Transitioning to a carbon neutral heating and cooling in Estonia by 2050

Summary report

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Introduction

This document is the summary report of the project ‘Transitioning to a carbon neutral heating and cooling in Estonia by 2050’ for the Ministry of Economic Affairs and Communications of the Republic of Estonia (MKM). To achieve the carbon neutrality target in the heating and cooling sector, the Estonian Government targets to assess the heating and cooling decarbonization technologies and the plausible policy measures to support their timely deployment over the next three decades. This study aims to identify and analyse scenarios for achieving carbon-neutral heating and cooling in Estonia by 2050. The study will support the Ministry of Economic Affairs and Communications of the Republic of Estonia by a) proposing carbon neutral heating and cooling scenarios covering the different sustainable energy vectors and infrastructural changes and b) developing a pathway Action Plan for the eventual adoption of carbon-neutral heating and cooling sector in Estonia.

The project team consists of Stockholm Environment Institute Tallinn – SEI (lead partner), Trinomics B.V., Pilvero OÜ, and Finantsakadeemia.

The deliverables and the analysis of this assignment are carried out for the following five scenarios (pathways):

Business-as-usual (BAU):

- The conventional technologies will be used to achieve carbon neutrality. There will be limited adaptation of upcoming carbon neutral heating and cooling technologies (non-industrial and industrial). The BAU pathway will focus on technologies already commercialized. It accounts for existing climate and energy policies affecting Estonia’s heating sector.

All-electric (heating and cooling through electrification):

- All infrastructure and technologies for local/district heating and cooling and for industrial heat demands will be based on electric solutions. The electricity needs will be covered by renewable electricity. The electricity demand will grow progressively depending on the resource availability, TRL, financial feasibility and access.

Push towards district heating and cooling (DHC):

- All possible heating & cooling requirements will be based on district heating & cooling solutions. Industrial heating will not be affected by the non-industrial heating and cooling infrastructure shift. Energy source will be based on technologies that are considered sustainable and usable for district heating systems. Local heating solution will be as limited as possible (only placed where district solutions are not in line with the balance of the pillars).

Push towards local heating and cooling (LHC):

- District heating will be phased out while shifting all the possible demand towards local solutions. Industrial heating will not be affected by the non-industrial heating and cooling infrastructure shift.

Technology neutral:

- A well-balanced technology mix for non-industrial heating and cooling and for industrial heating. No change in the current heating and cooling supply infrastructure (district or local) share.

Executive summary

The growth of share of renewable energy in electricity and heating and cooling sector in Estonia has been strongly driven by usage of biomass. However, rising bioenergy prices and the expected change in the sustainability criteria and environmental guidelines around usage of biomass, will make having more diverse and balanced technology mix a sound strategy for moving towards carbon-neutral heating and cooling.

We estimated Estonian heating demands[1] to decrease from 12.6 TWh in 2021 to 11.8 TWh in 2030 (a 6.3% decrease by 2021 demand levels) and to 8.5 TWh in 2050 (a 32.5% decrease by 2021 demand levels) and cooling demands[1] to increase from 325 GWh in 2021 to 697 GWh in 2030 (a 53.4% increase by 2021 demand levels) and to 1.4 TWh in 2050 (a 77% increase by 2021 demand levels). Renovation of Estonian building stock will play a major role in bringing the heat demand levels down. That is why, it is of utmost importance to make sure that Estonia meets 2030 and 2050 building renovation targets. Estonia is lagging to fulfil its renovation targets and the pace of renovations should be sped up several times of the current levels. Increase in cooling demands will most likely happen mainly due to the new demand evolution by the new building constructions. The cooling demands will mainly evolve due to the increase in services and commercial building stock. In addition to the renovations, demand side management (DSM) in terms of introducing digitalization (AI-based smart control systems) in Estonian building stock is estimated to shave off 10% of the heating (0.95 TWh) and cooling demands (0.16 TWh) by 2050.

Industrial heating demands are projected to increase from 3.2 TWh in 2021 to 3.6 TWh in 2030 (a 11% increase by 2021 levels) and to 4.39 TWh in 2050 (a 27% increase by 2021 levels). The increase in industrial heat demand is foreseen as a joint result of the heat conservation or heat integration and probable increase in the industrial activity (increase in process heat use) based on the data adopted from the Odyssee-Mure country profile[2] database (see section 2.5.3 of Deliverable 3 report).

In addition to the business-as-usual scenarios, we have investigated four different scenarios: All-electric, Technology neutral, district heating and cooling (DHC) shift, and local heating and cooling (LHC) shift. The scenarios are compared based on the key indicators from the scenario modelling, socio-economic impact analysis, risk analysis, and sensitivity analysis. Consequently, an Action plan containing the policy recommendations, priority actions, and the timeline for these actions is prepared. All scenarios share several common factors – such as Estonian electricity emission projections, buildings' energy efficiency targets, new building construction and building stock out-of-use prognosis, and digitalization rates. The key difference between those 4 scenarios is either technology driven (All-Electric or Technology Neutral) or heating and cooling infrastructure coverage driven (shift towards district heating or shift towards heating and cooling).

Based on the assessed scenario performance indicators (Table 2-3), we recommend shifting the Estonian H&C infrastructure to a mix of All-Electric[3] and DHC scenarios because it will offer to build on the positive impacts of both scenarios (e.g., energy-efficient electrified options and expansion of DHC to utilize regionally available waste heat sources, etc.) and will limit the extreme boundaries of both scenarios (shifting the HC system to a certain technological extreme or infrastructural extreme).**The mixture of both scenarios would mean a more balanced electricity demand and reduced bioenergy dependency for the heating and cooling sector (balancing electricity demand between 1.8 – 6.5 TWh and bioenergy-based fuel demand between 0 – 11.4 TWh).**

Deploying the recommended scenario mix for carbon-neutral heating and cooling system in Estonia will require approximately 18.8-19 billion Euro for the period 2022-2050.

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[1] Single houses, apartment buildings, and services/commercial buildings

[2] https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/estonia.html

[3] With the main assumption of fully decarbonized electricity by 2050

The major portion of the total investments constitutes renovations of the Estonian building envelope (16.739 billion i.e., ~88-89 % of the total investment needs). Renovation of the building stock has a vital and pivotal role in all the scenarios to bring the overall heating and cooling energy needs. **These investments will be borne mainly by individual consumers with state support under the renovation wave (investment coverage subsidies and easy loan requirements).**

The overall technology costs in All-Electric scenario are 2.274 billion Euro and 1.038 billion Euro in the DHC scenario. Whereas the DHC scenario also has an additional 1.012 billion Euro investment requirement in terms of DHC infrastructure expansion. Large part of the total technology investments for the period 2022-2050 will be required in the first eight years till 2030. After 2030, the technology investment requirements are relatively low based on the reduction in the heating requirements and the technology learning rates. This effect is most significant in the All-Electric scenario where the reduction in upfront investment in HPs will be reduced significantly over the years.

The mix of All Electric and DHC scenarios will require front-loading technology and infrastructure investments, compared to the two other scenarios (LHC and Technology neutral), which rely on the existing heating appliance stock, and therefore require lower investment in the short term. However, the replacement of these existing heating appliances will become inevitable over the 30 coming years, consequently reducing the difference between the investment needs of the All Electric/DHC scenarios and the other scenarios.

Joint development of renovation and heating and cooling infrastructure is vital and cannot be materialized without each other. Incentivizing the replacement of heating systems when undergoing deep renovation should be the priority measure. The state can support the incentive scheme for renewable system mortgages and repayment of investments through property taxes.

Our conclusion based on scenario evaluation indicators (see sensitivity indicators in Table 2-3) is that the All-Electric scenario is mainly CAPEX-driven, while the other three scenarios rely mainly on bioenergy cost and are therefore fuel-cost driven. This means that given the price hike of biomass and electricity, the Levelized costs of heating will be more affected in scenarios where bioenergy has a higher share in comparison to the All-Electric scenario. Based on the current (2022) electricity and biomass price increase, Table 2-3 (last row) shows 3-4 times increase in average household heating costs (24-32 EUR/MWh) for DHC, LHC, and Technology Neutral scenarios in comparison to the All-Electric scenario (8 EUR/MWh). This elevates the average household heating costs in the other scenarios very close to the Electrified household heating costs and any further biomass price increase will result in the All-Electric scenario having 2nd most competitive heating costs only after the DHC scenario. So, the mix of these will bring a well-balanced and positive impact on heating costs.

Self-initiative from consumers is required towards new H&C solutions that can support people's need to save money over time and live more sustainably through clean energy solutions.

Since **single houses** (both in urban and non-urban areas of Estonia) have the least share of DH among the other market participants (apartment buildings and services/commercial buildings), local-level technologies (ground source HPs, A/A, and A/W HPs complemented by bioenergy) penetration will be most important for single houses (both in urban and non-urban areas).

While for **apartment buildings and services/commercial buildings** (both in the urban and non-urban areas) bigger and more centralized units of heat pumps (~200kW per unit) are recommended. Ground source HPs require an additional financial charge due to the excavation costs of the land for underground piping. Local authorities (in areas especially with high heat consumption density/ high population areas like Tallinn, Tartu, and Ida-Virumaa) should include incentivizing ground source HP incentive schemes in their development plans.

District heating development will require good strategical planning to gain/maintain the necessary density of DH infrastructure. The supply infrastructure will develop according to the demand and circumstances (policy and planning framework etc.).

District cooling consumption volumes will mainly develop by the services/commercial sector in largely populated urban areas (e.g., in Tallinn and Tartu) and will mainly be driven by lucrativeness of demand and supply which might require less state support in comparison to the DH network extension where refurbishing of the DH lines and extension of the DH network outside the high consumption areas e.g., Tallinn, Tartu County, and Ida-Viru County will require investment support for deploying new production plants, heating lines, and substations.

