed as a network of entities/ objects and relations. This capability is already used today to describe buildings, factories and their processes, aircrafts, energy systems or even entire cities. Another important benefit is that rather than with traditional database systems, graphs enable a "business" view and queries of any type, e. g. in which area did we have the lowest energy cost for heat pumps or which assets had no failure over the last 12 years.



Goals:

- Aggregate and forecast regional heating demand
- Support operation with maintenance information

Below is a description of the solution properties to highlight the key capabilities:

Property	**Description**
Optimized operations	The graph knows at any time the current demand and supply capabilities. In normal operations, it will optimize the network for providing the required quality of service to citizens (depending on factors like weather and load) while considering costs. Storage enables responding to short term changes whilst adapting supply to the new demand. Some system elements, like the Local Energy System, include their own adaption capabilities, which is known to the graph, and only the “desired stage” is communicated. In asset **failure** situations, the system will notify maintenance near real time (details to be discussed for system integration) and **immediately adapt the energy system to the change**. In the beginning, we are not planning for machine learning based optimization, but rule based through the live execution environment. Optionally, we suggest an optimization recommendation engine, which could be simply data historian based or for highest level of optimization and robustness reinforcement learning (RL).
Near real-time event handling	The graph is a so called “live execution environment”. It receives change information from the connected assets (and optionally households) and accordingly updates the digital twin. **Upon any event** (e. g. demand change, failure, re-activation, exceeded threshold or AI prediction) it will instantly (typically sub-second) **respond to that event**, independent how complex the system is (“hot path”). Integration can happen with new and legacy systems to handle the events, such as field support where required.
Prediction	Two essential machine learning based predictive capabilities are designed in: 1. **Condition based monitoring of assets**: Connected assets (optionally including legacy assets) will be continuously monitored for anomalies and long term trends that can indicate a device failure. Service representatives will be notified to open a ticket in their system. 2. **Trends and KPIs**: Essential key performance indicators (KPIs) will need to be defined together with Helsinki. We expect KPIs like (1) carbon footprint by district (2) carbon footprint by consumer type (3) total cost of supply (4) number, size and length of outages. Whilst the calculation of the KPIs are simple statistics, we will extend predictions for KPIs to identify trends and, if necessary, notify city stakeholders and operators to discuss and implement course corrections.
Carbon reporting	**Transparency** of where energy will be produced and consumed in conjunction with the assigned carbon impact is expected to be an important requirement and is possible without any high effort with this solution design. Having this analysis would also be the basis for potential carbon fee concepts and citizen decision making (e. g. carbon and pricing impact if they need to load the eCar exactly at 6PM when many saunas are switched on). The **reports** can be provided as open data, confidential reports or (optional) individualized.
High reliability	The solution is designed for high availability and resiliency. The cloud solution itself is built for resiliency including high availability and disaster recovery with no services dependent on a single point of failure. For high availability, the services are built to run as designed in a healthy state with no significant downtime. The complete system reliability is, as typical, a shared responsibility of all parties. For connectivity reliability, we designed for a minimum of two communication methods for each gateway: Wired and wireless or 2x Wireless (e. g. 5G and LoRa). The next layer of reliability is provided by the concept of **Local Energy System** and a **hybrid cloud** approach. The failure of one local system does not impact the other ones. Each local system can also run non-connected to provide basic supply, though in that case not operating optimized (similarly to how energy provisioning works today).

Open and future ready	The above-mentioned concept of digital twins to build the graph is based on the fully **open-sourced Digital Twin Definition Language (DTDL)** as in industry standard. It provides the necessary agility to include both, connectivity and mapping capability of legacy and future assets, such as hydrogen fuel cells or virtual power plants.
Peak shaving capable	The **peak shaving** capabilities. Providing the capacity to supply also during peaks is one of the largest cost factors ("peeker plants"). We will distinguish between **reactive peak lowering** and optional **active load shifting** concepts. The solution has the capability to provide load balancing across Helsinki when the optional building and household "loop" will be closed. In that optional scenario, buildings and households are by default controlled by the Helsinki central operations for cost and carbon savings. At any time, the owner can override the default settings, whilst the carbon and cost impact will be made transparent.
Scalable	The solution is not limited to the current configuration. Legacy and future assets and backend systems can optionally be integrated. The solution is also conceptually designed to grow beyond Helsinki. Thus, the solution supports both, scale up and scale out.

2. Climate Impact

2.1 Impact on CO_2 emissions

The emissions are calculated based on the annual fuels and energy consumption (see table below). CHP emissions are calculated based on the Benefit Allocation method. Purchased electricity is calculated as direct emissions wherever electricity is the primary energy source of heat.

	Heat Pump (summer)	EGS	HOB Bio Vuo	Power to X ("City Refinary")	Seasonal storage (El Boilers)	Heat Pump	HOB Pellets	CHP Coal Salmi	CHP Coal Hana	CHP NCG Vuo A	CHP NCG Vuo B	HOB Coal	Electric boiler	Distr. Electrical boilers	Peak Oil/NCG	Local Energy Systems (LES)
primary energy:	electricity	electrici ty	wood chips	waste heat	electricity	electrici ty	wood pellets	coal	coal	natural gas	natural gas	coal	electrici ty	electrici ty	natural gas	electrici ty

The decarbonization journey start in 2021 with 3.4m t of CO_2, whereas 2m t CO_2 comes from power production and 1.4m t CO_2 comes from heat production.

The change in the assets structure (i.e. operation of central and decentral systems and HOB Biomass Vuosaari in 2024 and decommissioning of the CHP coal Hanasaari and HOB Coal in 2023) will shift the weight of the annual heat production from coal and natural gas CHPs to existing heat pumps and biomass boilers. Our plan is to reduce heat production associated CO_2 by 59 % (to 0.6m t CO_2), and total heat and electricity (CHP) associated CO_2 will be decreased by 56 % (to 1.5m t CO_2).

The journey until 2030 would include the continuous build-up of decentral electric boilers, the introduction of deep geothermal in 2027, and decommissioning of the coal CHP Salmisaari in the end of 2029. This would further reduce the emissions to 0.15m t CO_2 associated with heat production and 0.4m t CO_2 for total heat and electricity (CHP) production in 2030, meaning a decrease of ca. 90 % and ca. 88 % respectively, most of it coming from the natural gas CHPs.

From 2035 onwards, when the remaining natural gas CHPs are decommissioned, only 5 % of CO_2 for heat production will remain due to the electricity as primary energy source. The emission factor is taken as of 2030 (30 kg CO_2/MWh), as indicated in the instructions.

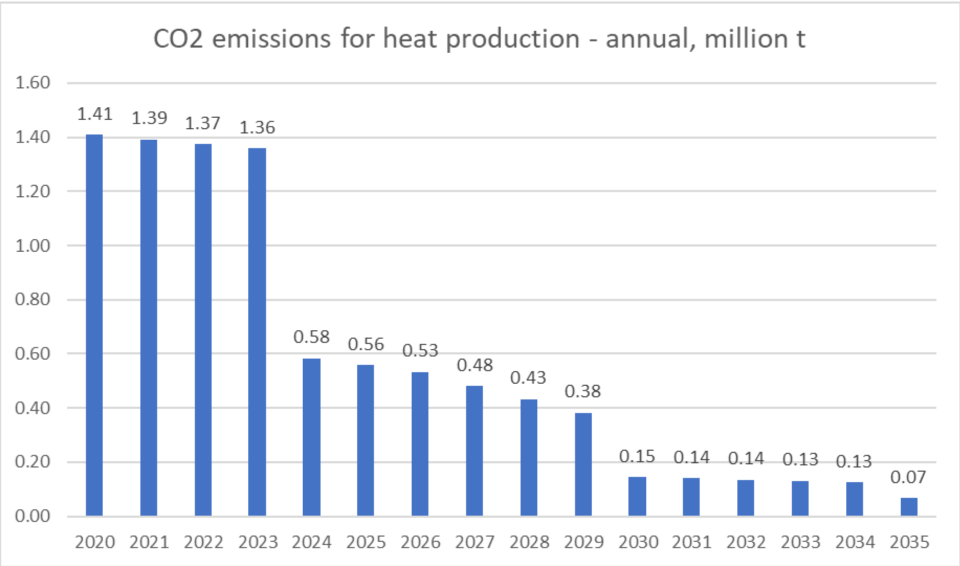
The impact on in-direct emissions, such as emissions from transportation, construction and decommissioning, is not currently included in the calculation. In this phase of investigation we are not able to evaluate these activities in details, as they are highly variable and depend on decisions that would need to be taken at a later stage. In any case, in-direct emissions are assumed to take a minor or even insignificant part.

