Helsinki Challenge

- *towards carbon neutrality*

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1. Summary of the proposed solution

In this section, the core idea (1.1), key benefits of the solution (1.2), foreseen business model arrangements allowing social inclusion (1.3), suggested solution for financing the energy transition (1.4) and the innovative features of our solution are highlighted (1.5).

1.1 The core idea

Our core idea is to design a District Heating System (DHS) for Helsinki that is circular and focused on making use of heat that is otherwise lost. The main heat sources that will be used are solar, ambient heat and waste heat sources. We combine the heat sources with different thermal energy solutions (TES), of which the borehole solution is deemed the most important for the DHS of Helsinki.

The main goal in the decarbonization of the DHS of Helsinki is to identify large amounts of renewable energy sources (RES) and waste heat sources. Available waste heat and RES are mostly low-temperature sources and thereby require use of heat pumps (HPs). An efficient use of HPs requires to lower the network and user operating temperatures as much as possible. Finally, since the RES availability typically does not match the demand profile, the introduction of large seasonal TES capacity is needed. Hence, our efforts were focused on identifying the most convenient available renewable and waste heat sources and, at the same time, on finding a compromise between their capacity, the corresponding land use, the possibilities to reduce operating temperatures and demands, and the capacity of TES solutions.

The starting point has been to find the most cost-efficient development of the DHS of Helsinki leading to its decarbonization. We have applied a techno-economic optimization model (developed in the modelling language GAMS) to the DHS of Helsinki, which allowed us to test alternative combinations of heat sources and TES solutions. As a result of approximately 40 different model runs, we have identified one development pathway for the DHS being the most cost-efficient. A model run is however, of limited value unless experiences from real life and local conditions are accounted for. Therefore, we have used the model output (made by the academics in the team) as input for further refinement (made by the practitioners in the team) of our proposed solution to identify investments to undertake in the periods of 2021-24 (start-up phase), 2025-29 (consolidated investment phase), 2030-34 (validation phase) and 2035-40 (stabilization phase).

1.2 Key benefits

The key benefit of our solution is the complete phaseout of coal by 2029 and the flexibility to use different heat sources when it is most cost-efficient to do so (enabled by seasonal TES solutions). This is reflected in the energy balance below (1.2.1). Further benefits are the significant decrease of climate impact (1.2.2), the introduction of upgraded business models, job creation and social inclusion (1.3), the outline of a plan for financing the necessary investments (1.4) and the innovative height (1.5).

1.2.1 Energy balance

The proposed solution is based on the principle of circularity, i.e., maximal reuse of waste heat and use of available RES. As seen in Figure 1 the heat supply of the city will gradually transition from being fossil fuel dominated into mainly being based on waste heat sources as well as on RES such as air and sea (in terms of generated energy, not installed capacity). We expect that already by the Year 2025, the usage of coal for heat generation will be significantly reduced and substituted with heat mainly generated by HPs, using already developed waste-water heat recovery, outdoor air and sea water as heat sources. During the transition period of 2023 to 2030 (portrayed by Year 2025 in the Figure 1, we assume increased utilization of biomass, which will partly cover the lost energy from coal- and gas-fired units. By the Year 2030, our solution assumes successful installation of a pipeline and HPs required for the extraction of industrial waste heat from the Neste Kilpilahti refinery, which will cover more than 1/3 of the total city's heating demand. In addition to the heat from the Neste refinery, the HPs utilizing waste-water, other low temperature heat sources, outdoor air and sea water are expected to provide around 51% of the total heating demand. The rest of the demand – 12 %, will be covered by the heat coming from the Vantaa waste-to-energy (WtE) heat only boiler (HOB) (during the summer months), solar thermal installations, existing biomass- and gas-fired units.

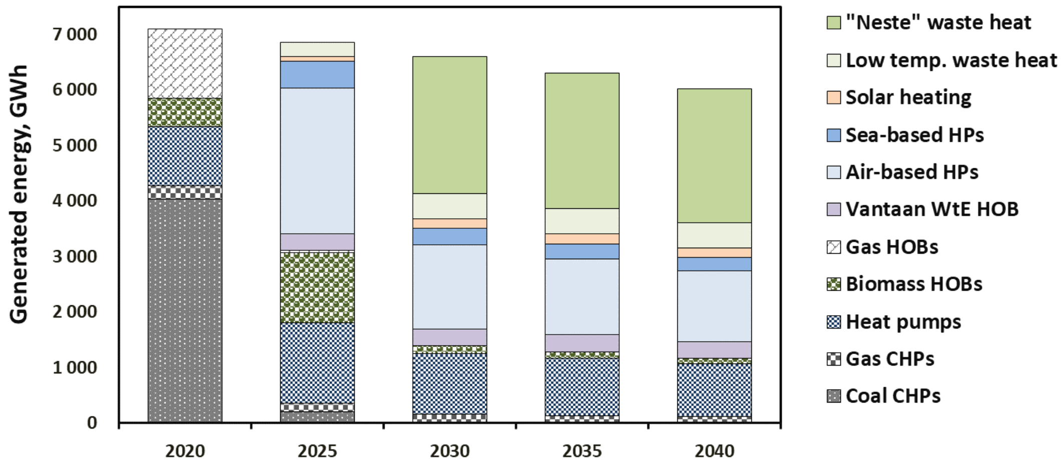


Figure 1. *Total generated energy in the DHS of Helsinki in the Years 2020-2040, based on the optimization modelling.*

The installed capacity of the heat generation and TES units, which will satisfy the above energy balance is shown in Figure 2. It can be seen that, in general, there is no proportionality between the generated energy and installed capacity, i.e., the largest units in terms of installed capacity do not necessarily generate the most of the energy, due to the different operation times of the various sources. The strong diversification of the generation system, while being more complex to manage, has the benefit of reducing risks related to a large dependency on a single energy source. More on capacity is found in section 8.

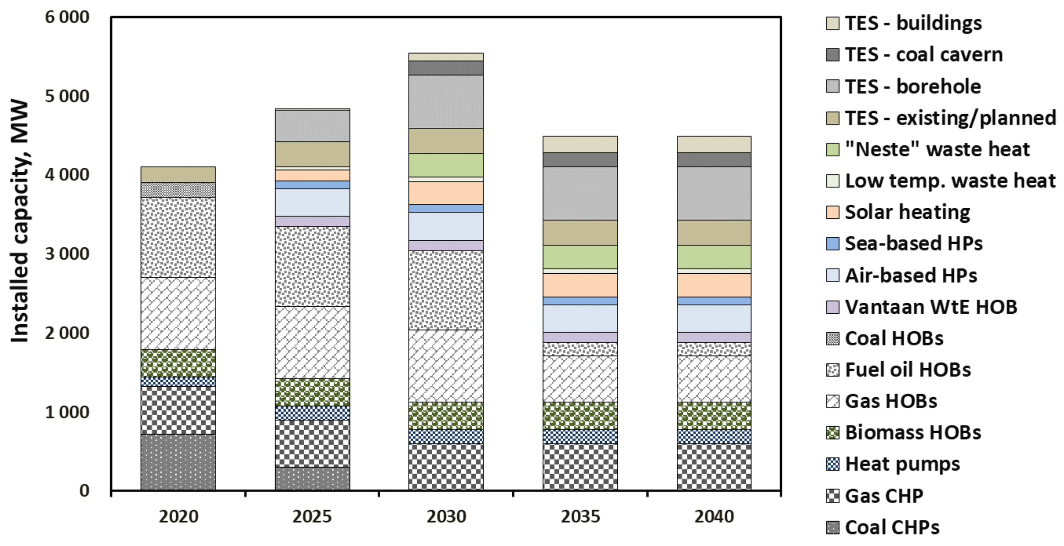


Figure 2. *Total installed capacity in the DHS of Helsinki in the Years 2020-2040.*

In Figure 3, the cost-optimal hourly dispatch of the heat generation and TES units available in the DHS of Helsinki in the Year 2030 is shown, as obtained from the applied optimization modelling. The main feature of the future operation of the DHS, which can be observed from Figure 3 is that heat generated by the generation units does not correspond to the total heating demand during noticeable periods of time. This is possible because of the availability of a great capacity of the TES units, which can store and release energy when necessary. It can be observed that during the warmer part of the year hourly values of the heat generation are noticeably greater than respective values of the demand. During these hours, the surplus of generated energy is being supplied (stored) to the seasonal borehole TES units (blue line in the Figure indicates state of charge of all the available TES units combined, but the borehole TES units constitute most of that volume). As a result, during the colder parts of the year the stored heat can be released ("storage discharge in Figure 3) and help satisfy, together with optimized dispatch of the heat generation units, even the highest peaks in the heat demand: creating the strong feature of flexibility characterized by our suggested solution.

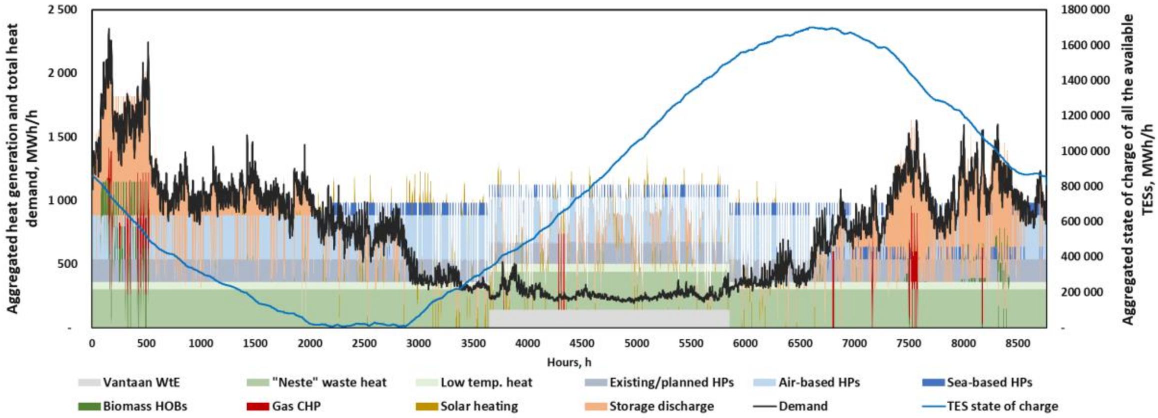


Figure 3. *The cost-optimal hourly dispatch of the heat generation and TES technologies together with the hourly demand profile (including network losses) and the aggregated state of charge of the TES units in the DHS of Helsinki in the Year 2030, as obtained from the optimization modelling.*

It can also be noticed from Figure 3 that during several hours, the heat generation from HPs is reduced to zero while the gas-fired combined heat and power (CHP) plant maximizes the output. This happens in the hours with high electricity prices, during which profitability of running CHP plants increases and operation of HPs is deemed not cost-efficient. This type of operational shifts indicates that a combination of HPs and some CHP capacity can be beneficial in the future with fluctuating electricity prices, which is expected considering rising shares of variable RES in the energy system.