It is recommended for local governmental bodies and authorities at the county and municipality level to analyse their building envelope and plan the subsidy schemes accordingly to sufficiently invest in the refurbishment and in network extension of DH mainly in urban areas with high heat consumption areas (e.g., Tallinn, Ida-Viru, Tartu, Pärnu, Järva, Lääne-Viru, and Viljandi counties), especially for large apartment buildings and services/commercial buildings. But also, in some semi-urban areas or more dense rural areas constituting major apartment buildings and single houses settlements e.g., village centres where minimum heat consumption density of 1.5[4] MWh/m can be maintained. **The investment supports needs should be decided individually by the local governments together with the DH companies for the regional development plans in a way that makes the DH extension a financially viable and lucrative option for DH companies and in return, local governments will ensure the security of heating supply to the areas with low population and to the financially vulnerable parts of the country**.

The existence of a district heating and cooling grid (network) is necessary to utilize low enthalpy energy sources (mainly local RES sources (geothermal and solar)) and to valorise waste or surplus heat, reducing the dependence on conventional energy production systems, ensuring efficient use of energy and for energy market integration via sector coupling (electricity and heat). **Local authorities should involve innovative solutions in their local development plans where low-temperature district heating (LTDH) networks can be an option via deploying solar or geothermal DH systems with the complementary addition of the waste heat sources directly in the vicinity of district heating areas.**

While developing the regional development plans for Tallinn, Narva, and Mardu, the state government should include pilots on shallow geothermal well fields (at the depth of <500m) and also for groundwater geoenergy in Narva region to make the best use of domestic energy sources.

The development and techno-economic feasibility tests of the seasonal heat storage technologies in the Estonian context should be one of the Governments' priorities till 2030. Underground thermal energy storage technologies can be one of the possible seasonal heat storage solutions e.g., heat storage in geothermal wells, wind and solar power storage as heat in the sand (underground sand batteries[5]). Heat storage capacities such as 'levelling tanks' will help to smoothen the consumption curve at the peak loads and will reduce the consumption of fossil fuels but hot water tanks as seasonal storage tanks is found to be financially impractical for district heating systems as the large capital investments in hot water seasonal storage tanks will spike the prices which will most likely result in difficulties in attaining approvals for the price of heat from the Competition Authority.

Like the deregulation of electricity and natural gas markets in many countries, the participation of different market participants in DHC market, challenges the natural monopolistic characteristics of the district heat companies with more competition. The district heating network can be a platform where solar heat or geothermal heat producers could sell H&C in the net or that can utilize surplus or waste heat. Taking an example from "Open District Heating[6], HPs have a bigger role to play in market coupling (interfacing electricity and heat markets), also, data centres, supermarkets, restaurants, and industries can sell their excess heat into the network, thus the network can provide a service where a consumer can buy heat from different sources. In such a district heating and cooling system, the Competition Authority of Estonia may choose to regulate third-party access in a non-discriminatory way. The actual costs of

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[4] Required usual minimum heat consumption density to deploy new DH lines [Stakeholder discussions with DH experts]

[5] https://polarnightenergy.fi/technology

[6] https://www.opendistrictheating.com/about/open-district-heating-how-it-works/

transmission and distribution will vary significantly depending on the characteristics of local sites. This information gap can complicate the harmonization of conditions and standards regarding third-party access. Local authorities should consider this aspect as a future smart goal in their regional development plans.

Achieving a carbon-neutral heating and cooling system will require fast and substantial actions. Estonia will require to take the following necessary actions (**Error! Reference source not found.**) for the decarbonisation of the H&C sector. **Error! Reference source not found.** below provides a general description of each policy areas, including objective, timeline, responsible body, key stakeholders, and scale of cost. The detailed policy action timelines per scenario are attached in Annex B.1.

Table 0-1. Necessary set of actions across all pathways

Action sets	Objective	Timeline	Responsible	Other key stakeholders	Cost
1. Streamline integrated H&C planning process	Increase planning coherence and optimize EE and RES actions	Mainly short-term	MKM	Local authorities, DHC and electricity grid operators, CA, KEM, MEM	Low
2. Phase the renovation wave and integrate renewable supply	Improve the energy performance of buildings to reduce heat demand and encourage the integration of RES H&C in renovation	Short/medium-term	BA & KredEx	Ministry of Finance, local authorities, construction sector, building owners	Medium/High
3. Development of the required infrastructure	Ensure that the DHC sector sufficiently invests in the extension and refurbishment of the DHC network	Short-term	MKM	DHC network operators, local authorities, KEM, CA, energy communities	Medium/High
4. Strengthen local authorities' role in H&C decarbonisation	Engage local authorities to be active in H&C decarbonisation planning	Short to long-term	MKM	Local authorities, CA	Medium
5. Set up level playing field and creating a market	Ensure that RES H&C technologies are competitive with fossil-based H&C	Short to long-term	KredEx & CA	HP sector, RM	Medium/High
6. Empower all consumers, especially households	Engage consumers to be active in H&C decarbonization	Mainly short/medium-term	MKM	KredEx, KIK, local/regional authorities, BA, industry, building owners	Medium
7. Strengthen professionals' skills and knowledge	Ensure that there is enough labor capacity in H&C sector	Short-term	Ministry of Education	Unemployment insurance fund, KIK, BA, professionals in H&C sector	Medium/high
8. Mobilize and mainstream financing and funding	Ensure that all financing/funding is effectively mobilized to H&C sector and consumers	Short to long-term	MKM	Financial institutions, building owners	High

The scenario risks were perceived differently by stakeholders considering their point of view and understanding of risks. Detailed risk assessment per scenario can be seen in Table 1-3. The main challenges and risks for technologies and the planning process are:

- Security of supply in economically vulnerable areas
- Electricity grid development
- Unexpected fuel/electricity price increase
- level playing field for new technologies (HPs etc.)
- Regulatory risks
- Social risks

The major technical measure for the recommended pathway selection will be to ensure that there is enough available grid capacity. Particularly, electricity grids in rural Estonian areas need to strengthen. Additionally, in city centres, there are also grid capacity constraints. There is a need to have a local plan, with a holistic approach (e.g., at the municipal level), considering the electricity grid, DHC network, renovation, and energy efficiency, etc. For the regions in Estonia with massive HP deployment, we recommend local authorities to include decentralized PV+storage systems as a recommendation for single houses and apartment buildings while developing their regional development plans.

The major technology development measure is to ensure a level playing field for different HP technologies, which at the moment have high investment costs in Estonia as compared to the average EU technology costs. In the current market situation, hydrogen-based local heating systems (boilers, micro-CHPs) are more expensive (investment and running cost) than direct electrification options (HPs). The inherent energy efficiency loss of hydrogen as an electricity-derived energy carrier is a critical factor in the faster rollout of hydrogen-based heating solutions.

The major infrastructural change for the process industry is to phase out the fossil fuels use with a balance between low middle & temperature range HPs, industrial solar thermal, bioenergy-based process heat, and electrified solutions (like electric furnaces, etc.). Different industries will need different technical solutions based on their temperature segment. 87% of the industrial heat demand in Estonia is from industries with a temperature segment of <100-300 °C. Industrial heat coverage for heat less than 100 °C will be fulfilled by conventional/commercial heat pumps and by electric boilers. For the temperature segment 100-300 °C, high-temperature HPs (up to ~200 °C). will play the main role with complementary capacities of solar thermal and biomass boilers. The heat demand for the industrial temperature segments beyond 300 °C will be covered by biomass boilers in conjunction with complementary capacities of hydrogen boilers and solar thermal as supporting technologies.

This study was made based on the best available data, however, currently data on local heating and cooling still has gaps and Estonia needs to invest into upgrading building registry, which would allow for even better and more targeted policies. Due to the absence of local heating and cooling consumption data, the demands during this study had to be calculated based on the yearly averaged heating and cooling factors of different building types. But this way of demand calculation is sensitive to the underline assumption and the quality of the building stock data. Digitalization of the Estonian building register data (ehitisregister-EHR) is inevitable to have an updated database in real-time. To increase the data availability, detailed data sets on heating and cooling consumption (especially for local heating and cooling) by fuel and by technology could also be included in the national statistics libraries (e.g., Statistics Estonia).

1 Overview of the project activities and results

The overall project consists of 8 deliverables with interlinked activities. Deliverable 1 is the inception phase during which the different steps and aspects of the projects were discussed with the client. Deliverable 2 is the **collection of data** describing the current situation of the Estonian heating and cooling sector and potential technologies that can be used for climate-neutral heat generation. Deliverable 3 is the **modelling of several potential heating and cooling scenarios**. Deliverable 4 is analyzing the **socio-economic impact assessment** on direct, indirect, and induced effects of each scenario. Deliverable 5 is the **risk analysis**. Deliverable 6 performs the **sensitivity analyses** on the previous modelling results. Deliverable 7 is compiling the **action plans** with proposed measures to achieve each decarbonization scenario. The final deliverable 8 combines all the deliverable outputs into a final report. **Figure 1-1** presents the information flow between eight project deliverables.

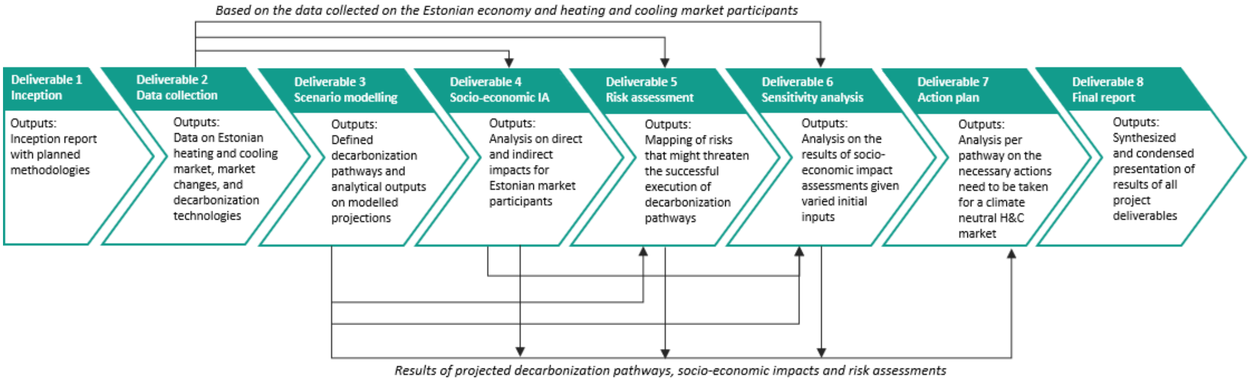

Figure 1-1. The flow of project activities

1.1 Deliverable 3: Modelling pathways

Deliverable 3 is aimed to present the answers for the knowledge needs presented in ToR. Key modelling results are presented in this subsection.