Overview of CO_2 emission of heat production 2020-3035

	CO_2 emissions for heat	CO_2 emissions for electricity	CO_2 emissions total	CO_2 emissions reduction based on heat only	CO_2 emissions reduction based on heat and electricity
	t/year	t/year	t/year	-	-
2020	1,410,840	1,966,866	3,377,707	0	0

2021	1,392,370	1,930,272	3,322,642	1%	2%
2022	1,374,840	1,895,507	3,270,347	3%	3%
2023	1,358,202	1,862,480	3,220,682	4%	5%
2024	584,382	892,700	1,477,082	59%	56%
2025	558,365	852,931	1,411,296	60%	58%
2026	533,472	811,998	1,345,471	62%	60%
2027	482,555	720,378	1,202,933	66%	64%
2028	432,992	629,106	1,062,098	69%	69%
2029	382,732	538,500	921,232	73%	73%
2030	145,341	260,392	405,733	90%	88%
2031	140,456	248,935	389,390	90%	88%
2032	135,799	237,982	373,781	90%	89%
2033	131,361	227,510	358,872	91%	89%
2034	127,133	217,500	344,633	91%	90%
2035	68,052	0	68,052	95%	98%

Note: The CO_2 emissions for electricity are related to electricity production by the existing CHP plants. This electricity is not consumed for heat production, but instead produced and exported to the public network.



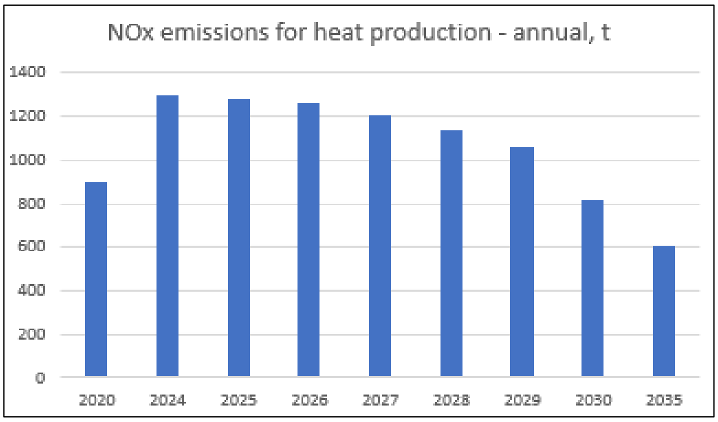
2.2 Impact on other emissions

Besides CO_2, other emissions contribute to the harmful effect on the air quality. NO_x and particles emitted during the heat production process in connection with the fossil fuels and biomass boilers / CHPs, have also been considered in our solution. By shifting to a solution based more on electricity, a clear reduction of other process-associated emissions can be achieved. The values are calculated with the specific values as indicated in the table below.

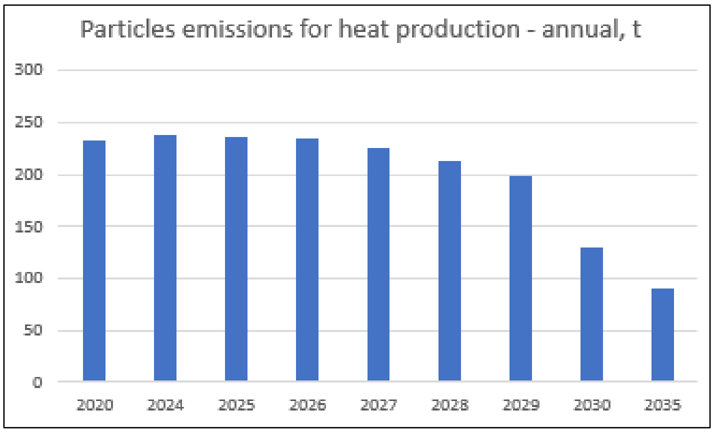
Fuels	NO_X	Particles
	t/GWh	t/GWh
Wood	0.374	0.053
Pellets	0.457	0.11
Coal	0.22	0.067
Gas	0.074	0

During the first years of the assessed period the amount of NO_x increases due to a slightly higher use of biomass. However in the later years, when electricity sourced technology, storage and waste heat take larger portion of heat production, the amount of NO_x decreases. In total, NO_x amount will decrease from 904 t/year to 816 t/year in 2030 and to 604 t/year in 2035. This is a total reduction of 33 %. The particle will be reduced from 233 t/year to 91 t/year in 2035, meaning a 61 % reduction.

	NO_X emissions for heat
	t/year
2020	904
2024	1,299
2025	1,281
2026	1,263
2027	1,204
2028	1,138
2029	1,059
2030	816
2035	604



	Particles emissions for heat
	t/year
2020	233
2024	239
2025	236
2026	234
2027	225
2028	214
2029	200
2030	129
2035	91



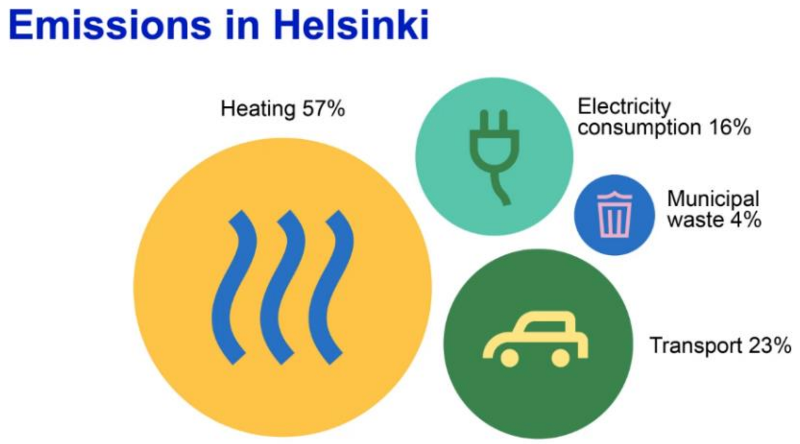
2.3 Total impact on emissions per MWh of produced energy

The reduction of emissions per MWh of produced energy is represented in the table below:

		Total electricity production (CHPs)		Total heat production
	kg/MWh	GWh/year	kg/MWh	GWh/year
2021	447	4,321	201	6,938
2022	451	4,204	201	6,848
2023	455	4,094	201	6,764
2024	401	2,226	88	6,619
2025	406	2,100	86	6,472
2026	412	1,971	84	6,326
2027	424	1,697	78	6,182
2028	438	1,436	72	6,040
2029	453	1,189	65	5,899
2030	300	868	25	5,790
2031	300	829	25	5,670
2032	300	793	24	5,557
2033	300	758	24	5,450

2034	300	725	24	5,350
2035		0	13	5,245

It is worth mentioning, that with sector coupling for transport and heat production, we can achieve significant improvements in decarbonization for both sectors. Waste heat is a desirable heat source as it has very low carbon footprint. Our solution includes waste heat from E-Fuel production based on CO_2 capturing of HOB Biomass Vuosaari burning process and electricity. Transport sector accounts currently 23 % of the emissions and the target is to reduce these by 69 % from 2005 level. Annual emission savings from the use of E-Fuels is approximately 580,000 tons when emission factor of 30 kg CO_2/MWh is used for electricity and 680,000 tons if only renewable energy is used. These savings would cover current transport emissions in Helsinki. So, while our team's solution decarbonises the whole heating in Helsinki, at the same time it decarbonises the transport sector as well – at least in the sense of balancing view.