<u>Key assumptions:</u>

- the total heating demand of the city is assumed to decrease linearly in the future. The measured heating generation (demand together with network losses) in the Year 2016 was 7,059 GWh and is applied in the modelling for the starting Year 2020. Considering linear decrease, the demand is then assumed to reduce to 6,380 in the Year 2030 and to 5,780 GWh in the Year 2040. The assumed demand of 6,380 GWh in 2030 differs from the suggested 5,400 GWh in the "Additional Challenge Instructions" document because we include network losses in our estimations, i.e., model computes required heat generation (further details can be found in the Attachment, Figure A.1.).

1.2.2 Climate impact

The proposed solution will have a significant positive effect on the climate impact of the DHS of Helsinki. By the Year 2030, the annual CO_2 emissions of heat generation are estimated to decrease 15-fold, i.e., from above 2500 ktCO_2 in 2020 down to around 150 kt CO_2.This is due to complete cessation of the coal-fired heat generation units and reduced heat output from natural gas-fired HOBs and the Vuosaari CHP plant. Starting in Year 2030, the main sources of CO_2 emissions in the system will be electricity use for HPs and utilization of biomass for heat generation, both of which are assumed to be not CO_2-neutral (further details below). Other emissions associated with heat generation, e.g., sulfur dioxide, ammonia, particulate matter, will also decrease greatly in the future contributing to better local environment, air and water quality.

1.3 Upgraded business models and social inclusion

We believe that in the future, the heat market will be characterized by digital solutions, a shared economy leading to new ways of conducting work and designing work places (impacting the use of buildings), customers that are actively engaged in their heat consumption (energy citizens) and owners of waste heat interested in capitalizing on the value of their heat sources (prosumers). At the DH company level, we believe that the key activities of DH companies will change from heat generation to distribution with increased flexibility allowed by means of TES solutions that can be charged and discharged when optimal. We foresee a future business model for DH where existing, high temperature DHNs are optimized to distribute heat within the central parts of cities, whereas less dense areas (newly built or refurbished) in the outskirts of cities resort to locally available heat sources in combination with heat distributed through the backbone.

As a result of the future development, it is likely that there will be an array of different business models applied by the DH operator in different parts of the city during different phases of the DHS transition. There will be a shift from a uniform business model to a diversity of models (engaging customers by motivational tariff (especially important to cut peak loads), engaging prosumers in a mutual win-win arrangement and optimization services). There is already a number of interesting initiatives (at Helen) to update the heat offer. Examples are renting out space for installed PV, provide district energy installation solutions outside of the Helsinki area (consultancy) and the “Heat promise” initiative undertaken to incentivize desired customer behavior by SMS communications on how to adjust the heating system. These initiatives indicate that energy as a service and end user engagement are already developments in Helsinki.

We identify that there are additional values than heat supply from using locally available heat sources. It is, for example, possible to establish a direct link between new heat generation solutions and the development of areas where the solutions are applied. The local heat recovery solutions can be performed including the residents in the areas. This will lead to increased knowledge level about energy and provide job opportunities both in the construction, operational and maintenance phases. We envisage that this kind of opportunity is especially relevant focusing on the young and international group of Helsinkians in the Eastern part of the city. This is an area with blended building stock, hosting post-war suburbs with apartment houses and old malls: a perfect place for implementing living labs to engage citizens, foster innovation and generate new knowledge. In the section on implementation below, we mention an energy highway being established. It is a highway to knowledge and engagement linked to an advanced energy hub (Vuosaari), locally based knowledge centers and socio-economically challenged residential areas, all joined together with a center for energy transition hosting different activities during the transition period.

There is a hurdle effect when it comes to changing a business model that is generating profit (the case for Helen). We suggest that the city of Helsinki appoints a facilitator team (organized as part of the city or as an own company). The facilitator team will be an important stakeholder for a successful transition and will be engaged actively in different parts of the transition (establishing secured investment funds, efficient procurement, efficient permit processes, ongoing modelling updates for delimitations of most efficient investment projects and other support such as facilitating business model development together with Helen). The facilitating team will also ensure knowledge building and involvement of citizens in the city focusing on the Eastern parts of it.

An approximation of full-time equivalent jobs created during the transition is 2550 jobs. These are arrived at when adding the facilitator team (a team of approximately 50 people), jobs created by energy empowerment of citizens in the vicinity to low temperature heat installations (400 people), energy educational measures/energy center development (100 people) and construction jobs (2000). Note that not all the construction jobs will be phased out after 2030. There will be growth of local companies taking part of the energy transition of Helsinki.

1.4 Suggested financing scheme

The investments needed for the energy transition in Helsinki are substantial and we find it likely that external capital is necessary. We suggest a pool of international investors to support the decarbonization of Helsinki across the entire transition period. With a long time-horizon, the investor pool will be informed about the progression of the city projects and can engage in the parts of it that suits its investment appetite.

Projects often suffer from a disconnect between technical project development and development of the structured finance options required for effective delivery of the technical solutions. Whilst this is less of a problem with business as usual investment, it is a significant challenge in projects breaking new ground or seeking to apply significant amounts of change in a short space of time (like the decarbonization of Helsinki). Also, projects can be subject to overpricing of finance where insufficient work is undertaken around risk mitigation; there is often a difference between perceived and actual risk when new solutions are to be implemented. We suggest that the facilitator team mentioned above builds the investor pool and supports the decision making of its partners to invest in the projects of the transition.

Already at the proposal stage we have identified 5 international investors' interest to partake in the investment pool. These investors are located in different countries (UK, Spain, Sweden, Luxemburg, Switzerland and Germany) but share the interest in green investments. We do not mention them by name here due to confidentiality reasons. Additional partners of relevance will be secured in the preparation stages during 2020-24 (an identification of interest in Finland and the Nordics will be the first step). The first, 5 potential partners have been made aware of the 4% real interest assumption when calculating the annualized investment but remain interested as the commitment of the city of Helsinki is viewed favorably and greatly reducing risk. An international investment pool can be an opportunity for the project to be seen as a world leading study in effective financing of decarbonization whilst also delivering results for the project itself. It will raise the profile of Helsinki with the international finance market, which is likely to be useful to the city in financing other activities.

Main stakeholders (the City of Helsinki and the DH operator Helen), will be able to identify the preferred financing alternatives and be part of a financially sustainable investment portfolio.

1.5 Innovative height

The suggested solution for Helsinki has a number of innovative features where the main aspects are related to (i) making use of waste heat both from industry and from low temperature sources applied to a number of areas in the backbone (DHS), (ii) shifting the business logic from centralized production to the DHS being a distributing unit where a number of heat sources are fed in, (iii) investing in solar thermal and other RES (like ambient heat) for DH linked to high temperature boreholes (that are shallow), providing significant flexibility potential for the DHS, and (iv) extend beyond technical innovation ensuring the creation of jobs, knowledge and increased social integration.

2. Climate impact

The proposed solution has a potential to greatly reduce CO_2 emissions, as well as other greenhouse emissions and pollutants, of heat generation in the DHS of Helsinki. Figure 4 shows the development of annual CO_2 emissions of heat generation in the DHS of Helsinki during the 2020-2040 period. It can be noticed that the CO2 emissions drop from around 2500 ktCO_2/yr in the Year 2020 to around 670 ktCO_2/yr in the Year 2025. Starting the Year 2030, annual CO_2 emissions of heat generation are estimated to be around 150 ktCO_2. In specific terms, the emission factor of heat generation is decreased from around 355 kgCO_2/MWh heat in the Year 2020 down to 100 kgCO_2/MWh heat in the Year 2025 and further down to around 25 kgCO_2/MWh heat starting the Year 2030.

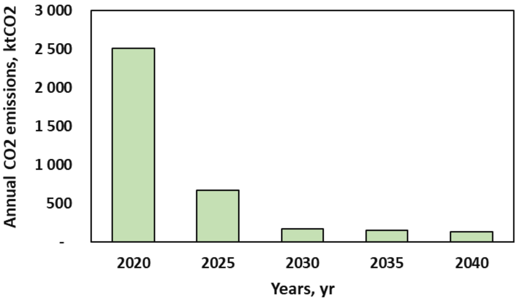


Figure 4. *The annual CO_2 emissions of heat generation in the DHS of Helsinki in the Years 2020-2040, as obtained from the optimization modelling.*

The main source of CO_2 emissions in the Year 2020 is coal-fired heat generation. By the year 2025, CO_2 emissions associated with coal firing are estimated to decrease 20-fold, while annual CO_2 emissions decrease only 4-fold. This is mainly due to the utilization of significant amounts of biomass in the Year 2025 (emissions from coal- and gas-firing are present, but smaller than from biomass), which helps the system to transition from primarily coal-based, in the Year 2020, to waste heat-based, in the Year 2030 and beyond. Starting in Year 2030, CO_2 emissions will be associated with the use of electricity for HPs as well as from the use of gas and biomass for covering peak heating demand. It can be noted that CO_2 emissions originated from the use of biomass are included in the balance above (Figure 4) but are not included in the total CO_2 cost presented in the Section 4 “Cost Impact”.

In addition to the CO_2 emissions, other greenhouse gas emissions and pollutants associated with the operation of the DHS of Helsinki in the future are also estimated to decrease greatly, as a result of the proposed solution. Total yearly emissions of sulfur dioxide (SO_2), for example, decrease from around 3.6 kt in the Year 2020 to just above 0.2 kt in the Year 2025 and down to nearly zero in the Year 2030. Emissions of ammonia (NH3) decrease 10-fold by the Year 2030, as compared to the Year 2020. Noticeably, emissions of particulate matter (PM2.5, PM10) increase from an average of 19 kt/yr in the Year 2020 up to an average of 30 kt/yr in the Year 2025. This is due to the higher use of biomass for heat generation. However, these emissions could be reduced by innovative pollutant abatement systems, which are actual topics of research. By the Year 2030, emissions of particulate matter are reduced to an average of 3.5 kt/yr. To summarize, all the emissions associated with heat generation in the DHS of Helsinki are expected to decrease significantly by the Year 2030, which should contribute to improved climate impact of the system.

According to the Greenhouse Gas Protocol, there are both indirect electricity emissions (scope 2) and other indirect emissions (scope 3). Assuming the suggested emission factor for the purchased electricity, the indirect emissions from the increased use of electricity are 56.4 ktCO_2 in the Year 2030, as compared to 10.2 ktCO_2 in the Year 2020. Please note that indirect emissions are included in the numbers presented in **Figure 4**: the model computes both direct and indirect emissions but we extracted the indirect emissions for your visibility here.