The model calculated the overall biomass consumption in 2050 as 12.986 TWh for BAU scenario, 11.37 TWh for DHC scenario, 7.93 TWh for LHC scenario, and 9.99 TWh for the technology neutral scenario in comparison to 12 TWh of biomass use in 2021. Whereas the All-Electric scenario presents no dependence on biomass by 2050. If biomass materials' sustainable/carbon-neutral status is to be changed in the future. In that case, the status quo will result in heat pumps favouring the most market-ready energy-efficient heating option.

In terms of total input energy consumption for heating and cooling production, All-electric scenario presents least input energy requirement i.e., 7.4 TWh against 14.2 TWh, 10.7 TWh, 12.9 TWh for DHC, LHC, and Technology Neutral scenario respectively. This is because of the high coefficient of performance (COP) values of heat pump technologies.

At the DHC level, the technologies which can be used in combination with the waste/surplus heat sources (e.g., air-to-water, water-to-water heat pumps, and absorption chillers) seem to be the most sustainable considering the whole supply chain.

At the local heating and cooling level, for consumers in urban areas, air-to-air and air-to-water heat pumps and for non-urban areas ground source heat pumps (in addition to the A/W and W/W HPs) are a viable sustainable option given the fact that ground source heat pumps required large excavation areas which usually in urban areas are hard to acquire. Hydrogen-based individual heating systems (boilers, micro-CHPs) are not recommended on energy efficiency basis as direct electrification solutions in buildings (as local solutions) are always preferred due to the inherent efficiency advantages (over hydrogen-based solutions).

Multiple factors, constraints, and social factors must be considered when the DH push is under consideration. The DH share in the overall demand can be expanded by adding new consumers on the already existing lines or adding new customers in the areas where DH was not present before and a new network must be then constructed. The real situation cannot be predicted but a simplification can be made to have an idea about the DH infrastructure expansion when a push towards DH takes place. To see the expansion of DH pipelines while maintaining the heat consumption densities, the DH supply line lengths can be calculated by dividing the heat demands with the average heat consumption density of the current DH infrastructure (i.e., 2.66[7] MWh/m). Based on the explained methodology, after the heat coverage shift from local heating towards DH, the overall length could increase from ~1,591 (2021) km to ~2,355 km by 2050.

By utilizing the same methodology, the DH network's length (km) shrinkage for the LHC scenario and the comparison with the other scenarios is presented in Table 1-1. After detailed discussions with the experts it was concluded that DC will expand but most likely in urban areas. The supply infrastructure will develop according to the need and circumstances and cannot be predicted to the exact line lengths. But a simplification has been made by taking a minimum cooling consumption density of 2 MWh/m. It is analysed that if all the cooling demand coverage in urban municipalities is shifted to the DC, 328 km of DC lines would be required.

low-temperature district heating areas (LTDH areas) can be created connected to RES HPs and waste heat recovery points from wastewater/sewage treatment plants, electrolyser stacks, data centers, and flue gas condensers. Expert input from DH companies reveal that one of the main challenges to achieve LTDH is that all the consumers connected to a certain network must be energy efficient. If only one of the consumers has poor building infrastructure and require high supply temperatures, then the concept of LTDH network could not be fulfilled fully in its practicality.

Within different scenarios, waste heat is to be utilized with in the DH networks by 2050. The utilisation of the waste heat in DH networks depends on the following points: location where suitability for transmission to the district heating network exists (either directly via a heat exchanger or a heat pump), uniform and year-round availability is guaranteed, and the source of waste is in the close vicinity of the district heating network. The details on the year-round availability of the industrial surplus heat and the temperature profiles of the low temperature heat sources are presented in the sub-section 2.5.6 of the Deliverable report.

Heat storage capacities such as 'levelling tanks' will help to smoothen the consumption curve at the peak loads. Seasonal heat storage as hot water storage tanks is found to be a financially challenging option for district heating systems as the large capital investments in hot water seasonal storage tanks will spike the prices which will most likely result in difficulties in attaining approvals for the price of heat from the Competition Authority. As of 2021, there are no heat and cooling storage present in Estonia. As a modelling result output, it is calculated that in the district heating scenario, 2.61 GW of heat storage capacities will be required by 2050 to deal with a large shift towards DH via hot water storage tanks for covering the peak demands. Underground thermal energy storage technologies can be one of the possible seasonal heat storage solutions e.g., heat storage in geothermal wells, wind and solar power storage as heat in the sand (underground sand batteries). The development and techno-economic feasibility tests of these technologies in the Estonian context should be one of the Governments' priorities till 2030.

Including renewable sources (solar thermal, geothermal, seawater, etc.) in the district heating and cooling systems will put an additional charge on the final consumers if not appropriately managed, as deploying these technologies will require significant investment costs. Nonetheless, these technology options are most viable for the Estonian regions with dense heating and cooling network consumption densities (e.g., Tallinn and Tartu). Nevertheless, it is rather challenging to make an innovative business

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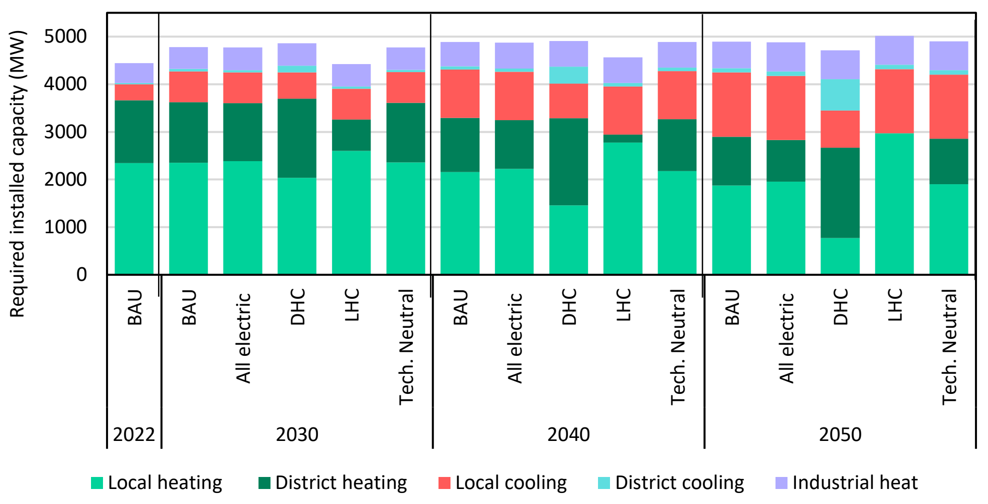
[7] Heat consumption density of Estonian DH network communicated by competition authority of Estonia.

model for the areas with small district heating networks having very low consumption densities. The market for heating and cooling will grow organically, but measures like significant incentives for building renovations to achieve energy efficiency in buildings, legislation and regulatory frameworks for the local companies and businesses to sell their excess heat at market price will be required to find an optimum solution for carbon neutral heating and cooling.

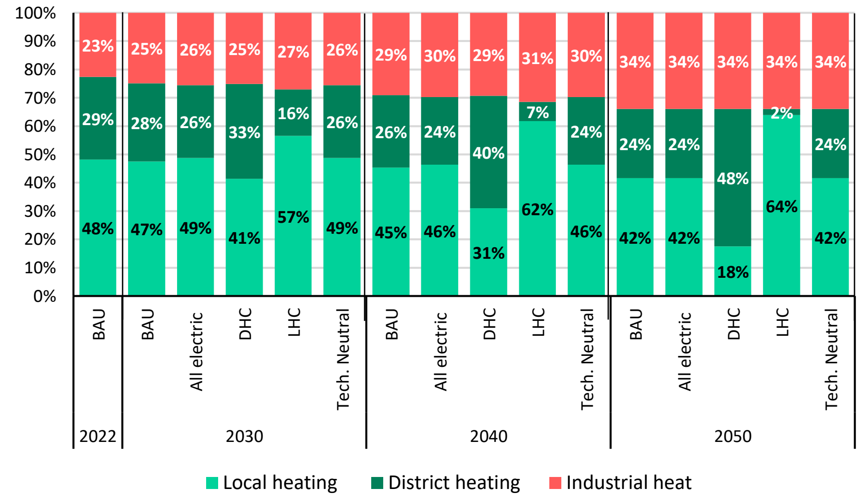
A cross-scenario result comparison is presented in Table 1-1, where installed capacity (MW), share of heating and cooling production per pathway, GHG emissions (kt$CO_{2eq.}$), fuel requirements (GWh), DH and DC network length change, and the required heat storage capacities (MW) for DH are compared.