2.4 Impact of Digitalisation

Active participation of citizens is fundamentally important for achieving Carbon-Neutrality, as they are both the key contributors and direct beneficiaries. Broader support is needed in order to facilitate such behavioural change, which could be supported by tools and insight into a person's individual impact.

Our solution does not come with an integrated carbon fee instrument. However, the capabilities of the digital solution allows for a broader application to also cover this aspect as an optional. We suggest using the carbon fee instrument to sustainably drive behaviour change and provide stable and affordable carbon free energy to Helsinki. The overarching goal is to enable measuring the social and economic impact of the energy transition – this insight could be impactful for all cities around the world.

Having the datapoints and the agreement of the local residents is essential for building advanced carbon consumption control instruments and drive behaviour change. A potential controlling mechanism could be introduced through a property owner tax and individualizing the tax based on the carbon footprint. Population behaviour could thus be indemnified/ incentivized. The use of proper mechanisms/sensors could enable a ban or significant reduction of unwanted fuel sources, such as carbon / wooden heating or fireplaces. In this document we also introduce the (optional) concepts of:

- Individual reporting of the carbon footprint and
- the active loop to empower peak shaving through load shifting (see Section 4.4 Digitalisation-based cost impact).

3. Impact on natural resources

Our solution has a minimal to negligible negative impact on natural resources, including use of land and water consumption. The impact of each component of the solution is analysed separately in the sections below:

EGS generates a vast amount of sustainable heat that is existing in the bedrock. No combustion, emission-free technology, needing little above ground-space and producing stable heat regardless of weather conditions. The same applies for shallow, semi-deep and deep technologies. The condition of the bedrock will be monitored. The energy centre footprint is small and when it is possible this solution should be located quite near to the existing energy centre. The current underground structures and the future underground plans should be taken into consideration for selecting the optimal location for EGS.

Low temperature Local Energy System minimizes the energy losses in the grid, utilizes larger volumes of low-grade excess heat and geoenergy and reduces the need for combustion. Compared to the traditional district heating Local Energy System can reduce primary energy need by up to 80 % due to the possibility to harvest adjacent waste energy sources such as excess heat from ventilation systems, saunas, data centres, supermarkets and low grade industrial waste. The smaller scale energy centre can be located also inside the building. Impact on water is not considered to have a significant negative, as a water circulation system is assumed.

Seasonal storage will not impact the surrounding or produce any emissions; however the construction needs to be handled with care. The new seasonal storages will be located underground and will not have any wider impact on the land surface itself. The residual rock material from excavation could be used for construction in the Helsinki area. To minimise the land use, the storages should preferably be located in direct vicinity to the existing energy centres, large energy assets and electric boilers. If it is not possible, then there is a need to secure (either rent or own) small land areas for constructing the pumps and the heat exchanger. The possible location needs to be further analysed with additional data not available to us at this stage.

Electric boilers utilize the existing electric and district heating grid and have no local emissions. Additionally, boilers can facilitate storage of excess energy as thermal energy. No transport of goods is required and the operation itself will serve to support the power system and the roll out renewable energy such as wind and solar power.

Heat pumps provide an efficient way to transform energy from one temperature level to another. They will be fuelled by electricity and there will be no local emissions. The development of refrigerants towards molecules with a lower Global Warming Potential is widely supported and so are the volumes needed. Natural refrigerants such as propane, ammonia and CO_2 will be the choice of the future.

CCGT plants powered by natural gas will be in some degree of operation until 2035. Natural gas has a negative impact on the environment when it comes to exploitation, as well as combustion. The advantage with a CCGT plant is that it is efficient, and local emissions are lower than for coal combustion. Transportation of gas also has a lower environmental footprint than coal.

Biomass for HOBs will be Carbon-Neutral over time but will have an impact when it comes to handling and transport. There will be some local emissions as well since flue gas cleaning will not remove all the emissions, but it is still to be considered a good choice of fuel for a country with vast amount of forest. In total 370,000 t of wood chips and 24,100 t of pellets will be needed in 2035. This amount of wood is under 2 % of the current yearly production of wood in Finland. The growing stock has increased over past 40 years by more than 40 % in Finland, supporting the capture of CO_2. The calculated amount of biomass is also smaller than the current plans of HELEN.

Excess heat from E-Fuel production is a Carbon-Neutral solution provided that renewable electricity is used in the production process, optional **hydrogen solutions** are used. The CO_2 from Vuosaari bioenergy heating plant is captured and utilized in E-Fuel production. Sustainable renewable E-Fuels replace the fossil fuels in transport e.g. with synthetic kerosene in aviation at Helsinki-Vantaa airport.

4. Cost Impact

The solution aims to optimize the energy triangle consisting of the environmental optimum (as much decarbonization as possible), economic viability (as little CAPEX and OPEX as possible) and reliability of the energy system (as resilient as possible). Our calculations suggest that after the implementation of the system, there will be a reduction of the annual heat production OPEX by ca. 50% (in real 2021 values).

4.1 CAPEX

The total investment for the proposed solution is ca. 663m€ by 2035, backed by the resulting energy price and presuming a stable and reasonable end customer price. Most of the investment is to be made between 2027 – 2030 (around 65%). The table below describes the proposed allocation of CAPEX over time. All costs are presented in real 2021 values.

	Heat Pump (summer)	EGS	HOB Bio Vuo	Power to X ("City Refinary")	Seasonal storage (El Boilers)	Heat Pump	HOB Pellets	CHP Coal Salmi	CHP Coal Hana	CHP NCG Vuo A	CHP NCG Vuo B	HOB Coal	Electric boiler	Distr. Electrical boilers	Peak Oil/NCG	TOTAL DH-network	Local Energy Systems (LES)	Digitalisation	TOTAL incl LES
	CAPEX Total, million €:																		
2021	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	-	19.0
2022	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	-	19.0
2023	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	0.7	19.7
2024	-	-	-	-	-	-	-	-	-	-	-	-	7.1	-	-	7.1	19.0	1.3	27.4
2025	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9	-	1.9	19.0	2.0	22.9
2026	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9	-	1.9	19.0	1.4	22.3
2027	-	52.5	-	-	-	-	-	-	-	-	-	-	-	3.8	-	56.3	19.0	0.2	75.4
2028	-	52.5	-	-	-	-	-	-	-	-	-	-	-	3.8	-	56.3	19.0	0.2	75.4
2029	-	52.5	-	-	-	-	-	-	-	-	-	-	-	3.8	-	56.3	19.0	0.2	75.4
2030	-	52.5	-	1.6	112.5	15	-	-	-	-	-	-	-	1.9	-	183.5	19.0	0.2	202.6
2031	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	0.2	19.2
2032	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	0.2	19.2
2033	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	0.2	19.2
2034	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.0	0.2	19.2
2035	-	-	-	6.1	-	-	-	-	-	-	-	-	-	1.9	-	7.9	19.0	0.2	27.1
Total, M€:	0	210.0	-	7.6	112.5	15.0	-	-	-	-	-	-	7.1	18.8	-	371.0	285.2	6.9	**663.1**

existing planned by the City new

In 2021 to 2023 some initial Local Energy System' investments and digitalisation must be undertaken costing around 58m€.

In 2024-2026, the installation of the low-Capex central electric boiler and some decentral electric boilers, start of investments related to digitization, as well as further development of the Local Energy System is expected to take place. This would lead to a total of 73m€ investment.

In 2027-2029, additional deep geothermal CAPEX comes on top, summing up to 75.4m€ per year.