Regarding the scope 3, we identify that the main indirect emissions will be linked to the production of DH pipes and HPs. Based on an existing study we know that the emissions associated with the energy delivered by DH pipes is much greater than the actual energy required to produce DH pipes and therefore deem its effect as negligible (moreover in our proposal, the existing pipes can be used until their lifetime ends, without the need of special replacements). For the substations needed (HPs), their number will increase. But again, the same study indicates that the impact of producing HPs is negligible compared to the energy delivered. Therefore, we do not attempt to quantify the scope 3 for the DH pipes or the HPs in this challenge.

Key assumptions:

- emission factor for purchased electricity - 30 kgCO2/MWh (the number is suggested for the Year 2030 in the Background Material; we assumed the same factor for other years);
- emission factors for fuels are checked against the data provided by Statistics Finland and can be found in the Attachment, Tables A.1 and A.4.

3. Impact on natural resources

The main natural resource used is land. We foresee to locate most of the boreholes under the solar thermal parks. In the team, we have drilling experts with experience from drilling in the city of Espoo. They have assessed the land in the Malmi area and identified that there is approximately 15 meters of clay at early stages of drilling but that it should not impact the possibility to make boreholes in the area. No such complications have been identified in the location of Vuosaari. For the solar thermal parks, we estimated a total land use of 300,000 m2. We have identified areas where there is available land for these installations (Malmi and Vuosaari mentioned above).

We will resort to the resources of **solar and waste heat**. The availability of solar is not constrained to anything else than the available land and rooftop area. The solar parks will be yielding slightly less than 5 % of the Helsinki’s 2035 demand (see Figure 1). A common denominator for the waste heat sources is that they are currently wasted, making the possibility to phase out fossil fuels with the waste heat source a very sustainable alternative. The waste heat recovery will be performed with the help of different HP solutions. The access to waste heat can be limited. The waste heat at the Neste refinery and city owned buildings relevant for waste heat recovery will be secured first, to identify available heat volumes. Next, businesses that generate heat and that are interested in a win-win prosumer relationship will be secured. According to our estimates (we used local and international surveys about waste heat from, e.g., data centers, shopping malls, subways stations), urban low temperature waste heat sources (at temperatures of the order of 25 °C) are available at volumes enough to cover about 7 % of Helsinki's 2035 demand. This is part of the "Low temp. waste heat" item in Figure 1.

Besides solar thermal and waste heat, we expect a significant contribution coming from sea water and air sources, extracted using HPs. For Helsinki's conditions, sea water can be feasibly exploited only during some parts of the year: for the three coldest months (January-March) operation is assumed to be stopped (except in particularly warm years), but the use of seasonal TESs would allow to reuse in winter what was generated during summer. In this way, the intake pipes could be kept close to the shore, at depths in the range 10-35 m, with reduced costs. For air source, a similar limitation could occur, though the installation of air heat exchangers is expected to be generally easier than that of sea heat exchangers. It can be seen from Figure 1 that air source could contribute at about 25% of the demand, while a noticeably smaller sea source share is selected by the model.

The usage of HPs means that one fuel will be increasingly important: electricity. Estimated (modelled) annual electricity generation by the CHP plants in the DHS of Helsinki in the Year 2020 is around 2400 GWh, while the electricity consumption for heat generation in HPs is around 370 GWh. In the Year 2030, the estimated electricity generation in the CHP plants is estimated to drop down to around 200 GWh, while the electricity consumption can increase up to above 2250 GWh. This means that the DHS of Helsinki will be transformed from a net electricity generator with yearly net generation of around 2000 GWh/yr, into a net electricity consumer with yearly net consumption of around 2000 GWh/yr (effect on the electric power system of roughly -4100 GWh). Besides the yearly consumptions, it is also relevant to consider the peak power (see Capacity section). We understand that this poses a significant challenge for the electric power system of the city and even the country. Yet, Finland is building its third nuclear reactor in Olkiluoto-3, a process that is ongoing (to be taken into operation in 2022). It is also known that substantial wind power capacity is planned to be added to the Finnish energy system in the near-term future. In combination with a robust electrical system in Helsinki, the increased electricity demand over time should be manageable. If any reinforcements in the electric network will be required, we believe they can be identified by the local electric power operator. We propose to use HPs distributed across the city and cannot, at proposal stage, identify the need for reinforcement locations.

Biomass for covering peak demand and as a back-up. As biomass is deemed as an increasingly valuable energy source in the future, we propose to use it as a source for covering peaking demand and as a back-up (in addition to other capacities, see Section 8 for more details). Our modelling results indicate that the consumption of biomass for heat generation can be successfully reduced by as much as 5-fold by the Year 2030, as compared to the Year 2020, and amount to around 120 MWh of fuel annually.

Key assumptions:

- capacities of the electric power transformers and of the electric power network as a whole are not limiting the heat capacity of the proposed HPs;
- land available for the installation of land-based solar thermal is limited to 300,000 m^2;
- area of rooftops available for the installation of rooftop solar thermal is limited to 200,000 m2;
- land used for the borehole TES unit(s) is limited to 430,000m^2;
- land area for the installation of sea water and air HPs will be accessible;
- existing coal storage under the Salmisaari CHP plant will be available for refurbishment into a TES.

4. Cost impact

Table 1 shows the indicative annualized investment costs, fixed costs and operating costs for the DHS of Helsinki for the Years 2020-2044. In our solution, we propose to make most of the investments in new heat generation and TES capacities during the 2024-2029 period (no investments are allowed before the Year 2025 in the model). **By the Year 2030, the net present value (calculated for the Year 2020) of the future total annualized investment cost is estimated to be 63 MEUR.** The largest share of the annualized costs will be spent on the installation of the new heat generation technologies as well as for the installation of building-side HPs, required for the proposed network temperatures. Investments in the TES technologies will constitute around 12% of the total annualized cost. The total lifetime investment cost of the proposed solution is estimated to be 2024 MEUR.

Please note:

- Table 1 includes data computed by the applied optimization model (columns marked with "model") as well as "extra" costs assumed by the involved experts. The "extra" costs include investment and operating (O&M and electricity) costs for the technologies, i.e., HPs, required at the building side. The cost of building refurbishments (e.g. improved insulation, replacement of windows) are not included in our calculations since they are assumed to be accounted for in the decreased total energy demand in the future.

- The lifetimes of the proposed heat generation and TES technologies are not assumed identical: 25-30 years – for heat generation units, 50 years – for borehole and cavern TES, 18 years – for building-side HPs. Therefore, the sum of the annualized investment costs in the period 2024-2044 indicated in Table 1 is not equal to the total lifetime investment cost. Further, the investment costs in the building-side HPs during the 2040-2044 period are renewed (new HPs are needed to be installed).

The net present value of the total cost of heat generation, i.e., annualized investment, fixed and operating costs, in the Year 2030 is calculated to be around 165 MEUR. This can be translated into levelized cost of heat of around 25 EUR/MWh. Note that the levelized cost of heat also includes the cost of the generation equipment, but not administrative costs. For comparison, in the current system, fuel prices range from 11 (for coal) to 35 EUR/MWh (for pellets); adding the investment costs of the corresponding equipment one can expect a similar order of magnitude as the one presented above. From a different perspective, the price of heat for the DHS customers in the Year 2020 varied from just below 30 EUR/MWh during the summertime up to 53 EUR/MWh during the wintertime (taxes excluded). The difference between these costs and the abovementioned levelized cost of heat, shows that there is a reasonable margin for the system manager, possibly further improving the cost-attractiveness of district heat in the future.

Table 1 also shows that the proposed solution results in significantly reduced operating and fixed costs of the DHS of Helsinki in the future, as compared to today's values. In our calculations, we consider heat generation cost, profit from electricity sales (indicated with the minus sign in the table since reduce the total cost) and CO_2 cost as constituents of the operating cost. In turn, the heat generation cost consists of fuel and variable O&M costs, energy and CO_2 taxes. **By the Year 2030, the operating cost of the DHS of Helsinki is estimated to decrease by up to 3 times, as compared to the estimated operating cost in the Year 2020.** It can be noticed that the positive dynamics of decreased cost of heat generation and significantly reduced cost of CO2 emissions is followed by reduced profits from electricity sales generated by CHP plants. **The fixed cost of the DHS is also prognosed to reduce in the future.** This is due to the retirement of more expensive coal- and gas-fired CHP plants and their substitution with HPs, which have lower fixed costs. Also, this is due to the fact the total installed capacity of heat generation units is reduced and substituted with TES capacity (see Section 8 for more details).

Table 1. *The annualized investment costs, fixed costs and operating costs for the DHS of Helsinki shown for the Years 2020-2044 (in case of investment costs, also over the lifetime). All the values are indicated in MEUR. Investment costs are presented as net present values as of the Year 2020. Fixed costs are calculated as per installed capacity (per MW); operating costs are calculated as per generated energy (per GWh).*

MEUR	**Annualized investment cost (model)**		Annualized Investment cost (extra)	**Fixed cost (model)**	**Operating cost (model)**			Operating cost (extra)
	Heat generation	TES units	Building-side HPs		Heat generation	Electricity sales	CO2 cost	Salaries, operation of building-side HPs
2020	-	-	-	43.2	257.8	-87.3	55.5	
2021	-	-	-	43.2	257.8	-87.3	55.5	
2022	-	-	21.1	43.2	257.8	-87.3	55.5	9.2
2023	18.0	5.7	21.1	43.2	257.8	-87.3	55.5	9.2
2024	30.6	5.7	21.1	43.2	257.8	-87.3	55.5	9.2
TTL 2020-2024	**48.6**	**11.4**	**63.2**	**216**	**1289.0**	**-436.5**	**277.5**	**27.7**
2025	30.6	5.7	21.1	38.3	114.9	-15.3	5.3	9.2
2026	30.6	5.7	21.1	38.3	114.9	-15.3	5.3	9.2
2027	30.6	9.1	21.1	38.3	114.9	-15.3	5.3	9.2
2028	30.6	9.1	21.1	38.3	114.9	-15.3	5.3	9.2
2029	30.6	9.1	21.1	38.3	114.9	-15.3	5.3	9.2
TTL 2025-2029	**158.8**	**38.7**	**105.3**	**191.5**	**574.5**	**-76.5**	**26.5**	**46.2**
2030	33.0	9.1	21.1	24.5	76.2	-10.3	2.6	9.2
2031	33.0	9.1	21.1	24.5	76.2	-10.3	2.6	9.2
2032	33.0	9.1	21.1	24.5	76.2	-10.3	2.6	6.2
2033	33.0	9.1	21.1	24.5	76.2	-10.3	2.6	6.2
2034	33.0	9.1	21.1	24.5	76.2	-10.3	2.6	6.2
TTL 2030-2034	**165.0**	**45.5**	**105.3**	**122.5**	**381.0**	**-51.5**	**13.0**	**37.2**
2035	33.0	9.1	21.1	19.2	58.3	-7.6	2.2	6.2
2036	33.0	9.1	21.1	19.2	58.3	-7.6	2.2	6.2
2037	33.0	9.1	21.1	19.2	58.3	-7.6	2.2	6.2
2038	33.0	9.1	21.1	19.2	58.3	-7.6	2.2	6.2
2039	33.0	9.1	21.1	19.2	58.3	-7.6	2.2	6.2
TTL 2035-2039	**165.0**	**45.5**	**105.3**	**96**	**291.5**	**-38.0**	**13.0**	**31.2**
2040	33.0	9.1	21.1	15.8	44.8	-7.6	1.9	6.2
2041	33.0	9.1	21.1	15.8	44.8	-7.6	1.9	6.2
2042	33.0	9.1	21.1	15.8	44.8	-7.6	1.9	6.2
2043	33.0	9.1	21.1	15.8	44.8	-7.6	1.9	6.2
2044	33.0	9.1	21.1	15.8	44.8	-7.6	1.9	6.2
TTL 2040-2044	**165.0**	**45.5**	**105.3**	**79**	**224.0**	**-29.0**	**9.5**	31.2
TTL investments over lifetime	**817**	**449**	**758**					
	2024							