Table 1-1. Key pathway results for deliverable 3

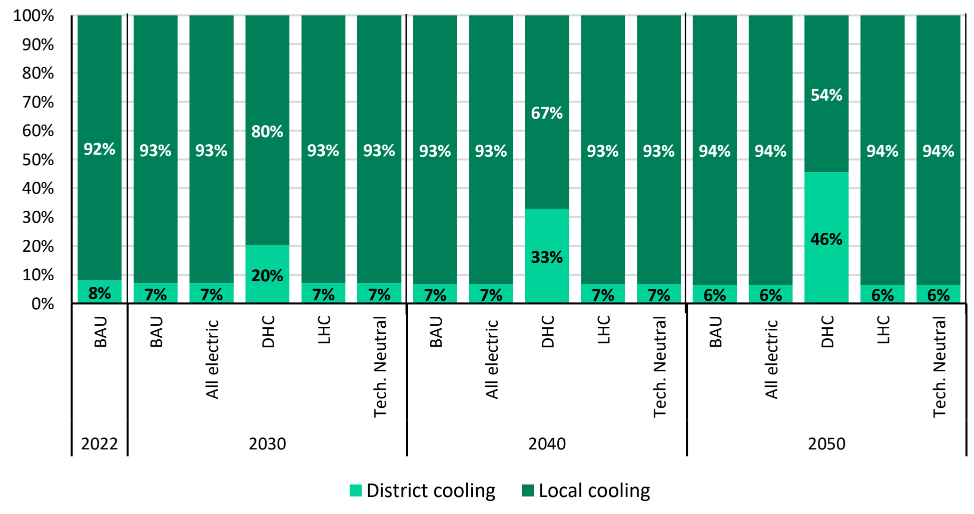
Heating and cooling capacity (MW), 2022-2050



Comparison of share of heating production per pathway, 2022-2050



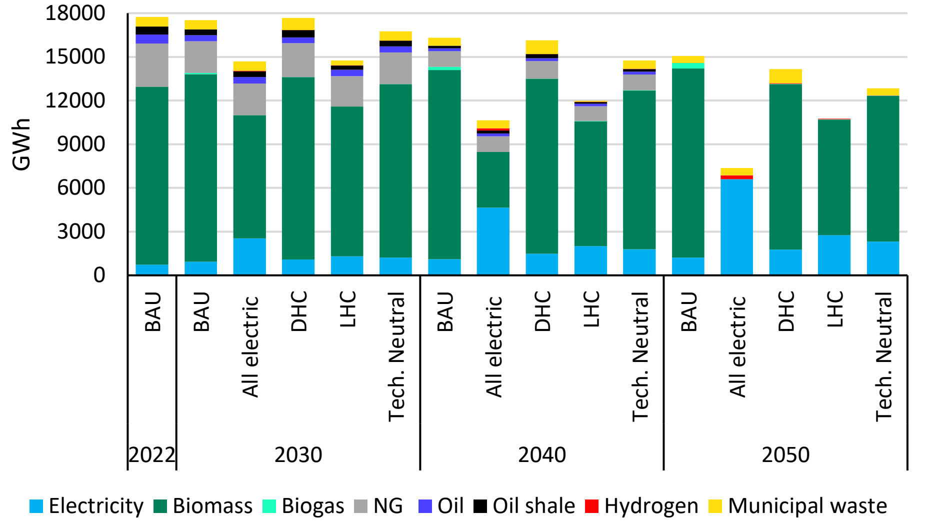
Comparison of share of cooling production per pathway, 2022-2050



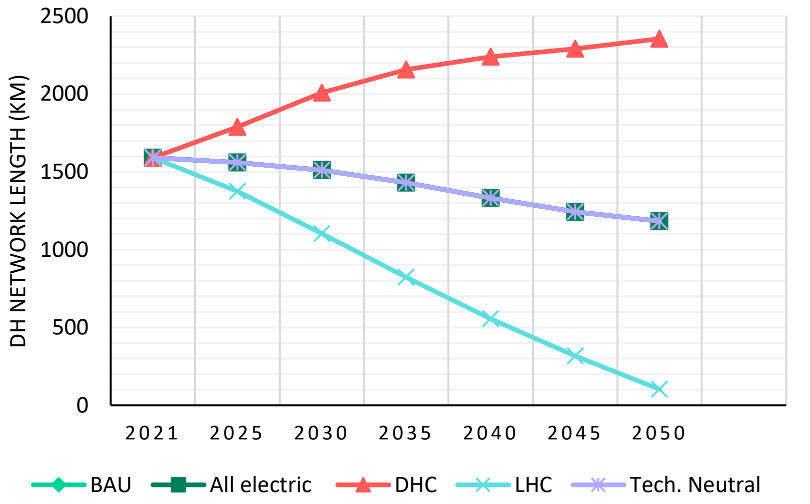
Emissions (ktCO2eq.)

GHG emissions	2022	2030	2040	2050	Total commulative 2022-2050
BAU	1312	786	352	12	2462
Alll electric	1322	876	363	0	2562
DHC	1314	844	409	0	2567
LHC	1304	736	300	0	2340
Tech. neutral	1309	785	349	0	2443

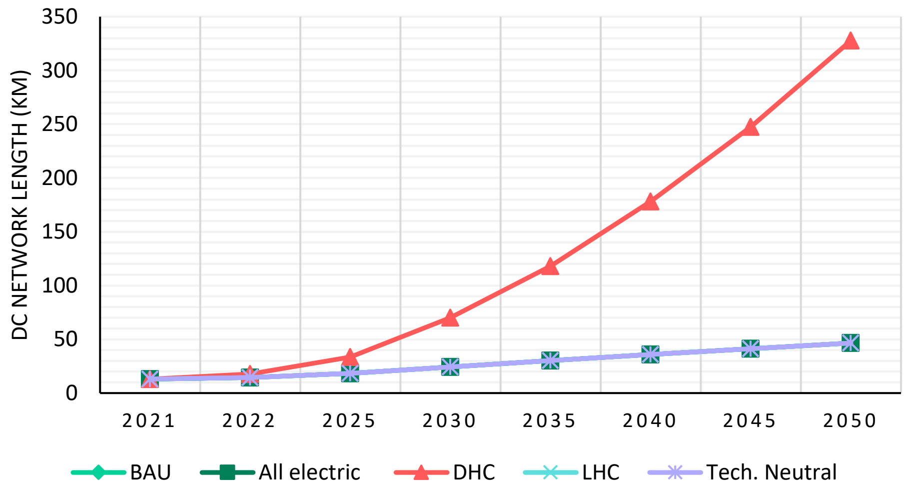
Fuel requirements (GWh)



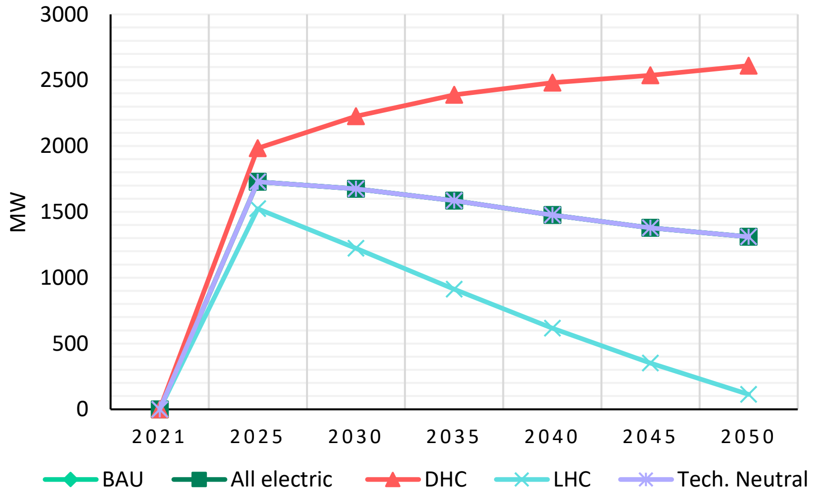
DH network length prognosis (km)



DC network length prognosis (km)



Heat storage requirement for DH (MW)



1.2 Deliverable 4: Analysis of Socio-economic impacts

The aim of Deliverable 4 was to assess the socioeconomic impacts of the pathways toward climate neutrality developed and analysed in Deliverable 3. The modelling focused on quantifying the impacts on energy sector investment, GDP, employment, and disposable income associated with each pathway.

Total Investment per pathway including) are presented in the following Table 1-2. The overall investment volumes include investments in building renovation, in H&C technologies, and in DHC infrastructure. Renovation of the Estonian building stock is the largest and a constant investment factor among all scenarios.

Table 1-2. Total Investment per pathway including (Technology investment, DHC infrastructure, building renovation)

	BAU	All electric	DHC	LHC	Tech. neutral
Total (2022-2050)	**€17,622M**	**€19,066M**	**€18,789M**	**€18,027M**	**€17,837M**
H&C technologies	*830*	*2274*	*1038*	*1236*	*1045*
DHC infrastructure	*€53M*	*€53M*	*€1,012M*	*€52M*	*€53M*
Building renovation	*€16,739M*	*€16,739M*	*€16,739M*	*€16,739M*	*€16,739M*

The recommended mix of All Electric and DHC scenarios will require front-loading important investments, compared to the two other scenarios (LHC and Technology neutral), which rely on the existing heating appliance stock, and therefore require lower investment in the short term. However, the replacement of these existing heating appliances will become inevitable over the 30 coming years, consequently reducing the difference between the investment needs of the All Electric/DHC scenarios and the other scenarios.

It was analysed that by 2050 the total GDP by main of H&C related activities grows in each scenario in comparison to the year 2022 (see Figure 1-2). In total the measured activities make up about 4.5% of Estonian GDP in 2022. But in 2050, this share is decreased to 3.0-3.8% with DHC scenario having the highest share of 3.8%. The H&C share in GDP decrease by 2050 mainly due to the decrease in heating consumption and decrease of renovation activities in later years of the period.