The year 2030 shows investment of 203m€. This is the highest investment year due to the construction of seasonal storage, additional geothermal wells and heat pumps. Waste heat from E-Fuels will start to be utilized from 2030, hence additional CAPEX of 1.6m€ is allocated for resilience electrical boilers (in case of shortage of waste heat).

After 2031-2034, a steady-state investment of 19m€ is planned mainly associated with annual growth (e.g. expansion and densification) of the Local Energy System.

In 2035 an investment of 27m€ is planned associated mainly with the annual growth of Local Energy System, increase of waste heat utilization and resilience electrical boilers (6.1m€).

Potential application for EU funding could be proved as a potential upside for covering CAPEX. As the proposed solution presents a high degree of innovation, the estimated eligibility for public funding is considerable. For more information please see section 6.3. Feasibility of the business model.

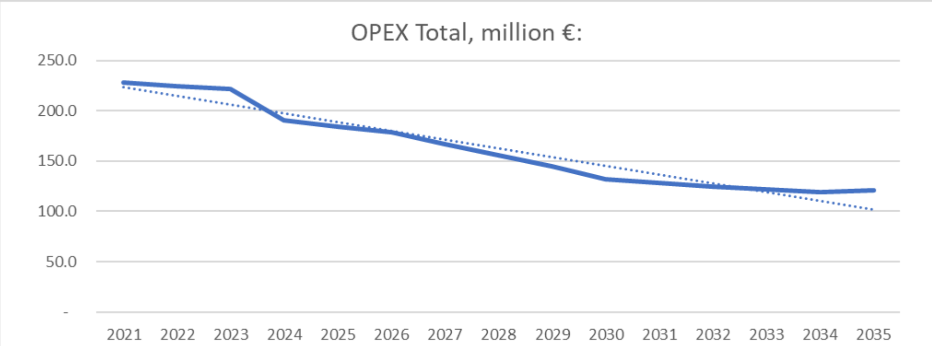
4.2 OPEX

The OPEX calculation considers all components of the proposed solution for heat production including operating the currently existing assets (please see table below). The assessment includes fuel consumption, operational and maintenance activities, REPEX (fraction) and EU ETS certificate cost. Existing District Heating pipework-related operational and maintenance costs are not included in the assessment as our solution does not affect the energy distribution but mainly its production. OPEX of all plants is calculated on the base of the consumed fuels/annual heat production (MWh). Fuels, electricity prices and taxation have been calculated based on the information given by the instructions.

In the first years, the operating costs average at 230m€ per year. A significant reduction of costs is expected over time starting 2024 due to the phase out of the old fossil-based assets and optimisation introduced by the introduction of the new solution (please see 4.1 CAPEX). By 2035, with the end of the proposed decarbonization journey the operational costs are expected to be reduced by half.

In this model, Digitalisation would mainly affect the utilisation of fuels and personnel. Digitalisation is assumed to reduce the amount of fuels needed for production by reducing the losses and better matching between production and demand. A gradual reduction of personnel costs is assumed through digitalisation and replacement of solutions which due to their operational complexity have high personnel costs, such as coal CHPs with less resource intensive solutions such as wind turbines.

	Heat Pump (summer)	EGS	HOB Bio Vuo	Power to X ("City Refinary")	Seasonal storage (El Boilers)	Heat Pump	HOB Pellets	CHP Coal Salmi	CHP Coal Hana	CHP NCG Vuo A	CHP NCG Vuo B	HOB Coal	Electric boiler	Distr. Electrical boilers	Peak Oil/NCG	TOTAL DH-network	Local Energy Systems (LES)	Digitalisation	TOTAL incl LES
	OPEX Total, million €:																		
2021	4.6	-	-	-	-	5.4	5.7	63.7	72.5	31.4	30.7	7.0	-	-	6.5	227.4	0.7	-	228.1
2022	4.6	-	-	-	-	5.4	5.5	63.7	72.5	29.8	29.1	6.7	-	-	6.1	223.4	1.4	-	224.8
2023	4.6	-	-	-	-	5.4	5.2	63.7	72.5	28.3	27.7	6.3	-	-	5.8	219.5	2.1	-	221.6
2024	4.6	-	45.3	-	-	14.2	19.0	47.8	-	19.1	20.9	-	10.5	-	6.0	187.4	2.8	-	190.2
2025	4.6	-	45.1	-	-	14.0	18.7	47.3	-	18.3	18.7	-	9.3	1.1	3.8	180.9	3.5	-	184.4
2026	4.6	-	44.8	-	-	13.9	18.5	46.7	-	17.5	16.5	-	8.2	1.7	2.2	174.5	4.2	-	178.7
2027	4.6	3.2	43.2	-	-	13.1	17.8	44.6	-	15.3	12.4	-	5.4	1.9	0.6	162.0	4.9	-	166.9
2028	4.6	6.3	41.2	-	-	12.4	17.0	41.8	-	12.6	9.2	-	3.3	1.4	0.1	150.1	5.5	-	155.7
2029	4.6	9.5	39.0	-	-	12.0	15.9	38.3	-	9.7	6.9	-	2.1	0.8	0.0	138.7	6.2	-	145.0
2030	4.6	12.3	36.9	7.4	7.8	16.1	13.4	-	-	15.7	8.1	-	1.8	0.5	-	124.7	6.9	-	131.6
2031	4.6	12.3	35.3	7.4	7.8	15.4	12.9	-	-	15.0	7.7	-	1.7	0.5	-	120.6	7.6	-	128.2
2032	4.6	12.3	33.7	7.4	7.8	14.8	12.3	-	-	14.4	7.4	-	1.6	0.5	-	116.7	8.3	-	125.0
2033	4.6	12.3	32.2	7.4	7.8	14.1	11.7	-	-	13.8	7.1	-	1.5	0.5	-	113.0	9.0	-	122.0
2034	4.6	12.3	30.8	7.4	7.8	13.5	11.2	-	-	13.1	6.8	-	1.5	0.5	-	109.4	9.7	-	119.1
2035	4.6	11.8	35.1	32.1	7.9	10.0	3.6	-	-	-	-	-	5.3	2.8	-	113.2	7.8	-	121.0
Total, M€:	68.4	92.2	462.6	69.1	47.0	179.8	188.5	457.6	217.5	254.1	209.1	20.0	52.2	12.2	31.2	2,361.6	80.6	-	**2,442.1**



4.3 Total cost of heat production

To analyse the cost of heat production we have assessed two periods: 2021-2030 and 2021-2035.

We have summated total CAPEX and OPEX for both periods respectively based on the newly installed capacity. Additionally, we aggregated the total heat production for the mentioned periods. As the result, the specific CAPEX per MW of installed capacity and averaged heat production cost per MWh was calculated for the both periods respectively. Heat production cost was split into two components: OPEX based (variable) and CAPEX based (fixed). Please note, that these figures reflect only the production costs associated with the proposed solution and do not include existing heat distribution system costs that were not affected by the solution. As per the figures below, the respective heat production cost for the period of 2021-2030 is a little bit higher compared to the period of 2021-2035 because the major part of CAPEX is spent before 2031 and the annual OPEX spend is strongly decreasing from 2031 onwards.

Averaged cost of heat production for the period of 2021-2035 in real 2021 values:

New installed, MW	1,414	Heat produced 2021-2035, GWh	91,148
Non discounted CAPEX, m€/MW	0.469	Non discounted averaged heat production cost (Variable), €/MWh	26.8
		Non discounted averaged heat production cost (Fixed), €/MWh	7.3

Averaged cost of heat production for the period of 2021-2030 in real 2021 values:

New installed, MW	1,135	Heat produced 2021-2030, GWh	63,877
Non discounted CAPEX, m€/MW	0.493	Non discounted averaged heat production cost (Variable), €/MWh	28.6
		Non discounted averaged heat production cost (Fixed), €/MWh	8.8

Additionally, to the values above, we discounted the values for the full decarbonisation period (by 2035) with the 4% interest rate according to the instructions given.