<u>Key assumptions:</u>

- Discount rate 4%;
- Electricity prices in the Years 2020, 2025, 2030, 2035 and 2040 are on average 32, 35, 40, 40, and 40 EUR/MWh. The reference hourly electricity price profile was extracted from the NordPool website for the Year 2016 and then adjusted to fit the average electricity price values in the respective years. The duration curves of the used in the modelling hourly electricity prices can be found in the Attachment, Figure A.2;
- Electricity grid fee (applied to HPs) was extracted from the Helen website;
- CO_2 emissions allowance cost (international market, not the same as CO_2 tax) was assumed to be 25, 30, 34, 40, and 45 EUR/MWh in the Years 2020, 2025, 2030, 2035 and 2040, respectively. The gradual increase of the cost is in line with the current global trend;
- Investment costs for the Neste waste heat, low-temperature waste heat sources, air and sea water include the cost of HPs required for their exploitation;
- For decentralized HPs in buildings we assume: 1) 70 % of the buildings in the city remain non-refurbished, supplied at 70°C, and are endowed with HPs sized at 30 % of peak power, used to boost the supply-return temperature difference only under peak conditions; 2) 15 % of the buildings are refurbished, supplied at 25 °C, and endowed with full size HPs; 3) the remaining 15 % of the buildings are refurbished, supplied at 70°C, and without HPs. Investments costs assume a specific HP cost of 500 EUR/kW. Yearly O&M costs (excluding electricity) are 3 % of the investment costs.
- Salaries for the facilitator team staff are calculated based on the assumed average salary of 5 kEUR/month for 50 people over the period of 10 years;
- Other assumed data, i.e., fuel prices, variable O&M costs, energy and CO2 taxes are based on the info provided by Statistics Finland and in the competition instructions and can be checked in detail in the Attachment, Tables A.2 and A.5.;

5. Implementation Schedule

We have split our proposal into phases: (1) 2021-2024 (start-up), (2) 2025-2029 (consolidated implementation), (3) 2030-2034 (validation) and (4) 2035-2040 (stabilization). Several investment projects are initiated in phase 1 and further developed to reach full potentials in phase 2. Therefore, the risks associated with phases 1 and 2 are similar. The risks are summarized for both phases at the end of the description of phase 2 (5.2). The two first phases reflect more activity than the two latter. An implementation schedule summarizing main activities is included at the end of this section (5.4). There we also include maps showing the energy transition over time.

5.1 2021-2024: Start-up Phase

5.1.1 Modelling, financing and permits

During 2021, the facilitator team is established (built up around key competencies in the areas of energy systems modelling, infrastructure finance and due diligence processes, DH operation and business model development, solar thermal expertise, HP expertise, borehole expertise, waste heat recovery expertise and local assets including city representation from Helsinki). The team further develops the modelling results from 2020 and a larger number of iterations are made to further fine tune the investments to be made: they will be delimited in rational investment projects (2021). A procedure for procurement is put in place (2021). The permits needed are identified as the investment projects are defined and the process of applying for permits is started (2021). Also in 2021, the establishment of the investor pool is initiated and the financing for different investment projects is planned.

In this period, foreseen investments (decided before the Helsinki Challenge) are undertaken. These include the seasonal TES unit foreseen in Mustikkamaa (former oil cavern: 2021) and Kruunuvuorenranta (rock cavern: 2024). The installation of Sea HPs (in operation 2022) and biomass-fired HOB (in operation season 2022-23) in Vuosaari and Vantaan Energia is also taking the operation of the new waste to energy plant into operation (2023), providing waste heat to Helsinki. We assume that new TES units mentioned above can store the heat from

Vantaan Energia at this point in time. One large unit is foreseen to be phased out: Hanasaari CHP (2024).

5.1.2 Preparatory works

Preparations are made of the foreseen sites for (i) Neste pipeline, (ii) seasonal borehole TES units, iii) solar parks, (iv) lower temperature of backbone DHS, (v) make use of buildings for TES, (vi) low temperature areas and (vii) installation of air- and sea water-based HPs.

i) **Neste heat recovery** Identification of landowners to contact for permission to cross land/acquire land is made and land is secured. The business arrangement with Neste is identified, the idea is that Helen makes the investment in the pipeline and that Neste provides the waste heat for free. Neste would gain a positive image, a stronger binding with the territory, and slightly reduced cooling costs (the operation of the sea-based cooling system could be reduced). Other users of the waste heat are identified and potential business arrangements with them are made. The necessary permits are identified and initiated. Neste waste heat recovery will be operational in 2030.

ii) **Borehole TESs** Implementation of the TES units is foreseen to be undertaken within two different time spans. Half of the borehole TES volume will be ready for use in 2025, whereas the other half will be ready for use in 2030. The ground preparations include preparations for the installation of solar thermal on top of TES. The boreholes will act as flexibility reserves being charged and discharged continuously from solar thermal (see next). The idea is to make the borehole TES units first, then prepare the ground for construction works to finally mount the solar thermal panels. In total, it is approximated that we need 430,000m^2 of land area for the total foreseen borehole investments. The foreseen area for solar thermal parks is 300,000m^2 (see more below), and 130,000m^2 of land for the borehole TES units are foreseen to be placed under ground in the area of Salmisaari CHP when it is dismantled (see more in 2025-29). In 2021-24, boreholes are installed under the Vuosaari solar thermal park (150,000m^2, to be operation in 2025) and first drillings (corresponding to 50,000m^2) are made in the area of the second foreseen solar thermal park of Malmi (this solar park is not foreseen to be operational until 2030 but work in this area is initiated in 2021-2024 and ongoing until 2029). According to our discussions during the challenge, other areas for the installation of ground TESs could be identified, especially in the city outskirts (sports areas, green areas) but also close to the city center (parks, which could be fully restored after drilling). Hence, the above places have to be considered as promising examples, but in case they should not fit with city plans, alternative options could be chosen. It is also worth noting, that while the total drilling length is large (estimated at 6730km: average length of a borehole being 200-300 meters), the planned time is fully in line with the experience from Northern countries.

iii) In combination with the borehole TES, **solar thermal parks** are designed and one of the foreseen sites (by 2030 two sites are foreseen) will be taken into operation in 2025 (placed on top of the first boreholes: location Vuosaari). This park reflects half of the surface of solar thermal foreseen in Helsinki (e.g 150,000m^2 out of 300,000m^2). In Vuosaari, there is much land available and it is a good location close to other energy activity. Based on experiences in the team, a solar park of this size is possible to construct in in the time range of 1.5-2 years making 2025 feasible. Also, half of the rooftop installations are foreseen to be operational in 2025 (e.g. 100,000m^2 out of 200,000m^2). The remaining solar installations will be operational by 2030.

iv) The existing DHS piping will be kept. To the DHS, heat will be fed from a number of sources transforming the focus of the DH business from heat production to distribution and making use of locally available heat sources. **The targeted temperature for the backbone is 70°C/30°C (for increased efficiency of HPs and future, increased use of low temperature heat sources)** and in essence it remains with limited reconfigurations. Instead HPs are placed to make the interaction with the LT sources and Neste efficient (more on the backbone transition is found under key technologies in Attachment, Subsection 1.2.). Areas of the network, with a large availability of local low-temperature sources are expected to be run at lower (neutral) temperature. The lower supply temperature with respect to current levels is considered crucial to get an economically convenient access to low-temperature sources (like sea source, of the order of a few Celsius degrees). Concerning the low-return temperature, this might be unfeasible for non-refurbished buildings. Hence, special substations including small decentralized HPs to boost the supply-return temperature difference are planned. These substations could also be endowed with cheap and easy-to-install electric heaters, for short operation (1 % of the time) during peak conditions (the corresponding impacts on the electric demand are taken into account in our estimates). The targeted 70/30 temperatures are in place by 2025.

v) Investments will also be made to use **buildings as TES**. Thermal mass of buildings can be successfully used for storing heating energy. Conceptually, this is done by temporality "overheating" (supplying more heat than required) with the followed "underheating" (supplying more heat than required) of a building, i.e., making the indoor temperature to vary around the set-point value (e.g., ±1 ºC). Using this principle, a significant amount of energy can be saved in buildings and used for successful peak-cutting of the demand. In our proposal, we propose to start making investments in buildings and DH substations, required for the usage of buildings as TES, already in 2021. First, the suitable buildings/locations are identified and then the investments are undertaken. The buildings will start to be used as TES in 2025. By that time, we assumed that 10% of the heated floor area of Helsinki can be used (5 mln.m^2 of the heated floor area). As a result of continuous refurbishment activities, we foresee another 22.5 mln.m^2 to be used by 2030 and the remaining building stock will be used by 2035 (50 mln.m^2 of the heated floor area).

vi) **Low Temperature District Heating areas (LTDH)** We foresee to section parts of the existing DHS into low temperature areas. This is, for example, being done in the city of Albertslund in Denmark and we will resort to hydraulic separation using shunts to arrive at desired temperatures. We foresee neutral temperatures in these areas with 25°C supply and 5°C return, so that direct integration of low-temperature sources is possible. Work will be initiated to identify the existing building stock in need of refurbishment to allow it to use the low temperature sources. Also, dialogue is taken with areas that are foreseen to be built new to make sure they are accommodated for LTDH. HPs with high COP values will be installed at the building level. Legionella will be avoided keeping separate circuits and temperatures for domestic hot water preparation and space heating. With neutral-temperature networks, losses are minimized and HP performances are maximized, raising the temperature only up to the needed level at the right place. The share of privately owned buildings will be kept at the lowest level possible to allow as rapid progression as possible. In the cases where there are private owners, the facilitator team will engage to identify commercially viable business solutions for both energy provider and building owner (again, the core idea is for Helen to make the infrastructure investment and the waste heat owner to provide it free of charge). For example, due to the significant investment cost of HP substations, it would be convenient that the network manager keeps their ownership and only charges the user of proper heat costs. This option would also allow a centralized control of the HPs, possibly matching their operation with lower electricity prices (e.g., higher wind production; this is one of the practical examples where digitalization and remote control would play a key role). We will have half of the volumes foreseen from low temperature heat sources (i.e., 30MW of 60 MW) in operation by 2025 and the other half by 2030.