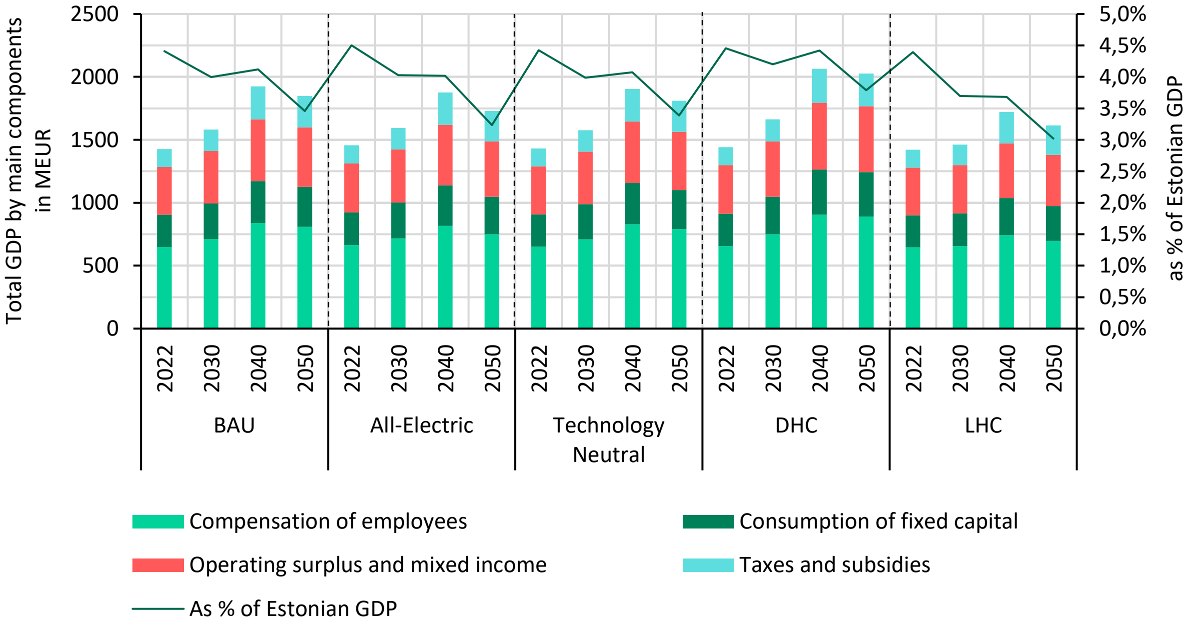


Figure 1-2. Total GDP by main components of H&C related activities and its representation as the % share of Estonian GDP

Employment changes follows the same decreasing trend by 2050, as H&C as the % of total Estonian GDP. H&C related employment will change from approximately 4% of Estonian employments to 2.4-3% by 2050 with DHC scenario presenting the highest share of H&C related employment among all scenario and LHC scenario presenting the least share of H&C employments in 2050.

Analysis of the distributional implications of the pathways on household income showed that renovations[8] will have considerable negative impact on disposable income in all scenarios. It was found that the total negative impact of renovation on disposable income significantly exceeds the positive impact of H&C costs decrease. Electrification scenario will have the strongest negative impact on disposable incomes due to the supposed high electricity prices and will less negatively impact all other scenarios having high bioenergy share. The impacts on disposable household incomes will significantly change if the fuel prices (bioenergy price increase, lower prices RES electricity) changes.

Figure 1-3 presents the average heating and cooling costs for households. Based on the baseline calculations in the financial model, the heating costs by 2050 are the lowest in DHC scenarios and relatively higher in All-Electric scenario. The household heating costs are affected significantly by the fuel or electricity price increase and scenario ranking should not be made without having a deeper look at the fuel and technology investment impact on the heating prices. We present the detailed of fuel/electricity and technology investment impacts on heating and cooling costs in the sensitivity analysis (Deliverable 6 – subsection 1.4).

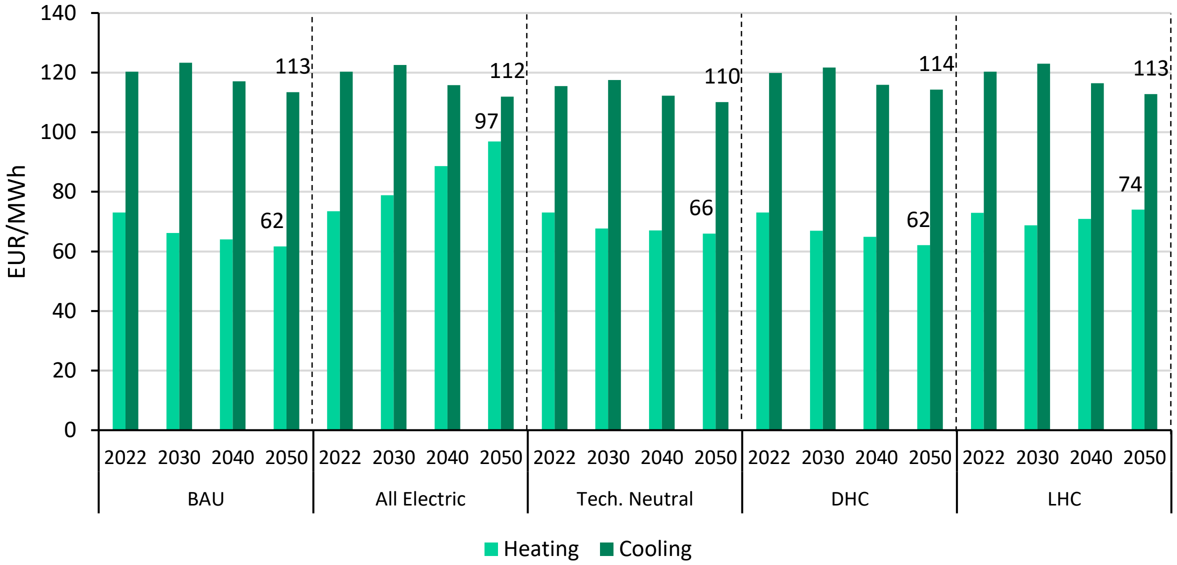


Figure 1-3. Average prices of heating and cooling for households per MWh (w.o. VAT)

1.3 Deliverable 5: Risk analysis

The overall aim of the risk analysis is to perform thorough risks by choosing alternative scenarios, with descriptions of their likelihood and potential impacts as well as proposed measures for mitigation and avoidance. Detailed risk analyses have been done for each scenario compared to the "business as usual" scenario. The risk analysis was focused on 6 risk groups: technological risks, regulatory risks, societal risks, energy markets risks, economical risks, and environmental risks. A detailed analysis of the risks can be found in the Deliverable 4-6 report.

The adopted methodology for risk analysis was aimed at evaluating stakeholders' perception of these risks, and how different scenarios may be affected by them. To do so, a questionnaire was shared with stakeholders, asking a series of open questions, and requesting stakeholders to rate the likelihood and severity of different risks for each pathway. Table 1-3 shows the maximum risk score for the likelihood of occurrence and the severity of the risk across the scenarios for their respective high-impact risk groups.

Table 1-3. Risk perception per pathway (Maximum risk score by scenarios)

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[8] In the base calculation of model, it was assumed, that 30% of renovation costs will be covered by state and other part with bank loan. The latter have been assumed to have 10-year term and 4% annual interest rate.

Scenario	Likelihood of occurrence (key risk group; score)	Severity of the risk (key risk group; score)	Total*	Summary
BAU	Energy market risk; 24	Regulatory risks; 25	16.33	Stakeholders perceive the BAU scenario (maximum use of bioenergy) of low to medium risk, where the conventional heating systems will not pose any new risks, but bioenergy's future climate and economic impacts will result in challenges
DHC	Regulatory risks; 32	Regulatory risks; 35	16.75	Less risky scenario, overall liked by stakeholders
Electrical	Energy market risk; 32	Social risks; 37	17.25	Medium risk scenario. Very exposed to electricity grid development and HP technology investment reduction in Estonia
Tech. Neutral	Energy market risk; 38	Energy market risk; 38	19.00	Moderately more risky. Exposed to high energy market risk
LHC	Energy market risk; 31	Energy market risk; 27	19.33	Riskiest scenario, stakeholders moderately negative about it. Main risks are energy market related (security off supply in economically vulnerable areas and, electricity grid development, and unexpected fuel price increase)

**The total points are obtained by adding the Likelihood and Severity max points and dividing by the number of respondents. Some were answered by 3 and some by 4 representatives of the interviewed institution.*

1.4 Deliverable 6: Sensitivity analysis

Sensitivity analysis is a method used to determine how different values of an independent variable affect a dependent variable based on a set of assumptions. The sensitivity analysis was carried out for relevant impacts estimated in Stage 4 (Deliverable 4) to scenarios developed in Stage 3 (Deliverable 3).

The sensitivity analysis has been performed for the following variables – which are inherently the most precarious to predict and least verifiable:

- fuel prices and
- technology cost.

The approach to sensitivity analysis was straight forward: the independent variables were changed within certain amplitude based on the middle value defined in modelling assumptions and then the respective values on modelling outcome (dependent values) were measured.

The fuel prices for NG, biomethane, electricity, wood fuels, shale oil, and hydrogen were varied in sensitivity calculations. Only the basic tariffs were changed and the so-called controllable factors – taxes, transfer fees, local mark-up – remained unchanged. Technology costs can be considered as second main source of uncertainty for H/C prices and costs. Investment costs of the heating and cooling technologies have been simulated in the sensitivity analysis:

- Heat pumps (all types).
- Hydrogen technologies (both, boilers, and CHP-s).
- Solar thermal collectors.
- Waste heat technology.
- All cooling technologies.

So-called old technologies (biomass and natural gas boilers and CHP's etc) have not been tested, as significant investments in these technologies are no longer planned and their cost uncertainty is lower.

The range of change (fuel prices and technology costs) was from -20% to +20% (with 5% steps) from baseline. Sensitivity was measured to the means of the dependent variables over the whole period (2022–2050). The key sensitivity results are presented in **Table 1-4**. It was analysed that the most important is to monitor the impact of fuel prices on prices of H&C, as they can be estimated with the greatest certainty (compared to impact on GDP, taxes etc).

The technology investment costs have the highest impact on All-Electric scenario (with a technology investment cost increase to H&C cost elasticity[9] of 0.14). Whereas the fuel prices have the highest impact on LHC scenario (with a fuel price increase to H&C costs elasticity[10] of 0.62).