Discounted values with 4% interest rate - cost of capital

New installed, MW	1,414	Heat produced 2021-2035, GWh	91,148
Discounted CAPEX, m€/MW	0.351	Discounted averaged heat production cost (Variable), €/MWh	21.5
		Discounted averaged heat production cost (Fixed), €/MWh	5.5

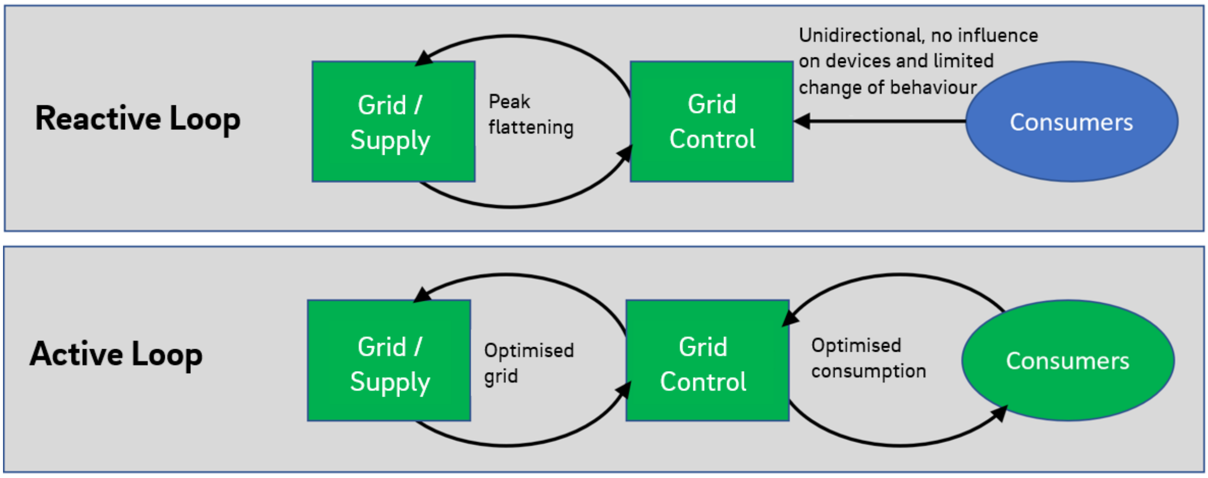
4.4 Digitalisation-based cost impact

To reduce the cost, a complex system needs an optimized running regime. Our approach is founded on the OT (operational technology) capabilities of increasingly carbon-reducing energy generation in Helsinki. However, it does not stop on the OT side but is capable to be extended by any forthcoming OT technology through the means of IoT, by running the Helsinki energy solution on:

- **Optimised operations** to reduce cost and enable high QoS for the citizens,
- **reacting in near real-time** to any incident,
- **predicting future incidents** (such as change of supply/demand or condition-based asset failures),
- **full reporting capability** to prove carbon impact and directions, as well as enabling local carbon tax concepts,
- **high reliability of supply** through a combination of Local Energy System, real-time event handling, condition-based monitoring, and hybrid cloud (which combines edge (local) control loops with central cloud capabilities for cost optimization),
- **future technology readiness**, virtually any new or additional OT solution such as hydrogen or new storage systems can contribute to the solution at any time,
- **peak shaving capabilities,** the concept enables reduction of peaks that typically create some of the **highest cost** (need for redundant energy providers to supply during peaks) with **citizen inclusion** to support individual needs and give transparency to everybody on the impact and
- **scalability,** upon demand the solution can be extended beyond Helsinki.

Levelling out peaks in energy consumption by commercial, public, and private consumers is important in terms of network stability and costs. Geothermal, wind and hydrogen energy for example is not dependent on time-of-day, but rather on actual capacity. Averaged citizen behaviour on the other hand follows predictively general load profiles for specific day, weather and season types. Our solution supports both reactive loop (peak flattening) and active loop (load shifting) types of peak shaving.

The figure below visualizes the two loops and demonstrates why from a systemic view they make a significant difference:



Digital feedback loops are one of the most important contributors to continuous improvement. Our concept already incorporates the loops to operations (network control) and the supply related products, as well as Helsinki government for essential decision making.

With our approach, we could add digital twins of a building and assign role based access rights to carbon "contributors" of a building. We can easily integrate with the Bentley Digital Twin of Helsinki which runs on the same graph technology and derive building twins from there. Our solution is fully capable to be extended to support GDPR compliant active loop implementations.

As we have seen in comparable industrial efforts, this is expected to have significant impact on the total cost:

- Asset failure and service time and effort to fix. Our solution predictively avoids such failures, reduces service time and repair efforts and broader unplanned outages in most situations with machine learning support. Asset lifetime can be extended depending on condition (RUL – remaining useful lifetime).
- No/less redundant energy provider required (peaker plants).
- Inclusion of more/all supply assets into the concept that have been isolated before
- Advanced solutions such as virtual power plant (VPP)
- Cost of operations (demand dependent distribution)

The size of these cost reductions are difficult to predict and depend on Helsinki's decision about the breadth and depth of integration.

4.5 Detailed assumptions

General:

1. All costs are presented in real 2021 values.
2. Only Direct Investment and Operational costs associated with the new solution for heat production are assessed. Parts of the existing system, that are not affected by the proposed solution (such as the distribution network) are not included in the calculations.
3. 4% interest rate - cost of capital – is included in the assessment of the discounted/net present values.
4. No major investment for Civil works or land use is required as the new equipment predominantly will be installed in currently available building after the existing plant is decommissioned as planned.
5. In the assessment it is assumed that 100% of electricity generated by the CHPs is exported to the network.
6. All electricity procured from the network is considered at the emission factor of 30 kg CO_2/MWh.

CAPEX:

1. Based on our experience, best knowledge and practice, the following assumptions are applied of newly installed capacities:
   - Electrical boilers – 37.5 €/kW installed
   - Heat Pumps – 500 €/kW installed
   - Deep Geothermal Heat – 1,500 €/kW installed
   - Seasonal storage – 750 €/kW installed (the cost is based on the estimation similar to the publicly available sources for Finland)
   - Local Energy System – 1,426 €/kW installed (the wells will be 300 and 600 m deep and the temperature will be boosted with heat pumps, the cost is the average cost for such a system)
2. Additional 30 MW of Heat pumps from the waste heat of the local energy networks, industry and commercial (e.g. swimming pools, supermarkets, data centres) included in the CAPEX – only 15 MW planned / operated by the City, additionally to the existing.
3. CAPEX for the E-Fuels refinery will be planned by the City or different sector (transport), not part of the calculation.
4. No Capex included for the diesel generator as back-up for the electricity based solutions. This cost is relatively low compared to the main investments. Electricity safety of supply is at high level and likelihood of the electrical black-out is very low.
5. Decommissioning costs for the coal CHP and the old boilers are not included, because this cost would occur in any event(no extra costs associated with our solution). We anticipate, that part of this cost can be reduced, because of the continued use of the existing buildings (CHPs and coal HOB).
6. Building level improvement of Controls and Metering is included in Digitalisation investments.