We foresee 7 LTDH areas as outlined in the table below. Jointly these decentralized heat solutions will provide heat to 103 000 inhabitants and 36 000 office spaces. The low temperature systems will be partially fed by the backbone (50% of annual heat demand) and partially by local heat sources making them a flexibility reserve (yet, these local heat sources are included in our overall balance, **Figure 1**). In the first round of implementations we foresee that Malmi and Pasila: two areas in active exploitation as well as the two areas in the Eastern parts of Helsinki (referred to as Energy Highway 1 and 2 below) are operational by 2025. As construction progresses in the other areas presented in the table, so will the LTDH installations: ready to be taken into operation in 2030.

Table 2. *The LTDH areas*

Low temperature DH areas	**Inhabitants connected to LTDH**	**Offices**
1. East-Helsinki Energy Highway (1) Puotinharju-Itäkeskus-Puhos the “business stop”	5000	
2. East-Helsinki Energy Highway (2) Myllypuro- Kontula-Kurkimäki, the “knowledge stop”	5000	
3. Pasila	20000	20000
4. Malmi	20000	
5. Jätkäsaari	20000	6000
6. Kalasatama	20000	10000
7. Kruunuvuorenranta	13000	
	103 000	**36 000**

Our idea is to use decentralized solutions to generate knowledge about energy as well as jobs in the vicinity. In Eastern Helsinki, we foresee an “**energy highway**” starting at the top notch Vuosaari energy hub. Between the energy hub and a strong educational environment (for example Metropolia University of Applied Sciences and Stadia Helsinki Vocational College) the energy highway goes through the area of Myllypuro an area of great potential for knowledge growth, job creation and social integration. At the Vuosaari energy hub we foresee the construction of a knowledge center accommodating visitors (see more below).

In **the first highway stop (Puotinharju- Itäkeskus- Puhos)**, “the business stop”, refurbished residential multifamily buildings will be ready for LTDH that will be fed by heat from the metro, the swimming hall of Itäkeskus, and shopping malls (Itis, new Puhos and Easton). The facilitator team will work with the local businesses to generate innovative business cases: incorporating data centers, vertical farms or other excess/waste heat suppliers inside shopping malls creating new and exciting business opportunities that shift shopping malls to food and energy providing units.

In **the second highway stop** (Myllypuro Kontula-Kurkimäki), “the knowledge stop”, a close interaction with Metropolia University of Applied Sciences and the Stadia Helsinki Vocational college (both located in the vicinity) is feasible. Refurbished city owned residential buildings as well as new residential buildings will together create area that can utilize low temp sources such as Helsinki metro, ground HP, and the local swimming and sport halls (Kontula, Myllypuro).

For **Pasila**, a development area with a significant amount of new residential and offices buildings being erected (densely), in 2010-2040, the possibility to renovate city owned buildings in East- and West-Pasila (450 apartments) and the buildings of Yle (the national broadcasting company) should be important. Low temperature waste heat will come from the Tripla shopping mall, the Hartwall Arena, the Helsinki Ice Hall, Meira/Paulig roastery, the Messukeskus Helsinki, Expo and Convention Centre and the Mäkelän rinteen swimming hall. This network will be connected to the backbone through the Alpilla HOB.

In **Malmi**, a new area is being erected (2022-2035). It will be the home of approximately 25 000 people. At Malmi, a solar thermal park is foreseen. It will be linked to the backbone through the Patola HOB.

Jätkasaari will be completed in 2030. There, it is relevant to recover heat from the Ruoholahti shopping mall, Helsinki metro, and connection to Salmisaari sea water HP. The proximity to the former coal TES of Salmisaari allows for heat TES for this area in this refurbished TES. We suggest a connection to the backbone by means of the Salmisaari HOB.

There is an area in the central part of Helsinki (new buildings ready in 2040) with several large freezers and coolers available at Tukkutori (**Kalasatama)**. The cooling waste heat will be combined with heat from a nearby shopping mall. The Katri Vala HP station will be the link to the backbone (we aim at recovering existing pipelines from the Hanasaari power plant to be decommissioned).

In **Kruunuvuorenranta** Here a residential area is planned for.The heat source is solar on roofs and the backbone connection will be at the Vuosaari HOB connection point.

vii) Heat Pumps harvesting heat from air and sea water are invested in. Based on model iterations it has been identified that approximately 450 MW from of air and sea water HP capacity is optimal for the system in total. In 2025, 350 MW of air source HPs and 100 MW of sea water HPs will go into operation. There is a risk that the output capacity of the sea water HPs will be reduced if the entering sea water temperature falls below +2 °C during the Winter period (January-March). This risk has been accounted for in the modelling runs. The air source HPs will be placed in the Malmi area at an energy station erected in the vicinity of the first fraction of Malmi boreholes (50 000m2 operational in 2025) and solar plant (that comes into operation in 2030). This way the energy area of Malmi is initiated with new units going into operation in between 2025 and 2030. The sea water-based HPs will be placed in the area of Salmisaari (and possibly Vuosaari). The air-based HPs will be placed in the Malmi development area.

5.1.3 Knowledge generation

In 2021, the facilitator team engages in dialogue with relevant knowledge communities on the foreseen buildup of the “energy highway to knowledge”, the linked knowledge center and foreseen activity to build the energy capacity of residents in the areas where LT areas are foreseen. An outline of scope, size and content of the knowledge generation (one pathway is energy transition of cities) will be established by 2022. It is foreseen that the center will be ready to use by 2024 to actively showcase the many investment projects undertaken. It is established by the facilitator team and the city of Helsinki jointly.

5.2 2025-2029: Consolidated implementation Phase

5.2.1 Modelling, financing and permits

The masterplan of the transition will be updated with information as investment projects are identified and implemented. Further model runs will support efficient design of the upcoming investments: hence the modelling activity will be continued. As investment projects are undertaken, the risk profile of remaining projects will change (risks will lower) and an ongoing activity is undertaken to maintain the investor pool, informing its partners about the profile of upcoming investments. New investment projects will necessitate new procurements and permits. Securing both is therefore an ongoing activity.

In this period, coal fired Salmisaari CHP (2029) is phased out.

5.2.2 Implementations and further preparations

(i) Neste heat recovery In 2026-2029, the construction is assumed to occur. Then, in 2030 the waste heat will be recovered into the backbone DHN. From the background information we know that there is a volume of 1000MW available at 30°C. However, to mitigate the risk of Nestle shutting activity down and allow other stakeholders in the vicinity to use part of the available heat we have assumed that 300MW can be recovered by means of a pipeline from Neste plant in Kilpilahti to the current placement of the Vuosaari units (30 kilometers).

(ii) Boreholes and (iii) Solar thermal We foresee two solar thermal parks to be in operation by 2030. The first one is the one mentioned in the previous phase located in Vuosaari (in operation 2025). The second one is foreseen for the Malmi development zone, it will be feeding the boreholes beneath and it can be connected to the HOB of Patola in the backbone. The park measures150,000m^2 and is feasible in Malmi where there is land availability. Under the park, there will be one of the borehole TES units occupying the same land area. 50,000m^2 are already developed and operational by 2025 when the air HPs in the same location are taken into use. The remaining 100,000m^2 of boreholes are installed to be operational in 2030: at the same time that the solar thermal plant is operational.

In 2029, when the Salmisaari CHP is dismantled, we also invest in the remaining borehole TES units needed in that location. The holes will need approximately 130,000m^2 and will be placed into the ground before any other exploitation of this land is made. These boreholes are important to ensure that the city center can obtain heat continuously also during cold winter months. The boreholes are fed by the heat from the sea HPs installed in the Salmisaari area in 2021-2024 and operated starting 2025 (see above). We have identified that there is a coal storage under the Salmisaari CHP. When it is decommissioned in 2029, the cavern will be refurbished to be used as a TES. This refurbishment and the 130,000m^2 borehole TES units will be synchronized.

The model also invests in solar thermal using rooftop space. These collectors will predominantly be placed in the harbor area of Kruunuvuorenranta where substantial construction is foreseen (making the inclusion of the collectors feasible at planning stages), (100;000m^2). Roof collectors are more expensive than solar fields on land: if the Helsinki municipality could identify larger spaces on land than what is planned in this proposal, it would be convenient to substitute roof-top installations with more field installations. Some of the collectors will also be placed along highways to improve the landscape and generate heat. A test stretch is suggested between Vuosaari area and Itäkeskus (8,000 m2).

iv) LTDH Remaining, foreseen LTDH will be prepared as described in the previous section. The remaining, foreseen volumes (30MW) will be operational in 2030.

5.2.3 Knowledge generation

The creation of knowledge, jobs and social integration is foreseen to follow the transition of the city. By 2025 there will be an active energy center implemented to serve as the hub for disseminating and generating new knowledge on the energy transition of cities. It is to this hub (located in Vuosaari) that the residents in the LTDH areas outlined will be linked. It is managed by the facilitator team and the city of Helsinki jointly.

In the table below, key implementation risks, foreseen mitigation of them and their impact on the implementation schedule are outlined for 2021-2024 and 2025-29. The risks are identified for the modelling/financing/permit activities and for the investment projects. There are, however, several risks generic to the implementation of construction projects. These are added last: it is among those that the most probable risks are found (e.g. none of the investment projects is riskier than the others).