Our conclusion based on scenario evaluation indicators (see sensitivity indicators in **Table 2-3**) is that the electrification (All Electric) scenario is mainly CAPEX-driven, while the other three scenarios rely mainly on bioenergy cost and are therefore fuel-cost driven. This means that given the price hike of biomass and electricity, the Levelized costs of heating will be more affected in scenarios where bioenergy has a higher share in comparison to the All-Electric scenario. Based on the current (2022) electricity and biomass price increase, Table 2-3 (last row) shows 3-4 times increase in average household heating costs (24-32 EUR/MWh) for DHC, LHC, and Technology Neutral scenarios in comparison to the All-Electric scenario (8 EUR/MWh). This elevates the average household heating costs in the other scenarios very close to the Electrified household heating costs and any further biomass price increase will result in the All-Electric scenario having 2nd most competitive heating costs only after the DHC scenario. So, the mix of these will bring a well-balanced and positive impact on heating costs.

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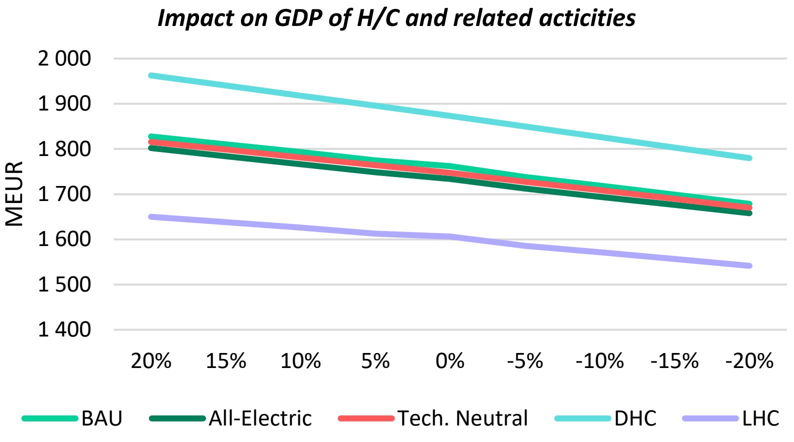
[9] Elasticity 0.14 means that when the technology investment costs increase by 1% the H&C costs will increase by 0.14%.

[10] Elasticity 0.62 means that when the fuel prices increase by 1% the H&C costs will increase by 0.62%.

Table 1-4. Key sensitivity results

<table>
<tr><th>Sensitivity to changes of fuel prices</th><th>Sensitivity to changes of fuel prices</th></tr>
<tr><td>


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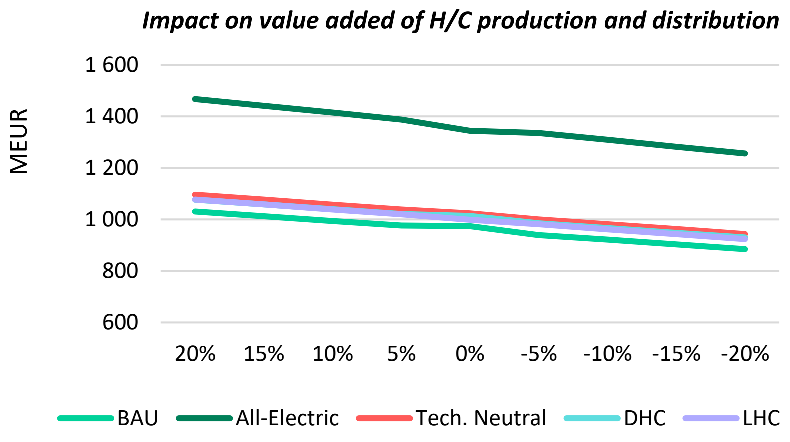

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<tr><td>Sensitivity to changes of fuel prices</td><td>Sensitivity to changes of technology costs</td></tr>
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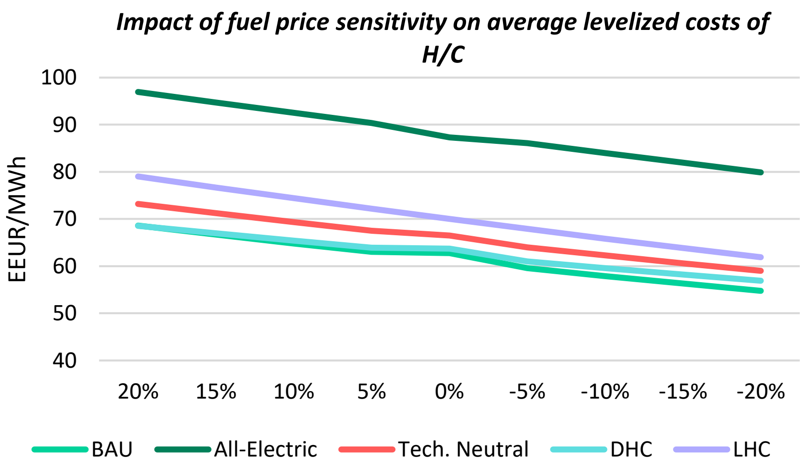

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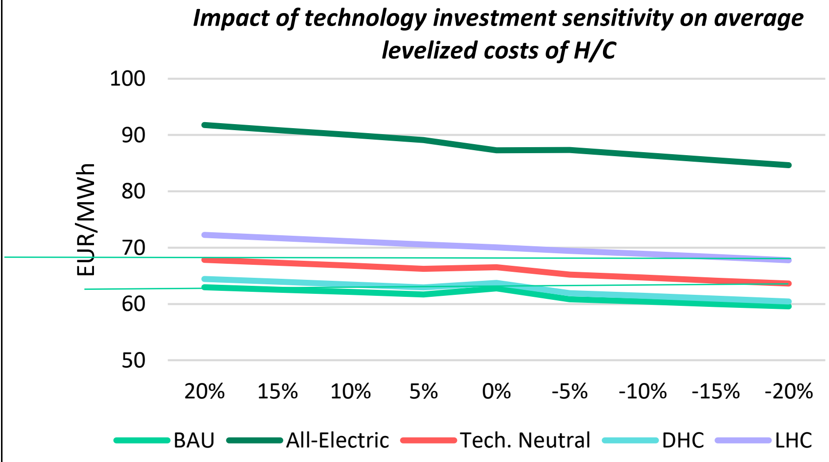

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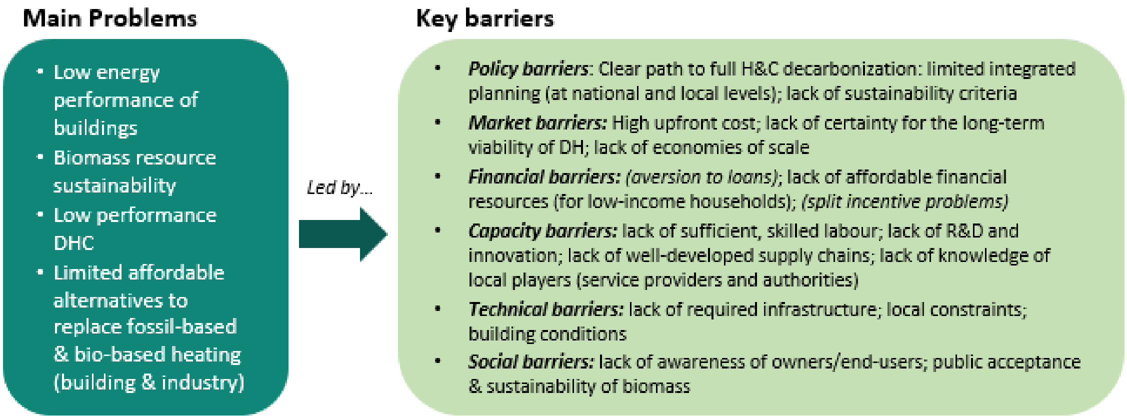
1.5 Deliverable 7: Action plans

The aim of Deliverable 7 is to bring together the results of the previous deliverables and propose policy actions for the facilitation of implementation of each pathway.

Main problems and key barriers

The Deliverable 7 report provides policy actions based on the main problems and key barriers relating to fully decarbonising H&C in Estonia. Figure 1-4 below summarises these main problems and key barriers. Addressing these problems and tackling these key barriers are crucial to ensure that consumers and the H&C sector opt for renewable H&C solutions and invest in energy efficiency improvements.

Figure 1-4 Main problems and key barriers to fully decarbonising H&C in Estonia



Key actions at pathway level

In the report, eight policy areas are identified, which each have a set of related policy actions addressing the main problems and key barriers. Table 1-5 provides a general description of each of the policy areas, including objective, timeline, responsible body, key stakeholders, and costs. In the report, the policy actions are differentiated for each pathway where appropriate.

Table 1-5. Key messages (action sets) as per responsible stakeholders (consumers, State Government, local authorities etc.)

Action sets	Objective	Timeline	Responsible	Other key stakeholders	Cost
1. Streamline integrated H&C planning process	Increase planning coherence and optimize EE and RES actions	Mainly short-term	MKM	Local authorities, DHC and electricity grid operators, CA, KEM, MEM	Low
2. Phase the renovation wave and integrate renewable supply	Improve the energy performance of buildings to reduce heat demand and encourage the integration of RES H&C in renovation	Short/medium-term	BA & KredEx	Ministry of Finance, local authorities, construction sector, building owners	Medium/High
3. Development of the required infrastructure	Ensure that the DHC sector sufficiently invests in the extension and refurbishment of the DHC network	Short-term	MKM	DHC network operators, local authorities, KEM, CA, energy communities	Medium/High
4. Strengthen local authorities' role in H&C decarbonisation	Engage local authorities to be active in H&C decarbonisation planning	Short to long-term	MKM	Local authorities, CA	Medium
5. Set up level playing field and creating a market	Ensure that RES H&C technologies are competitive with fossil-based H&C	Short to long-term	KredEx & CA	HP sector, RM	Medium/High

Action sets	Objective	Timeline	Responsible	Other key stakeholders	Cost
6. Empower all consumers, especially households	Engage consumers to be active in H&C decarbonization	Mainly short/medium-term	MKM	KredEx, KIK, local/regional authorities, BA, industry, building owners	Medium
7. Strengthen professionals' skills and knowledge	Ensure that there is enough labor capacity in H&C sector	Short-term	Ministry of Education	Unemployment insurance fund, KIK, BA, professionals in H&C sector	Medium/high
8. Mobilize and mainstream financing and funding	Ensure that all financing/funding is effectively mobilized to H&C sector and consumers	Short to long-term	MKM	Financial institutions, building owners	High

MKM = Ministry of Economic Affairs and Communication; RM = Ministry of Finance; CA = Competition Authority; KEM = Ministry of Environment; MEM = Ministry of Rural Affairs; BA = Building Authority; KIK = Environmental Investment Centre
Timeline: short-term = 2023-2024; medium-term = 2025-2030; long-term = 2030+
Costs: low = admin. costs only; medium = admin costs but long-term; high = admin. costs + investment costs required

Priority actions per pathway

Table 1-6 below provides an overview of these actions and identifies which actions are a priority for which pathways. Priority actions are policies that are crucial for the success of the pathway, whereas supporting actions are important policy actions but not as critical. The actions which are shared priorities across the pathways are highlighted. These policy actions are considered no-regret actions, as they play an important role regardless of the pathway selection.