OPEX:

1. Commodity wholesale prices are accounted in constant real prices.
2. We assume that the commodities prices for 2030 are given in nominal values (in the instructions documents), hence applying 2% we deflated the 2030 value to get to the real 2021 price. As no information on energy price development is given by the instructions, we assume constant real 2021 price is applied for each future year and the final result is presented in real 2021 money.
3. EU ETS costs are applied in addition to the national Finnish fuel taxation on coal and natural gas based plants.
4. CHP emissions are calculated based on Benefit Allocation method, and consequently, the CO_2 and fuel taxation are based on the fuel consumption calculated according to the method.
5. In CHP production the taxes are calculated based on the produced heat.
6. In HOB the taxes are calculated based on actual consumption.
7. We assumed all electricity consumption to be taxed as Class II because of industrial scale use and feed into district heating.
8. Operation and Maintenance (O&M) and partially REPEX is assumed as 0.5-3 €/MWh of fuel consumption for respective plants due to unavailability of information on the total CAPEX of the existing plants.
9. No total cost of REPEX is included in the assessment of the duration of 2021-2035 as the new installed plant life expectancy is longer than the assessed period.
10. Personnel cost is included in the O&M costs, minimum personnel presence will be required for electricity based technologies in the future – less presence compare to the existing fossil fuels based plants.
11. Seasonal storage is loaded with direct electric boiler when electricity price is less than 20 €/MWh - average of 6.3 €/MWh is included in the calculation for this purpose. These values are based on hourly electricity price forecast given in the instructions. These prices can be achieved for maximal 1,150h annually.
12. After 2030 Oil/Natural gas boilers of 700 MW, of existing 1,910 MW, are only used as emergency back-up. No OPEX is allocated to this back-up capacity.
13. E-Fuel waste heat is accounted at 35 €/MWh.
14. Existing gas CHP(s) if needed can be left for cold reserve – quick start.
15. No OPEX is included for the existing plants kept in cold reserve. Cold reserve to be used as backup capacity in case of e.g. electric blackout.
16. Auxiliary energy cost (mainly electricity) is negligible in comparison with the main electricity consumption as primary energy. Auxiliary energy (electricity) for geothermal solutions has been considered though.
17. Operational Business margins and revenue flows are not included in the assessment as the final Operational and Ownership model is unknown. The calculation is cost-based only.

5. Implementation Schedule

The **starting point** of the implementation schedule is as currently performed by the Helsinki heating operator. The system will be operated as such until the CHP Coal Hanasaari and the HOB coal will be decommissioned. The implementation of Local Energy System will start already in 2021, as well as some conversations to on-site solutions using geoenergy with a heat pump. Also it this quite important to start the identification of the right location of the geothermal solutions as soon as possible, after which the process of the requesting the necessary permits should start.

End of 2023: Decommissioning of CHP Coal Hanasaari and the HOB coal

Beginning 2024: Beginning of operation for HOB Bio Vuosaari (276 MWth); Commission the central electric boiler (190 MWth). A heat pump will lower the return flow further and the condensing unit will perform better, improving the performance of the plant with an additional 16 MW.

2025 – 2030: 50 MWth, decentral electric boilers will be distributed in the central system, replacing fossil peak boilers, build out to 450 MWth in 2030. The peak boilers will support distribution and enable a lower supply temperature from the large generation plants, thus reducing the losses. Local energy networks that either disconnect from central networks or are new builds that will continuously be added to the decentral system.

2027 – 2030: Gradual build out of deep-geothermal solutions with 35 MWth each year, ending in 2030 with 140MWth.

End of 2029: Decommissioning of the CHP Coal Salmisaari, replaced by full build-out of deep geothermal and decentral electric boilers, first waste heat from the refinery (42 MWth) and **seasonal storage of 150 MW (190 GWh storage capacity).**

End of 2034: Decommissioning of the natural gas CHPs Vuosaari A and B through either waste heat from the refinery (162 MWth) or synthetic gas usage or hydrogen usage to fill the gap. Also the rest of the missing capacity will be covered by the yearly reduction of the heating demand and the shift to local energy solutions.

Implementation of the **digital infrastructure** could start in 2021 and the schedule is partly independent of the transition schedule of assets. Connecting *existing* infrastructure and assets will be in focus for 2021 to 2025. All *newly* deployed assets will be connected immediately to the system. Operations of the optimization system will start from 2022, delivering immediate value on carbon reduction and costs and will be further expanded going forward.

Phasing of central and decentral system Helsinki from 2021 to 2035 – turning the merit order from cost to CO_2

Heat Capacity, MW	2021-2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Heat Pump (summer)													
Deep Heat	-	-	-	-	35	70	105	140	140	140	140	140	140
HOB Bio Vuo	-	276	276	276	276	276	276	276	276	276	276	276	276
Power to X ("City Refinery")	-	-	-	-	-	-	-	42	42	42	42	42	204
Seasonal storage								150	150	150	150	150	150
Heat Pumps	105	105	105	105	105	105	105	150	150	150	150	150	150
HOB Pellets	90	90	90	90	90	90	90	90	90	90	90	90	90
CHP Coal Salmi	300	300	300	300	300	300	300	-	-	-	-	-	-
CHP Coal Hana	430	-	-	-	-	-	-	-	-	-	-	-	-
CHP NCG Vuo A	170	170	170	170	170	170	170	170	170	170	170	170	-
CHP NCGVuo B	430	430	430	430	430	430	430	430	430	430	430	430	-
HOB Coal	190	-	-	-	-	-	-	-	-	-	-	-	-
Electric boiler	-	190	190	190	190	190	190	190	190	190	190	190	190
Distributed electric boilers	-	-	50	100	200	300	400	450	450	450	450	450	500
Peak oil/NCG	1,910	1,910	1,860	1,810	1,710	1,610	1,510	700	700	700	700	700	700
SUM Central DH:	**3,625**	**3,471**	**3,471**	**3,471**	**3,506**	**3,541**	**3,576**	**2,088**	**2,088**	**2,088**	**2,088**	**2,088**	**1,700**
Local Energy Systems	40	53	67	80	93	107	120	133	147	160	173	187	200
Total, MW:	3,665	3,524	3,538	3,551	3,599	3,648	3,696	2,221	2,235	2,248	2,261	2,275	1,900

Note:

Heat Pump 105 MW operates in different merit order in winter and in summer (first priority).

No CAPEX allocation, it will be implemented by different sector (transport)

30MW additional HP included, the rest is covered by the existing 105 MW and 15MW planned by the City.

After 2030 only reserve boilers, no planned operation.

Risks and mitigations for the implementation schedule

Risk factor	Possible impact(s)	Likelihood (1- very unlikely, 5- very likely)	Mitigation measures
Preparatory work for EGS	Time delay, costs increase	3	The start of exploration for the right EGS positioning (location), as well as the permitting process needs to be started in advance, preferably already after the selection of the winning solution.
Delivery of systems or components	Time delay	1	Procurement procedures should be initiated well in advance of construction.
Construction of additional heat storage systems	Time delay, costs increase	2	The analysis regarding the location and the timing assessment of the excavation works needs to be done in advance, preferably already after the selection of the winning solution.

Decrease in the amount of produced energy or heat demand	Later decarbonisation of the network, cost increase	2	Geothermal or peak load boiler must be introduced to the system earlier than planned.
Reduction of the use of waste heat	Later decarbonisation of the network, cost increase	2	Increase of the interest to connect waste heat sources to the district heating network.
Lower production of E-Fuels	Cost increase	3	Need to scale up the production from other units.
Higher electricity prices for loading of the heat storage	Cost increase	2	Risk can be reduced with an own build-out of renewable electricity.

6. Implementation Feasibility

This chapter analyses the technological, financial, legal, administrative, cultural and ethical feasibility with respect to the main components of the proposed solution. There is a special deep-dive for E-Fuels and the business model that provide more details and background information.

6.1 Feasibility of the system components

Large **electric boilers** can be installed quickly with a rather low cost of investment. Electric boilers are introduced before any major changes in the power markets has taken place, this being possible due to the operation of the large CCGT plants. The two large CCGT plants at HELEN will always be able to directly feed the boilers when still in operation. The operation is relatively easy and will not require any fuel transport into the city, other than the transport of electricity in the already existing power lines. Due to the large CHP plants that are in operation today, the power lines already exist, and the network is stable, and blackouts are rare. Due to the massive build out of wind and solar power, the electricity market is bound to change expecting fluctuating prices and curtailment of wind, perhaps even negative electricity prices from time to time. The cost of electricity will probably be the lowest at times in the warmer part of the year, then the electric boilers will deliver thermal energy to the seasonal storage at a marginal cost. To make this happen, the plant will be connected to a virtual power plant system that will predict and introduce a start and stop signal to the control room. Electric boilers will also be able to raise the temperature of the network in the case of excess electricity on the power market. The implementation of large electric boilers is considered as a well-established and known technology and assumed to be feasible as such.