__Table 3.__ The key implementation risks 2021-2029

Risk factor	Probability (1-5: 1 low and 5 high)	Risk mitigation foreseen	Impact on implementation schedule
Modelling, financing and permits			
1.Wrong project delimitation & risk assessments	1. P(3)	1.Due diligence performed jointly with financial and DH expertise (facilitator team) and modelling iterations	2-3 months
2. Low interest to invest- not enough investors to cover investment projects	2. P(2)	2. Identify (2021) and keep (2022-29) investors with interest in sustainable cities	2-3 months
3. Permits overlooked- delays or simply slow permit procedures	3. P(4)	3. Active permit management (2021-2029)	2-6 months
Investment projects			
i. Neste: Agreements not met -contracts with landowners, Neste, other potential users of the waste heat (2021-24) -lower volumes possible than foreseen (2025-29)	i. P(2) i. P(1)	i. Active and efficient contractual process by facilitator team (2021-24)/ upgraded investment case (2025-29)	6 months 2 months
ii. Poor ground conditions or land cannot be obtained: delayed operation of TES the TES units- postponing seasonal TES possibility	ii. P(2)	ii. Shallow boreholes can be made almost anywhere (experience from experts in the team), just a matter of redesigning them if needed (inclinations etc). (2021-2029)	2-4 months
iii. Delayed boreholes will delay solar thermal park	iii. P(2)	iii. Close synchronization between borehole and solar projects (2021-29)	2 months
iv. Not possible to reach 70/30 in backbone	iv. P(1)	iv. Alternative solutions for optimizing the buildings are identified and installed and booster HPs; (2021-24)	2 months
v. Not all foreseen buildings can be used as a TES	v. P(2)	v. The amount of buildings used as TES is remodeled and investment projects are upgraded (2021-24)	2 months
vi. Not all foreseen buildings can use LT	vi. P(1)	vi. Individual buildings are included in the LT context but with booster HPs installed (2021-29)	2 months
vii. Difficult to identify efficient locations for HPs	vii. P(1)	vii. Locations for HPs are flexible, a question of upgraded investment plans (2021-29): foreseen locations should be large enough	2 months
viii. Foreseen investments before the Helsinki Challenge are delayed- delaying the transition plan	vii. P(1)	viii. Adjust the foreseen timeplan to make use of new investments in the DHN in the most efficient way possible (2021-29)	4-6 months
Knowledge generation			
Delayed erection of energy knowledge center	P(1)	Identification of most crucial activities for boreholes, HP installations and LTDH implementation around the energy highway and knowledge generation: these are activities are advanced first (2021-24)	2-4 months
Generic risks to construction projects			
1.Shortage of companies to implement investment projects	P(2)	1. Efficient preparation phase 2021-2024	2-4 months
2.Not enough manpower with capability to implement innovative schemes (LTDH, high temperature boreholes)	P(3)	2. Build necessary capacity in preparation phase 2021-2024 (part of energy knowledge center buildup)	2-4 months
	P(5)	3.Map review with city units	2-6 months

3. Broken cables (water, electricity)			
4. Shortage of electricity: much work ongoing	P(3)	4.Identification of access and plan of project progression /add shifts if needed to avoid delays	1-2 months
5.Amendment and additional works	P(5)	5.Efficient contracts for change management	2-3 months
6. Emissions occur during construction phases	P(3)	6. It's important to keep track on the emissions during installation of our solutions. With knowledge and evaluations during the implementations the indirect emissions can be minimalized.	NA

5.3 2030-2034: Validation phase

The third phase is a validating phase. It is characterized by the activities (i) backup reconfiguration and (ii) knowledge generation.

5.3.1 Backup establishment

Considering requirements for resilience and security of supply, our solution includes several peak-load covering and back-up heat generation units. This function will mainly be served by the existing and planned biomass-fired Salmisaari and Vuosaari HOBs, along with natural-gas fired Vuosaari, Patola and Myllypuro HOBs and the light fuel oil-fired Alppila HOB. The total capacity of those units will be 1105 MW. Alppilla is run on light fuel oil but this will be replaced by biodiesel.

When we remove the CHPs in Hanasaari and Salmisaari, electricity generation is significantly reduced. To not remove all electricity generation capacity, we keep the Vuosaari gas CHP.

The investments undertaken in 2021-2029 lead to complete removal of coal in the DHN of Helsinki which was the goal of the Helsinki Challenge. In the validation phase and later in the stabilization phase we suggest refurbishing the mentioned backup HOBs and the gas fired CHP in Vuosaari. We suggest phasing out the demand for natural gas to ensure future energy security. We would suggest the establishment of a liquid natural gas (LNG) terminal in the harbor and an LNG storage in Vuosaari. This investment has not been quantified for the challenge and is a suggested further (post 2030) development for a stable and resilient DHN in future Helsinki.

5.3.2 Knowledge generation

The energy center is by now well established and has generated significant output on energy transition in cities. It is maintained to ensure local participation around future energy solutions and can serve as a test bed for future, innovative energy solutions for Helsinki in the decades that come. It has also established an international network making it a global driver of city energy transition. The administration of the center is phased out from the facilitator team to the city of Helsinki.

5.3 2035-2040: Stabilization phase

5.3.2 Preparations to phase out waste heat from Neste

In this phase, we have validated the installed equipment and it is time to stabilize the system. No further investments are undertaken for new implementations. However, first preparations for the potential phase out of the waste heat from Neste are undertaken. This activity is foreseen as it is questionable if refineries will remain post 2050.

5.4 Implementation schedule for the energy transition of Helsinki

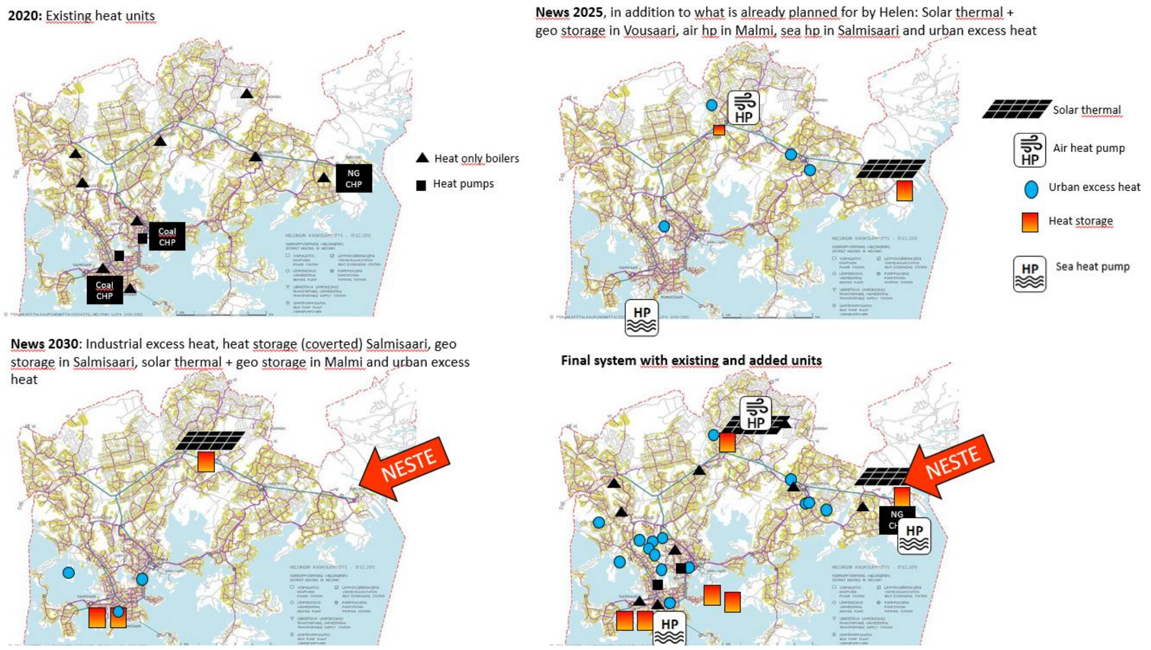
Most of the main tasks mentioned above are reflected in tasks to be performed for the Helsinki transition. The chart shows how to progress with different activities over time to arrive at installed units that can be used for heat generation and storage. Preparatory activities are marked in lighter green and operational activities are marked in darker green. The x in each colored area indicates that there is ongoing activity. The main parties are Facilitator Team (FT), Helen (H), Procured parties (P) (see more on stakeholders in section 6).

x	Preparatory activity
x	Ongoing operation of unit

Table 4 Implementation schedule

Main parties: Facilitator team (FT), Helen (H), Procured resource (P)		Phases	2021-2024				2025-2029					2030-2034					2035-2040					
		Years	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Modelling, financing and permits																						
Main parties	**Main steps**																					
FT	**Task 1**	Modelling iterations on an ongoing basis to refine investment project delimitations																				
FT	**Task 2**	Establish investment projects and install/ maintain investor pool																				
FT	**Task 3**	Establish & maintainan efficient procurement structure																				
FT+H	**Task 4**	Identify necessary permits and establishing efficient processes for obtaining them																				
Investment projects																						
Main parties	**Main steps**																					
	Task 5	**Neste**																				
FT+H		-contract, aquire land, agreement with other interested parties	x	x	x																	
FT+H		-permits		x	x	x																
P		-construct pipeline				x	x	x	x	x	x											
H		-operate										x	x	x	x	x	x	x	x	x	x	x
	Task 6	**Boreholes**																				
FT+H		-design (for first and second half)	x	x			x	x														
FT+H		-permits (for first and second half)		x	x			x	x													
P		-install (first and second half)			x	x			x	x	x											
H		-operate (first half start is marked in bright green and start of second half/ full operation is marked with darker green)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 7	**Solar thermal**																				
FT+H		-design (for first and second half)	x	x			x	x														
FT+H		-permits (for first and second half)		x	x			x	x													
P		-install (first and second half)			x	x			x	x	x											
H		-operate (first half start is marked in bright green and start of second half/ full operation is marked with darker green)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 8 Building used as storage																					
H		-identify buildings and implementations	x	x				x	x				x	x					x	x		
H		-install		x	x	x			x	x	x			x	x	x				x	x	x
H		-operate (scaled up gradually from 2025)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 9 Backbone temperatures lowered																					
H		-actions identified	x	x																		
H		-install		x	x	x																
H		-operate (70/30)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 10 LTDHs																					
H		-prepare buildings (including HP installations at buildings)		x	x	x			x	x	x											
H		-prepare low temperature sections of DHN		x	x				x	x												
H		-permits		x	x				x	x												
FT+H		-secure heat sources		x	x				x	x												
FT		-empower locals for operation		x	x	x			x	x	x											
H		-operate (first half is marked in bright green and start of second half/full operation is marked with darker green)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 11 Heat Pumps																					
FT+H		-identify configuration and locations	x	x																		
FT+H		-permits	x	x	x																	
H		-install			x	x																
H		-operate					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 12 Refurbish Salmisaari coal storage/cavern																					
H		-permits							x	x	x											
H		-refurbish									x											
H		-operate										x	x	x	x	x	x	x	x	x	x	x
	Task 13 Erect Energy Knowledge Center in Vuosaari																					
FT+H		-design	x	x																		
FT+H		-permits	x	x																		
H		-erect		x	x																	
		-operational				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Task 14 Refurbish Vuosaari CHP to LNG and upgrade backup HoBs to LNG: Optional																					
H		*-design*											x									
H		*-permits*												x								
H		*-refurbish*													x							
H		*-can be used for backup (in refurbished mode)*														x	x	x	x	x	x	x

In the maps below we provide a schematic illustration of the transition. The first picture shows current heat generation units. The second illustrates new heat sources in 2025. The third identifies new heat sources in 2030 and the fourth and last picture shows the final energy system of Helsinki with existing and new units aggregated. In the last picture we have depicted the future pathway of an increasing number of low temperature heat sources being harvested.