Table 1-6 Overview of priority actions per pathway

Policy area	Actions	All electric	DHC	LHC	Tech neutral
Streamline integrated H&C planning process	1.A. Establish integrated infrastructure planning at local level	P	P	P	P
	1.B. Promote cooperation between electricity grid operators and DHC grid operators	P	✓		✓
	1.C. Mainstream bioenergy in a complete bioeconomy roadmap/strategy	✓	P	P	P
Phase the renovation wave and integrate renewable supply	2.A. Incentivise replacement of heating systems when undergoing deep renovation	P	P	P	P
	2.B. Accelerate the renovation of worse performing buildings	P	P	P	P
	2.C. Energy efficiency/renewable system mortgages and repayment of investments through property taxes	✓	✓	✓	✓
Development of the required infrastructure	3.A. Incentivise existing DHC refurbishment & shift to geothermal, solar and HPs	P	P		P
	3.B. Combine renovation programmes with DHC refurbishment	✓	✓		✓
Strengthen local authorities' role in H&C decarbonisation	4.A. Empower local authorities to play an active role in H&C decarbonisation, oblige them the plan H&C decarbonisation	P	P	P	P
Set up level playing field and creating a market	5.A. Incentivise/promote individual HP when most appropriate option	P		P	P
	5.B. Establish a gradual carbon pricing	✓	✓	✓	✓
	5.C. Adjustment of markets, investments, regulation, taxes, tariffs & levies to promote HPs, and other RES based heating appliances or DHC	P	P	P	P
Empower all consumers, especially households	6.A. Engage dialogue with industry to analyse best decarbonisation options (at 2050)	P	P	P	P
	6.B. Facilitate the renovation of specific market segments to replace heating systems	✓	✓	✓	✓
Strengthen professionals' skills and knowledge	7.A. Support developing the entire supply chain with qualifying companies (design, architects, construction workers, installers, operators, owners)	P	P	P	P
	7.B. Education, training and certification of energy consultancies and heating installers	✓	✓	✓	✓

Policy area	Actions	All electric	DHC	LHC	Tech neutral
	7.C. Support research and development of new technological solutions	P	P	P	P
Mobilise and mainstream financing and funding	8.A. Ensure adequate and integrated financing of all renovation instruments	P	P	P	P
	8.B. Establish integrated financial and fiscal strategy for long-term decarbonisation of H&C	P	P	P	P

P = priority action; ✓ = supporting action
Shared priorities are in bold.

2 Deliverable 8: Key results and findings

Deliverable 8 aims to summarise the performed activities and provide corresponding recommendations for further actions based on these previous project results, including evaluation and monitoring of project outcomes. The result of which is a synthesised presentation of the results of all of the project activities.

2.1 Key findings

Estonian heating and cooling sector can reach carbon neutrality by deploying different technologies up to 2050. **All the considered scenario options follow GHG emission reduction trajectory and achieve carbon neutrality by 2050**. The comprehensive summary of the key findings can be found in Table B - 1 in the Annex B.2.

2.1.1 Heating and cooling data availability and key challenges

Currently available data on local heating and cooling has significant gaps and Estonia needs to invest into upgrading building registry, which would allow for much better and more targeted policies. Due to the absence of local heating and cooling consumption data, the demands during this study had to be calculated based on the yearly averaged heating and cooling factors of different building types. But this way of demand calculation is sensitive to the underline assumption and the quality of the building stock data. Digitalization of the Estonian building register data (ehitisregister-EHR) is inevitable to have an updated database in real-time. To increase the data availability, detailed data sets on heating and cooling consumption (especially for local heating and cooling) by fuel and by technology could also be included in the national statistics libraries (e.g., Statistics Estonia).

2.1.2 Data breakdown and excel tool usability

Heating and cooling demands for each market participant according to their location and heating connection type were not obtained rather they were calculated by the building stock data obtained from Estonian Building Register (EHR). Most recently updated numbers (data obtained up till 2021) for current areas (m^2) for each market participant (single houses, apartment buildings, and services/commercial buildings) are multiplied with the heating and cooling requirements (kWh/m^2y) for that respective market participant.

The excel modelling tool provides a user-friendly interface for the heating and cooling calculation. The model performs calculations of heating and cooling production from a list of different technologies (see technology list in Figure B - 1) depending on the chosen penetration level for different market participants up to 2050. Heating and cooling consumption factors can be manipulated along with the other heating and cooling coverage and technology parameters by building type and location (urban/non-urban). Local governments can use the excel tool as a useful calculation tool to create a local strategy for carbon-neutral heating and cooling.

2.1.3 Biomass dependency and status quo change

In terms of Biomass dependency across the scenarios, the key finding is that based on sustainability, availability, and security of supply, biomass use is to maintain the status quo in local and district heating (except All-electric scenario). Future export reductions can also act as a triggering effect for the domestic biomass availability in large volumes. The overall biomass consumption in 2050 is 12.986 TWh for BAU scenario, 11.37 TWh for DHC scenario, 7.93 TWh for LHC scenario, and 9.99 TWh for the technology neutral scenario in comparison to 12 TWh of biomass use in 2021. Whereas the All-Electric scenario presents no dependence on biomass by 2050.

If biomass materials' sustainable/carbon-neutral status is to be changed in the future. In that case, the status quo will result in heat pumps favouring the most market-ready energy-efficient heating option. Then irrespective of the selected scenario, high level of integration of electrified solutions will take precedence (both in local and at district level technologies).

2.1.4 Energy efficient technologies

Heat pumps are versatile and offer high efficiency levels even in cold temperatures. Just 25%[11] of the energy used by a heat pump installed in a single house or apartment building is provided by electricity, with the remaining 75% being generated by the environment through the ground, water or air (depending on the type of HP system). Owing to this fact, large HP installations for services/commercial buildings or for district heating systems can take advantage of different waste heat streams as an input (sewage water in W/W HPs, lake/sea water, mine water, industrial low exhaust air etc.). Owing to the stated technology benefit, All-electric scenario will require 6.5 TWh of electricity (2.583 TWh for building sector's H&C demand and 3.9 TWh for industrial heating demand) where Estonia heating and cooling will completely shift to the electrified solutions.

2.1.5 Technologies to be developed further

The list of considered technology in this study for different market participants can be seen in the Annex B.1 – Technology list and overview of the model structure

Research and innovation priorities for building sector:

1. Develop solutions to accommodate fluctuating supply and demand from renewable energy sources, especially combined with large-volume seasonal heat storage for DHC infrastructure. Invest in new storage technologies (e.g., underground sand batteries[12]). which serve will serve can be used for sector coupling (power and heat sectors).
2. Test Estonian geothermal resources with operational pilots (a project from the Geological survey of Estonia is underway).
3. Foster research into solar thermal technologies to provide both clean electricity and heat in large quantities.

Research and innovation priorities for industries:

1. Design high-temperature (up to 200°C) heat pumps for industrial use – one of the main potential game-changing technologies.
2. Apply technology's integration approach when designing industrial heating solutions. Integrate thermal energy storage (TES) technologies with other thermal technologies. For instance, waste heat recovery and concentrated solar power (CSP) storage[13], in a modular manner to satisfy different industrial needs.
3. Develop solutions that can help couple the heat sector with the electricity sector.

2.1.6 Heat storage

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[11] Typically, achievable coefficient of performance (COP) of 4. Meaning, one unit of input electricity gains 4 units of produced heat.

[12] https://polarnightenergy.fi/technology

[13] https://www.solarpaces.org/how-csp-thermal-energy-storage-works/

Heat storage capacities such as 'levelling tanks' will help to smoothen the consumption curve at the peak loads. Seasonal heat storage as hot water storage tanks is found to be a financially challenging option for district heating systems as the large capital investments in hot water seasonal storage tanks will spike the prices which will most likely result in difficulties in attaining approvals for the price of heat from the Competition Authority. As of 2021, there are no heat and cooling storage present in Estonia. As a modelling result output, it is calculated that in the district heating scenario, 2.61 GW of heat storage capacities will be required by 2050 to deal with a large shift towards DH via hot water storage tanks for covering the peak demands.

Underground thermal energy storage technologies can be one of the possible seasonal heat storage solutions e.g., heat storage in geothermal wells, wind and solar power storage as heat in the sand (underground sand batteries). The development and techno-economic feasibility tests of these technologies in the Estonian context should be one of the Governments' priorities till 2030.

2.1.7 District heating and cooling supply infrastructure development

District heating development will require good strategical planning to gain/maintain the necessary density of DH infrastructure. The supply infrastructure will develop according to the need and circumstances and cannot be predicted to the exact line lengths. But a simplification has been made to analyse the change in DH and DC pipeline lengths. Based on average heat consumption density of the current DH infrastructure (i.e., 2.66[14] MWh/m), after the heat coverage shift from local heating towards DH, the overall length could increase from ~1,591 (2021) km to ~2,355 km by 2050. By taking a minimum cooling consumption density of 2 MWh/m, if all the cooling demand coverage in urban municipalities is shifted to the DC, 328 km of DC lines would be required.