Electric boilers have a low footprint on ground and do not cause any local emissions and as an additional benefit - will free up land. In addition, electric boilers' auxiliary equipment will require less space, especially compared to a coal based plant, which is especially beneficial for busy city centres. It will also improve the aesthetics of the sites and the comfort of the local residents, as the massive and dirty coal power plant will be replaced by new compact solutions.

Local Energy System. The technology is well known and could be applied in all new build areas as well as areas that have supply constraints today. The ownership models could be slightly different - end consumers could create an energy community. An updated control system to keep down the installed capacity will be introduced.

The technology in the solution is based on harvesting all free excess heat available in the surrounding, being able to provide cooling from the same installation if applicable and using low temperature energy sources. The Local Energy System will be sourced by geoenergy solutions of different depth, parts of the wells will be recharged in the case of surplus thermal energy, and parts will be integrated with the BMS of the buildings. Heat pumps will be installed in a many times distributed manner with the ambition to reduce the thermal losses as much as possible. In some areas, the return flow (supply acting as back-up) will source the Local Energy System that will be hydraulically decoupled by a heat exchanger or the temperature shunted down to a lower level. This procedure will give the wider possibility for waste heat sources to feed into the network and increase the delta T of the main network. Local energy networks are mainly planned for areas in the vicinity of Helsinki and in new build areas that do require cooling as well as heating. There are no major constraints that would appear as risk for the feasibility of the Local Energy System.

Additionally, the LES require overall much less installation space (compared to a central heat generation concept) due to the distributed character of the generation assets. The “energy center” is much smaller than for a purely central solution. In this way, the locally available space can be optimally utilized.

EGS is feasible today and the technology is being developed to be more commercially viable. Deep geothermal is considered to cover depth range from 1 km downwards, with and without heat pump technology. Deep Geothermal is a scalable technology that is being developed from existing technologies towards deeper and more demanding bedrock areas. Combined knowledge from geothermal projects in existing plants in Europe and globally is being used to develop a concept for the Nordic bedrock and geological conditions. The above ground equipment is well known, and the underground drilling procedure is under rapid development. There is also a possibility to recharge the deep wells using surplus thermal energy, using the wells as storages.

Seasonal storage systems will be a future game changer for thermal energy systems. The bedrock in Helsinki is well suited for underground storages and several storages like Mustikkamaa do already exist. The knowledge of underground work in Helsinki is extensive and the rock material will be reused in the construction sector. The coal pits at Salmisaari could be converted to a long-term storage. Some of the boreholes that are a part of the Local Energy System will still have an interface to the main district heating network and will be recharged to deliver more energy during the wintertime. The seasonal storages will act as large thermal batteries and enable the transition to a renewable energy system. In addition to the already existing storages, two more storages will be constructed of 90 GWh each. The storages will be charged with surplus energy from the electric boilers and waste heat from the E-Fuel factory. In order to store large amounts of energy, the temperature will be kept around 90ºC. Thermal storages will be a crucial way to store electric energy and avoid unnecessary curtailment of renewable power generation.

Another possibility is to bring energy from sea water pumps to a higher temperature, store it and then bring up the temperature further using the same installed capacity. This is not considered in the calculations presented, but is still an attractive option.

Heat pumps there are already extensive heat pump operations in Helsinki, for instance 100 MWth in Katri Vala and more heat pumps are planned to be installed. Sea water will be used for operations as well as sewage water and geoenergy.

A broader application of heat pumps could also bring more of social benefits, such as the growing work possibilities in the heat pump sector. If Finland were to achieve the same level in heat pump sector that currently exist in Sweden, that would imply an addition of ca. 7,000 new work places in the Finish renewable energy sector.

Import/export from/to Fortum and Vantaan Energia some exchange with these surrounding networks already exists and might increase. Since the knowledge of the expected development of these networks is limited, focus has not been on these networks, although this might be of interest and will serve to optimize the sourcing in the larger Helsinki. The waste is being delivered to Vantaa and although this is expected to decrease in the future due to recycling, the waste burning plants might serve as a source to charge the seasonal storage in the network of HELEN.

The **digital transformation** of the energy system is feasible with today’s existing technology considering the requirements on cybersecurity, security of supply, performance and GDPR compliance. Adaption of the technology is ongoing broadly in various industries.

Excess heat from E-Fuel production. Although technology readiness level of E-Fuel production is good, the system level process is at the early stages of development and production costs are comparatively high. However, costs are reducing. Electrolyzer costs have reduced by 60 % in the last ten years and are expected to halve by 2030. Several demonstration projects are ongoing in Europe aiming into large-scale operation. It is expected that hydrogen and E-Fuels will have an essential role in the integrated low-carbon energy system by 2030.

The E-Fuel production operates with CO_2 from Vuosaari as an input component, meaning that the Bio HOB needs to operate for the E-Fuel production to take place. In general, when the Bio HOB operates, the E-Fuel production operates as well. If there is no need of excess heat from E-Fuel production at all time the Bio HOB is operating, this excess energy will be stored in the seasonal storage.

6.2 Economic feasibility and potential risks associated with E-Fuels

Although there is a strong demand for E-Fuels driven by EU’s strategies, the overall investment for large scale power-to-x ecosystem is high. In addition, there are investments to wind power on top of that.

However, these investments can be done gradually step by step. There is very strong willingness to find and invest in sustainable solutions and decarbonize the transport sector, which gives high pressure to politicians to create regulation and funding program which will support this transition. Synthetic fuels market and prices are assumed to follow the trend of biofuels creating profitable business with EU and national support to investments.

We anticipate that the most likely approach will be that a consortium of several stakeholders from the whole value chain will be required to do this investment. These stakeholders can be local players in power- and heating sectors, technology providers, fuel suppliers and distributors as well as stakeholders in end use sectors like shipping, aviation and industry.

Economic feasibility of E-Fuel production depends mainly on:

- availability of competitive renewable energy in the network
- regulative framework and RED2 implementation, which have effect on E-Fuel market prices
- investment costs e.g. the price of electrolysers

Overall TRL for the separate elements in E-Fuel production is in a good level:

- Carbon capture from point sources: TRL 9
- Electrolyser: TRL 6-9
- Synthesis: TRL 8-9 in most of the technology routes

However, the overall concept of E-Fuel production is still at the demonstration scale.

Despite the first positive indications, there remains a risk that some of these elements would develop in an unfavourable direction and the investment decision for E-Fuel production is not taken. The production process is energy intensive and requires large amount of renewable electricity. Although the main idea is to use low cost electricity when surplus electricity is available, power-to-x facilities will need also to be operated during higher electricity price periods in order for investments to be viable.

However, even given such risks, in order to reach the climate targets and make the energy transition to happen, large investments are needed. This requires close co-operation with several stakeholders both inside and outside of energy value chain and companies need to join forces. Several projects are already announced in Nordics as well as in other European countries. There are lot of funding possibilities for these kinds of plans. Investment risk can be lowered, and investments will be supported. As an example, both Next Generation EU and European Clean Hydrogen Alliance will play crucial role in delivering EU's hydrogen strategy.

6.3 Feasibility of the business model

The implementation of the proposed solution would require an active engagement of several energy operators and players of the municipality. Today, HELEN is the operator of the Helsinki district heating system. The consortium is ready to partner with HELEN and the city of Helsinki to get the decarbonization journey done as proposed.