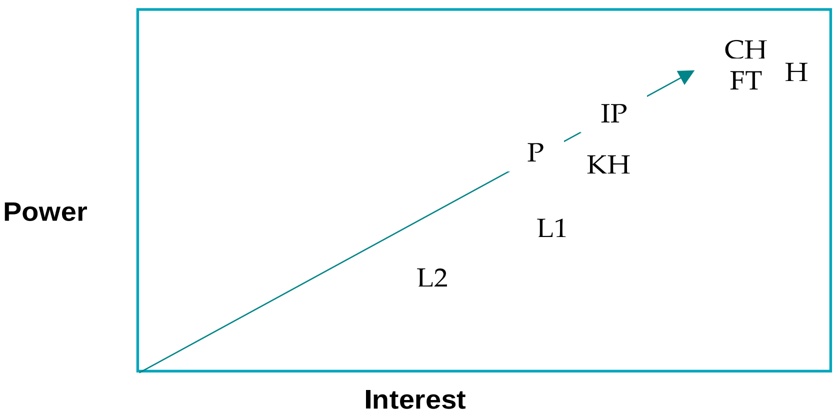


6. Implementation feasibility

The main stakeholders of the Helsinki energy transition are presented (6.1), and the feasibility of the suggested solution is addressed (6.2).

6.1 Main stakeholders for the Helsinki energy transition

Above, main parties involved in implementing the transition have been mentioned. These are the Facilitator Team (FT), the City of Helsinki (CH), the current DH operator Helen (H), the Investor Pool (IP), the procured parties (P), the knowledge hub generation parties (KH) and locals (both engaged in the transition itself): L1 and experiencing the transition (L2). Stakeholders in projects are often mapped as primary or secondary stakeholders where the interest in the project and the power to impact the project is highest with the primary stakeholders. For the mentioned stakeholders the situation is the following in the Helsinki transition context:



This means that the stakeholders most crucial to make the transition happen are Helsinki City, Helen and the Facilitator Team. The FT will be created to support the transition and it is imperative to identify the right competencies for the team. On the other side, the inhabitants of Helsinki will need to be informed about the progression as they have high interest in it and as it affects their everyday lives (heat is a basic need).

6.2 Feasibility assessment based on six factors

Feasibility of the suggested transition is made based on the six outlined factors: (i) technical, (ii) financial, (iii) legal, (iv) administrative, (v) cultural and (vi) ethical.

6.2.1 Technical feasibility

The proposal is built on a combination of different technologies. None of the technologies is new (shallow boreholes, solar thermal, waste heat recovery and HPs). What can be a barrier, is the capability of local installers to undertake the work, which necessitates an efficient procurement process (foreseen). The feature to charge shallow boreholes with high temperatures is less common than charging at lower temperatures but based on the expertise of our team members in this field, this should not be linked to any specific barrier. The land usage has also been accounted for and is managed efficiently; not seen as a barrier for the implementation of the foreseen technologies.

In our analysis we considered all the needed technologies to adjust the operating temperatures in the backbone and existing buildings, mainly through HPs, in order to achieve the right transmission power in all the needed conditions keeping the existing pipes. This facilitates the introduction of the new units into the backbone.

Our suggested solutions are flexible and several of our proposed technologies could be re-evaluated in the coming years. For example, the capacity of the sea water HPs could be increased if the first operational experience or future technological improvements would show better performances than expected. The diversification of our source portfolio offers the benefit of exploring multiple paths, with the time to adjust planning in blocks of about 5 years (further facilitated by the foreseen ongoing modelling activity).

6.2.2 Financial feasibility

We suggest an investor pool, which secures a match between the investment projects and the most relevant investors. There will be no delay as a result of shortcomings of funds during the active years 2021-29. Also, the main stakeholders (CH and H) will be able to identify the preferred financial risk level and be a part of a financially sustainable investment portfolio.

In terms of investment costs, they are in the range expected for this kind of project (see section 4). Also, our solutions can further improve the cost-attractiveness of district heat in the future.

6.2.3 Legal feasibility

There will be compliance to the Finnish building regulations. Any contractual arrangement needed will be compliant to best, Finnish practice. It is not foreseen that any legal updates are required for the foreseen transition to be feasible.

6.2.4 Administrative feasibility

From the bootcamp we understand that there is a 2-3 year permitting time to assume. This has been considered in the proposed plan (see implementation schedule). The FT will design a timely permit process and FT will be in contact with the city and its different department to ensure efficient communication and progression of investment projects. FT will also have close dialogue with HC and H which speeds up administrative matters. Most activities to be undertaken are under direct control of the City of Helsinki.

6.2.5 Cultural feasibility

The transition will be used to create circular flows allowing people to engage in their energy choices. The transition will rely on digital tools for monitoring and optimizing the system. There is a foreseen development of digital tools on the consumer side (taking GDPR into account): and providers of heat can engage to become active prosumers.

Heat can be used to improve the landscape of areas (like solar thermal panels along highways) and least but not last heat can be used to heat the ground, bus stops and benches in Winter (improving everyday life). There is already today DH in Helsinki which means that there is no cultural barrier to further develop the system.

6.2.6 Ethical feasibility

In terms of the active years (2021-2029) it will be ensured that work conditions and safety codes are well established and maintained. In terms of use of resources, no natural resources are depleted, instead sources that are currently wasted will be reused in a circular energy flow.

In terms of innovation, the proposed solutions are innovative in themselves (see 1.2.5). The energy transition will also generate new knowledge that in combination with increased energy capabilities in residents will provide a breeding ground for further energy innovations (from the local district to city level energy transition).

Also, worth mentioning, all the emissions associated with heat generation in the DHS of Helsinki are expected to decrease significantly by the Year 2030, which should contribute to improved climate impact of the system: leading to improved local air and water quality.

7. Reliability and security of supply

In this section, a discussion on reliability and security of heat supply is requested. Our understanding is that reliability is to be interpreted as “resilience” which ensures that business can be performed even if it is being challenged by different shocks (e.g technical, operational, system level, fuel supply, capacity risks). We understand that resilience is explicitly asked for in the Challenge instructions (how to manage peak load and backup capacity) as well as how secure the heat supply is (in terms of heat delivery). However, security can also address protection of access to the business (e.g. badge entries to access sites, antivirus software, fencing). Below, we focus on the reliability/resilience/security of heat supply analysis.

7.1 Reliability/ resilience

To assess the reliability of the DH supply during the active phases (2021-24, 2025-29) we resort to the Energy Resilience Framework developed by Arup (technology consultants). The framework includes four factors: technical, financial, organizational and social. These are addressed first (7.1-7.2), then we make an overall resilience assessment of the energy system of Helsinki after the transition (seven qualities of resilient energy systems from the same framework are addressed).

7.1.1 Technical risks

In the framework, the technical factor encompasses planning, design, delivery, operation and maintenance. What the Challenge Instructions refer to as technical, operational, system level, fuel supply and capacity risks we refer to under this section “technical risks”. Planning-design-delivery reflect the active years 2021-30 and operation-maintenance the post transition years (after 2031).

<u>Planning-design-delivery (2021-2030)</u>

In 2021-30, the future sites for heating Helsinki will be planned, designed and commissioned (delivered). Several new technologies are combined in the future energy system. Boreholes, caverns, HPs, solar thermal parks and waste heat. None of the technologies is untested but the risk that one or the other technology will not be successfully implemented in one of the foreseen sites is likely: things do not always go as planned. This can lead to delays (for example borehole preparation delay would delay the solar thermal park installations) but delays are manageable with efficient planning processes and process management systems (like for example PlanRadar).

In 2021-24, new units come into operation: the seasonal TES foreseen in Mustikkamaa (former oil cavern: 2021) and Kruunuvuorenranta (rock cavern: 2024). The installation of Sea HPs (in operation 2022) and biomass fired HOB (in operation season 2022-23) in Vuosaari. Vantaan Energia is also taking the new waste to energy plant into operation (2023), providing waste heat. This is also the period when preparations are made on the first borehole TES and solar thermal park, air and sea water-based HPs and first low temperature heat sources (all in operation in 2025). It is our assessment that the phaseout of Hanasaari CHP (2025) and Salmisaari CHP (2029) is feasible as a result of the new capacities coming into the system. We want to point out that the approach of our solution (with modelling iterations, a facilitator team and stepwise investment phases) has been designed to ensure a transition that is not disruptive but smooth. The ongoing updates on progression of the planned construction will allow an identification of any capacity gaps of heat supply well before they occur: allowing for upgraded time planning and progression pace of different investment projects. The implementation of the waste heat recovery of Neste is, in our modelling, assumed to be 2030 but if it is identified that the heat needs to be entered earlier- say in 2029 to avoid any failure of heat supply during 2029 this will be identified and can be adjusted speeding the Neste preparation phase up.

The new units will be delivered at different points in time allowing for an efficient integration of them into the operations and maintenance systems used at Helen. One important part of the project master plan for Helsinki will be to ensure that once units are delivered, they are entered into relevant systems. There will be preparatory test runs and validating runs on the performance of the units (proactively supported by modelling runs). The ambition is to make the future system as transparent as possible: transparency will support efficiency.

In sum, during the active years (2021-30) the technical resilience should be good assuming that the phase in and phase out of units is proactively planned.

<u>Operation-maintenance (2031 and beyond)</u>
Several heat sources are supplying the city with heat from a number of different connection points. This means that a major shock (could be flooding caused by extreme weather, an external action to damage the system) has limited possibility to take the whole system out. There are also backup units and storages across the network to alleviate disruption.

Addressing peak load, we identified that the old buildings with high temperature demands in the city center were at particular risk. As part of the review of the backbone, the buildings that risk not being able to access full heat demand at peak load conditions will be identified and equipped with auxiliary electrical heating. Small HPs will be installed at the buildings in combination with electrical units that can cover peak load (included in the cost calculations presented in Section 4). Also, sea water-based HPs are installed and linked to the TES borehole unit in the Salmisaari location, to ensure heat supply to this area at all times. For other parts of the system the peak load problem was identified as less severe and existing backup capacity units in combination with stored heat will suffice to ensure reliable heat supply also in cold winter weeks.

The system is based on the use of HPs in different configurations which means that there is a large reliance on electricity. It is only large and long-term electricity outages that will significantly disturb the reliability of heat post 2031. This is one of the main reasons we keep the gas fired CHP in Vuosaari. In the event of a large shortage of electricity it will play an important role to keep the most critical parts of the DHN operational.