What the consortium could bring on the table is the following:

- Technical Competence of any of the proposed solution to plan, build, operate
- Commercial competence to finance the assets incl. Third-party financing and EU-&national Funding (see below, with proven track record) and try to find the right pricings & business models around it
- Legal competence especially around permits and time frames
- Openness to partnerships in the city – via different models as city of Helsinki wants – Joint ventures, new joint legal entities, being the service provider

Currently available EU funding programs cover key focus topics of our proposed solution. Examples of the programs that support highly innovative projects driving the digitalisation and decarbonization of energy systems in general and district heating in particular: 1) The "EU ETS Innovation Fund" (total budget: 10bn€ 2020-2030) focusses on first-of-its-kind industrial-scale applications of renewable energy generation units, e.g. deep geothermal installations and hydrogen- or synthetic fuel-based solutions. 2) The "European Recovery and Resilience Facility" estimated budget for Finland: 2.3bn€ 2021-2023) to support economic recovery from the COVID-19 crisis will likely cover – amongst others - low temperature district heating applications. 3) The new EU research and innovation funding program "Horizon Europe" (total budget: 95bn€ 2021-2027) will succeed the current program "Horizon 2020" and include as 2 of the main focus areas the "Climate Energy" and "Digital Industry" clusters as well as the focus topic of "Climate Neutral Cities". The team and the companies behind this submission have extensive experience in applying and securing public funding from various European funding sources. The team was able to win 24m€ of EU and national public grants in 2020 for district heating-related activities (incl. several EU Horizon 2020 projects) and to build a submission pipeline of >60m€ (incl. EU ETS Innovation Fund).

7. Reliability and security of supply

A fundamental of district heating systems is security of supply, maintained by technical redundancy, meaning that production assets have excess capacity. In the **Local Energy System** the production is distributed over several plants and the entire system will not be impacted if one heat pump fails. Several of the traditional substations that today consists of heat exchangers will be replaced with heat pumps in a standardized manner. The system will be designed in such a way that most buildings will have more than one heat pump installed. Then even in case of a problem with one compressor, the building can still be heated although not at full capacity. Through decentralization and distribution of assets and their digital connectivity, the system as a whole becomes reliable, resilient against outages and long-term flexible. As the local energy storage has smaller scale storage, this also increases flexibility.

Importing heat from an external provider **producing E-Fuel** will imply that the redundancy measure could be facilitated at the E-Fuel plant since that plant will have a large electric connection to the electrolysis plant. With electric boilers as a bridging solution the security will be improved in the overall system since they will be powered from the electricity that normally supplies the E-Fuel plant.

The most critical part of our solution is the *security of supply for electricity*. More than 98 % of the power lines in Helsinki is underground and black outs are scarce. The generation assets are being fed from different directions and if one power line will go down, others will still be in operation. The location of the **electric boilers** and the E-Fuel plant will be placed where the network is already strong due to the large CHP that is operation today. The E-Fuel factory is directly dependent on CO_2 from HOB in Vuosaari and will be located in the direct proximity. In the 2035 when the large scale gas CHP are dropped out, some enforcement of the electrical network might be needed, but this will concern only the eastern industrial part of Helsinki. This area has still a strong electrical network and the distributed energy centre. However this issue should be analysed in relationship with the future development plans of Helsinki. In the rare case of a total black out of Helsinki, there are large diesel generators for the electricity production for the circulation pumps for the deep geothermal and underground storages. In the future, we anticipate an increased need for electricity, especially from renewable resources like wind. This might raise an issue in the future; however we assume that the policy development will continue to be in favor of renewable sources and the available electricity will grow over time.

The existing oil boilers will be kept for redundancy purposes, but not as a part of the planned operating regime even in the coldest period of time. Shorter problems with heat production capacity we can cover with the different large scale storages (existing and new ones) and the smaller storage in Local Energy System.

The security of supply and flexibility can be increased through the existing heat exchanger and a heat connection with Vantaa and Espoo.

The system complexity will increase, but the handling will be optimised with digitalisation. The **digital solution** monitors, controls & optimizes the system while improving reliability and security of supply. Data is constantly analysed to ensure stability. Malfunctions are reduced through predictive O&M and solved more efficiently ad-hoc. Advanced production, distribution and consumption forecasting and modelling detects potential supply issues and identifies countermeasures immediately.

The solution is based on a hybrid cloud architecture, with a focus on cybersecurity. Device connectivity follows the certified high security requirements. Cloud data is encrypted, complying with ISO 27001 and additional certifications. The hybrid cloud approach ensures system stability in case of connectivity failure. On premises controllers provide fallback operations when not connected to the system and manual overruling is always possible.

The high level of connectivity and data exchange is done without compromise to the meeting all legal and best practice requirements in terms of data protection and cyber security. Digital technologies employed in the system will offer the highest levels of security.

8. Capacity

Once fully implemented, our solution's installed capacity is estimated at ca. 2GW (described in detail in section 5. Implementation Schedule). The produced annual heat volume will follow the expected demand trajectory and cover the expected demand of 4.9 TWh in 2035.

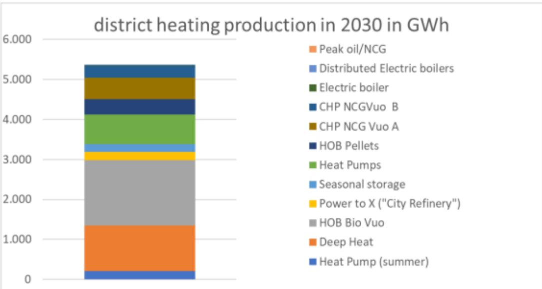
2030 total capacity	2.2 GW	2030 heat production	5.8 TWh/year
2035 total capacity	1.9 GW	2035 heat production	5.2 TWh/year

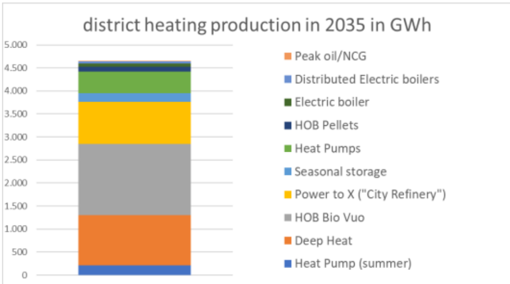
Note: The annual values represent heat production consisting of heat consumption and heat losses.

The proposed decarbonization plan for Helsinki has significant impact on the cessation of coal combustion in Helsinki. With decommissioning of first coal CHP and coal HOB end of 2023, the first major step toward a full coal exit has been undertaken, as seen in the CO_2 calculation. By the end of 2029, Helsinki will no longer burn coal. By 2035 other fossil fuels will be phased out and Helsinki will become close to net zero carbon emissions. The coal exit is reachable through the holistic plan for Helsinki, and a plan that is replicable and scalable, with Helsinki as the “role model” for other municipalities. This is achieved with five integrated measures:

- Optimization of the network through decentralization and decoupling of suburbs, leading to local decentral energy solutions with own local production through decapsulation from central network or in the new build space. Introducing Local Energy System, coupled or detached, with low temperatures will enable the reuse of waste heat from sources such as supermarkets, data centres and swimming pools
- Enhanced optimization through digitization of the network using peak shaving, balancing and optimized storage usage; AI enabled optimization of the energy system, utilizing advanced forecasting systems for production, distribution and demand of energy to reduce peaks by balancing demand and production through system flexibility
- Electric boilers both central and decentral, making immediately the phase out of coal happen and tackle the fossil peak boilers over time
- Innovative geothermal solutions
- Large-scale seasonal storage
- Waste heat usage from E-Fuel refinery or potential hydrogen solutions

Annual energy balance of the solution in 2030 and 2035





Our solution also foresees more cooperation between the cities of Helsinki, Espoo and Vantaa to strengthen the system due to redundancy, optimization and capacity. It is in line with “The Carbon-Neutral Helsinki 2035 Action plan” with 147 actions and can be easily integrated or coupled with other actions in other sectors or other stakeholders, for instance customer segments like housing companies, housing associations, real estate developers, and other like municipal stakeholders, energy companies like HELEN, own employees and inhabitants. Final aspect to consider is positive employer development that is needed for implementation of the solution in terms of heat pump knowledge and digital.