In sum, the operational resilience of the system once it is in place should be high as a result of the built-in flexibility (different heat sources and technologies combined). As a result of the flexible heat supply there are few shocks that will impact the system as a whole. The back-up functionality (based on units able to generate heat and seasonal TESs) is assessed to be strong; e.g. the capacity of the system is appropriate.

Turning to *fuel supply*, the fuel of the highest importance is electricity (addressed above). Other energy sources are RES and waste heat (from Vantaan Energia, Neste, ambient air, sea and other urban sources). We do not assume any major impacts on reduced solar radiation or decreased amount of available air or sea water. For the waste heat sources, the main complication is that somebody owns them. Hence, in the event that Neste would close down its activity in Kilpilahti, this source of waste heat will be lost. This is a risk in any waste heat recovery arrangement, which can be modified by explicitly stipulating an action plan for lost heat volumes. This kind of contract: of who is responsible for what in the event of Neste shutting activity down will be implemented by the Facilitator team. For other low temperature waste heat sources, the ones used will primarily come from publicly owned units facilitating the access to them.

7.1.2 Financial, organizational and social

In the instructions for writing the proposal it is addressed that it should be mentioned who should invest in backup capacity if such is needed. Therefore, we address this point here. Depending on the investor appetite of Helen and the City of Helsinki the investor pool will determine what kind of investors are most suitable for different investment projects. It is, however, foreseen that any debt solutions are assumed by Helen. For the active years 2021-30, the establishment of the investor pool is crucial to ensure financial resilience. The pool will ensure that none of the investment projects has to be abandoned or delayed as a result of shortage of funds.

In terms of organizational resilience, the facilitator team will have an important role to support the local organizations with different tasks ensuring compliance to the master project plan. It will ensure a city-wide perspective of the implementations made and identify the most efficient formats to interact with different stakeholders (one example of this is the permitting processes to be established early on). Other aspects like the development of efficient operational systems (e.g. digitalization) and knowledge about appropriate levels of internet and data security will be parts of the transition and areas where the organizations that will manage the DHN of Helsinki in the future will build capability along the way.

Last but not least, the energy transition of Helsinki will be inclusive and empower residents and heat consumers. The active approach of social inclusion (knowledge and job generation) will support areas that are challenged today. Addressed above, there is a reasonable margin and further improving the cost-attractiveness of district heat in the future is realistic.

In sum, the financial- organizational and social factors of the energy transition in Helsinki are very strong.

7.1.3 Overall assessment of the reliability of the future energy system of Helsinki

The seven factors are (i) reflective, (ii) flexible, (iii) integrated, (iv) robust, (v) resourceful, (vi) redundant and (vii) inclusive.

- ✓ Reflective is the ability to understand the importance of internal and external conditions on assets. *The combination of a number of heat sources and assets necessitates this capability and is therefore reflected in the future energy system of Helsinki.*

- ✓ Flexible is the adaptability to changing circumstances and deliver energy via various pathways. *This is the characteristic of the future energy system of Helsinki.*

- ✓ Integrated is the essence of optimizing efficiency and performance of multi vector systems. *The future system in Helsinki is complex but will be optimized for maximized efficiency resorting to efficient operational systems.*

- ✓ Robust is being well designed, constructed and managed physical infrastructure. *This is the characteristic of the future energy system of Helsinki.*

- ✓ Resourceful is having a range of resources and infrastructure to meet critical demand. *The Helsinki system is resorting to different resources and infrastructure also ensuring critical demand in the event of external shocks and peak load conditions.*

- ✓ Redundancy is ability to spare capacity or duplicated infrastructure to accommodate disruptions. *The Helsinki system has a well-designed backup system and can resort to alternative infrastructures in disruption.*

- ✓ Inclusive is broad consultation and engagement of energy users. *This is the characteristic of the future energy system of Helsinki*

8. Capacity

Figure 6 shows a detailed description of the installed heat generation and TES capacities in the DHS of Helsinki in the Years 2020-2040, based on the results from the applied optimization modelling and considering requirements for resilience and security of supply (identical to Figure 2). The presented capacities can be divided into two main groups: 1) existing and already approved for construction capacities by Helen and 2) new capacities proposed as our solution. Further, installed capacities can be characterized as base-, mid-, and peak-load units, which contribute to the heat balance (Figure 1) with generated energy, and so-called back-up units.

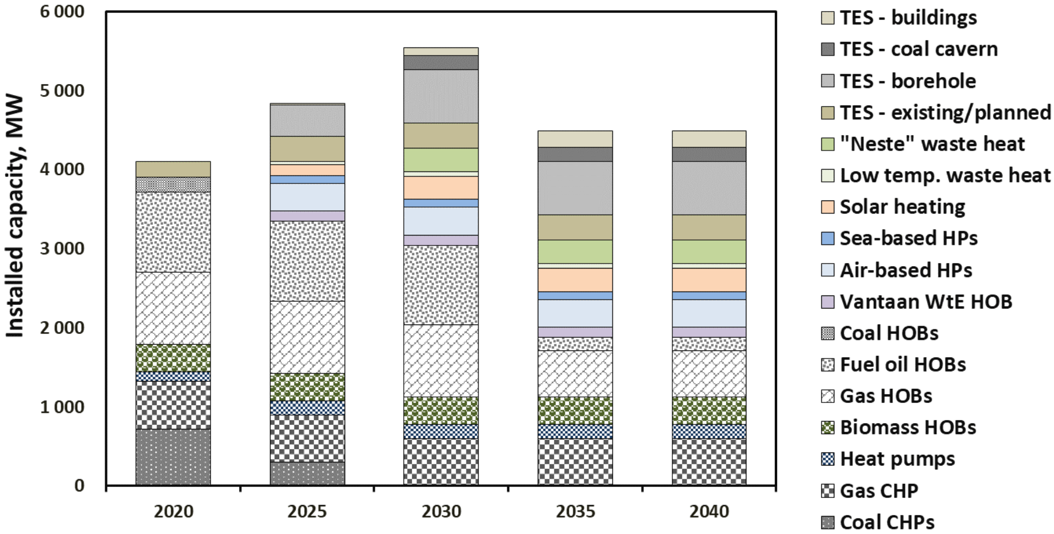


Figure 6. Total installed capacity in the DHS of Helsinki in the Years 2020-2040.

As mentioned in the previous Sections, our solution is largely based on the utilization of waste heat sources and significant energy TES capacities. From **Figure 6**, it can be seen that new heat generation capacities entering the generation mix already in the Year 2025 are sea water and air-based HPs, low temperature heat sources and solar thermal with the total heat generation capacity of 625 MW. It is also assumed that 130 MW of heat originating in the Vantaa WtE HOB will be available during the summer months. By the Year 2030, the total heat generation capacity increases by another 475 MW. Neste waste heat will contribute with 300 MW, while the rest will be secured by increased capacity of solar thermal and waste heat sources.

Figure 6 also shows that by the Year 2030 the total of 1270 MW of charge/discharge capacity will be available for dispatch in the DHS of Helsinki from the existing and proposed TES units. The largest proposed TES unit is a borehole TES with 675 MW of available charge/discharge capacity and extraordinary size, in terms of maximum stored energy, of 1680 GWh. Other TES technologies will include 1) already existing Vuosaari and Salmisaari units, 2) planned Mustikkamaa and Kruunuvuorenranta units, 3) refurbished into thermal TES Salmisaari coal storage, and 4) so-called TES in the thermal mass of buildings (proxy of demand response).

Considering requirements for resilience and security of supply, our solution includes several peak-load covering and back-up heat generation units. This function will mainly be served by the existing and planned biomass-fired Salmisaari and Vuosaari HOBs, along with natural-gas fired Vuosaari, Patola and Myllypuro HOBs and the light fuel oil-fired Alppila HOB. The total capacity of those units will be 1105 MW. Considering that firing of fossil fuels is to be limited/prohibited in the future, we reserve an option of converting the gas- and fuel oil-fired units into (LNG) and biodiesel-fired HOBs.

In addition, we propose to keep the Vuosaari gas-fired CHP operational beyond the Year 2030. With the cessation of coal-fired CHP plants – electricity generation units, and significant new capacity of HPs – electricity consumption units, the net electricity balance of the city will be impacted greatly, i.e., drastically increased demand for electricity. Under such conditions, the Vuosaari CHP plant can play an important role as a reliable provider of both heating and electricity. Furthermore, in the future with higher shares of intermittent renewable energy sources in the electricity system, the Vuosaari CHP plant has a potential to provide flexibility to the electric power sector, especially given its characteristics of having a flexible power-to-heat ratio, i.e., ability to adjust the shares of heat and electricity output. This can provide additional energy security and back-up capacity to the city and profit for Helen.

Key assumptions:

- the coal-fired Hanasaari CHP will be phased out by the Year 2024, while both the coal-fired Salmisaari CHP and HOB will be ceased by the Year 2029;
- natural gas and heavy fuel oil-fired HOBs will be ceased by the Year 2032, except for the HOBs chosen and left for operation as peak-load/back-up capacity (indicated above);
- planned by Helen biomass-fired Vuosaari HOB (260 MW), the sixth KatriVala HP unit (40 MW), and the sea-based HP (13 MW) will be operational by the Year 2022;
- waste heat from the Neste refinery will be available at maximum capacity of 300 MW and is assumed to be operational starting the Year 2030;
- total capacity of HPs, which utilize low-temperature heat sources for heat generation, will be limited to 30 MW by the Year 2025 and to another 30 MW by the Year 2030;
- building side HPs will have an aggregated power of about 620 MW thermal, corresponding to about 120 MW electric (different COP values of 4 and 5.4 are assumed depending on building type); auxiliary electric heaters in old buildings (operating about 1 % of the time, in peak conditions) have a power of 350 MW electric;
- heat supplied to the DHS of Helsinki from the extension of the Vantaa WtE HOB will be limited to 130 MW (available heat exchanger capacity between the DHSs of Helsinki and Vantaa) and will be available only during the summer months;
- Mustikkamaa and Kruunuvuorenranta TES units will be available for utilization by the Years 2021 and 2024, respectively;
- maximal installed capacities of borehole and building energy TESs are limited to 2 000 GWh, and 10 GWh, respectively

9. Closing words

Working on this challenge has been a very rewarding experience. We are convinced that an efficient energy transition can be done in a city like Helsinki in a decade. We suggest that the City, apart from focusing on the energy system and its transition, takes the opportunity to transfer Helsinki into a carbon sink for real (not only carbon neutral in 2035). All the energy centers designed for the air-based HPs and the energy knowledge center should be erected in wood. The same could be applied for all new living spaces and offices planned for in different areas of the city. Things like transforming the garden waste of the region into bio-coal and other innovative elements should characterize the development of the city overall.