2.1.8 The necessity of DHC infrastructure

The existence of a district heating and cooling grid (network) is necessary to utilize low enthalpy energy sources (mainly local RES (geothermal and solar)) and to valorise waste or surplus heat, reducing the dependence on conventional energy production systems, ensuring efficient use of energy and for energy market integration via sector coupling (electricity and heat). A major first step towards low temperature district heating (LTDH) networks can be to deploy solar or geothermal DH systems and to add the waste heat sources directly in the vicinity of district heating areas, where the small waste heat recovery sources can be the local supermarkets (services and commercial sector) and sewage water lines and large sources of waste heat provision can be industrial waste or surplus heat.

2.1.9 Benefits of demand response measures

The peak shaving effect of the demand response measures will direct the heat producers, and the reduced energy bills can direct the consumers to use demand response measures. Under the normal load, district heating is produced in an increasingly eco-friendlier way. But the heat during consumption peaks is generally produced in backup heat plants powered by fossil energy sources. Implementation of demand response measures can reduce the extent of these peaks by using artificial intelligence-based smart control systems on the consumer side to reduce the temperature levels at times of high district heating grid load. Digitalization (AI-based smart control systems) will encourage consumers to be able to save energy during the time intervals when the heated space is not occupied and will reduce the temperature to the minimum just to keep the space warm enough. State support under the digitalization drive can be the motivating factor for DH companies to offer consumers these smart solutions without posing large costs directly to the consumers.

2.1.10 Effect of advance building materials on H&C sector of Estonia

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[14] Heat consumption density of Estonian DH network communicated by the Competition Authority of Estonia.

Using Building integrated photovoltaic (BIPV) in Estonian building stock will trigger decentralized electricity production close to its use for heat production to further support the deployment of heat pumps and other electrical technologies. The annual average of BIPV geographical potential of Tallinn is 637 kWh/meter square[15]. To show the indicative effect of BIPV on Estonian building stock, Table 2-1 presents the collective electricity production with BIPV by 2050 If an installation of 10% on the total building stock for different market participants is assumed. (The 10% installation rate is only taken as an indicative effect and does not represent a possible exact prognosis of the exact situation. The market will decide what percentage of Estonian building stock will have BIPV technology).

Table 2-1. An indicative electricity production potential of installing BIPV on 10% of the building area for different market participants by 2030 and 2050

Building type	**2030**		**2050**	
	Installation area (mil. m²)	**Electricity production (GWh)**	**Installation area (mil. m²)**	**Electricity production (GWh)**
Single houses	28.84	1837	31.59	2012.2
Apartment buildings	25.47	1622.3	29.62	1886.6
Services /commercial	28.71	1829.1	41.64	2652.2

2.1.11 The role of mobility in H&C sector of Estonia

We have analysed the Vehicle-to-Home (V2H)[16] or Vehicle-to-Building (V2B)[17] concept in Estonian context by employing small scale on-site storage, comprising BEV batteries. With advance AI based digitalized systems BEVs will have a big role in provide heat via HP. Table 2-2 exhibits the electrical energy provision potential of BEVs in Estonia for 2030 and 2050 which can be used to satisfy the heating and cooling provision of the Estonian Building stock, assuming if all BEVs are connected to buildings in providing electrical energy. (For detail assumptions on these calculations, see Chapter 8 of deliverable 3 report).

Table 2-2. Indicative electrical demand coverage by BEVs for electrified heating and cooling solutions for different market participants

Houses						
	2030			**2050**		
Scenarios	**Electricity demand for H&C (GWh)**	**coverage from 1 cycle**	**coverage from 25 cycles**	**Electricity demand for H&C (GWh)**	**coverage from 1 cycle**	**coverage from 25 cycles**
BAU Scenario	370	1.3%	31.8%	309	7.1%	100.0%
DHC	391	1.2%	30.1%	303	7.3%	100.0%
LHC	419	1.1%	28.1%	420	5.2%	100.0%
Electrification	638	0.7%	18.4%	869	2.5%	63.3%
Tech. Neutral	417	1.1%	28.2%	414	5.3%	100.0%
Apartment buildings						
BAU Scenario	79	5.9%	100.0%	108	20.3%	100.0%
DHC	56	8.3%	100.0%	7	100%	100.0%
LHC	116	4.1%	100.0%	300	7.3%	100.0%

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[15] Gholami, Hassan & Røstvik, Harald & Steemers, Koen. (2021). The Contribution of Building-Integrated Photovoltaics (BIPV) to the Concept of Nearly Zero-Energy Cities in Europe: Potential and Challenges Ahead. Energies. 14. 6015. 10.3390/en14196015.

[16] https://blog.wallbox.com/why-bidirectional-charging-is-the-next-big-thing-for-ev-owners/#:~:text=V2H%3A%20Vehicle%20to%20Home,embedded%20within%20the%20EV%20charger.

[17] https://sinovoltaics.com/learning-center/electric-vehicles/what-is-vehicle-to-building-charging-v2b/

Electrification	174	2.7%	67.5%	276	8%	100.0%
Tech. Neutral	81	5.8%	100.0%	110	20%	100.0%
Services/Commercial						
BAU Scenario	438	1.1%	26.8%	666	4%	82.5%
DHC	339	1.4%	34.7%	201	10.9%	100.0%
LHC	552	0.9%	22.5%	1060	2.1%	51.9%
Electrification	642	0.7%	18.3%	1248	1.8%	44.1%
Tech. Neutral	449	1.0%	26.2%	701	3.1%	78.4%

2.1.12 Socio-economic and sensitivity aspects of the pathways

Deploying the recommended scenario mix for carbon-neutral heating and cooling system in Estonia will require approximately 18.8-19 billion Euros for the period 2022-2050. Renovation of the Estonian building stock is the largest and a constant investment factor among all scenarios (i.e., 16.739 billion Euros). Renovation of the building stock has a vital and pivotal role in all the scenarios, especially in All Electric scenario, where HPs deployment at a wider scale is not feasible and cost-efficient with an older (poorly insulated) building stock. The overall investment volumes include investments in building renovation, in H&C technologies, and in DHC infrastructure.

All-Electric scenario is mainly CAPEX-driven, while the other three scenarios rely mainly on bioenergy cost and are therefore fuel-cost driven. This means that given the price hike of biomass and electricity, the Levelized costs of heating will be more affected in scenarios where bioenergy has a higher share in comparison to the All-Electric scenario. Based on the current (2022) electricity and biomass price increase, Table 2-3 (last row) shows 3-4 times increase in average household heating costs (24-32 EUR/MWh) for DHC, LHC, and Technology Neutral scenarios in comparison to the All-Electric scenario (8 EUR/MWh). This elevates the average household heating costs in the other scenarios very close to the Electrified household heating costs and any further biomass price increase will result in the All-Electric scenario having 2nd most competitive heating costs only after the DHC scenario. So, the mix of these will bring a well-balanced and positive impact on heating costs.

It was analysed that by 2050 the total GDP by main of H&C related activities grows in each scenario in comparison to the year 2022(see Figure 1-2). In total the measured activities make up about 4.5% of Estonian GDP in 2022. But in 2050, this share is decreased to 3.0-3.8% with DHC scenario having the highest share of 3.8%.

Employment changes follows the same decreasing trend by 2050, as H&C as the % of total Estonian GDP. H&C related employment will change from approximately 4% of Estonian employments to 2.4-3% by 2050 with DHC scenario presenting the highest share of H&C related employment among all scenario and LHC scenario presenting the least share of H&C employments in 2050.

Analysis of the distributional implications of the pathways on household income showed that renovations will have considerable negative impact on disposable income in all scenarios. It was found that the total negative impact of renovation on disposable income significantly exceeds the positive impact of H&C costs decrease. Electrification scenario will have the strongest negative impact on disposable incomes due to the supposed high electricity prices and will less negatively impact all other scenarios having high bioenergy share. The impacts on disposable household incomes will significantly change if the fuel prices (bioenergy price increase, lower prices RES electricity) changes.

2.1.13 Risk perception of the pathways

DHC was liked by most of the stakeholders and was perceived as the less risky scenario. Stakeholders perceive the BAU scenario (maximum use of bioenergy) of low to medium risk, where the conventional heating systems will not pose any new risks, but bioenergy's future climate and economic impacts will result in challenges. All-Electric scenario was projected as a medium risk scenario as it is very exposed to electricity grid development and HP technology investment reduction in Estonia.

Technology Neutral scenario was announced as moderately riskier as it is exposed to high energy market risks. LHC scenario was found to be the riskiest scenario as stakeholders were in general negative about it. As its main risks are energy market related (security of supply in economically vulnerable areas and, electricity grid development, and unexpected fuel price increase) and the abandonment of the well-developed DHC infrastructure. In conclusion of risk perception, the mix of DHC and All-Electric scenarios will serve better to achieve a carbon-neutral H&C system in Estonia.

2.1.14 Actions necessary to reach the goal

Across all the pathways, there are several actions that are necessary to enable the decarbonisation of the H&C sector, including:

- **Actions to streamline the H&C planning process**. The same intensity and commitment is required for all pathways, as this is a central piece for a long term decarbonization. Of course, planning should be tailored to the selected pathway(s), for instance, focusing on integration of planning for H&C and electricity in the All-electric pathway and mainstreaming bioenergy in the bioeconomy strategy in the pathways reliant on bio-based heating.
- **Mainstreaming bioenergy in a complete bioeconomy strategy**. The current energy system in Estonia relies massively on bioenergy, hence, whatever the expectations in the future, the use of biomass resources should be regulated and/or promoted in coherence with a global bio-economy vision.
- **Phasing the renovation wave and integrating renewable supply**. All pathways require the Renovation Wave to be effectively implemented to make buildings sufficiently energy efficient (to lower H&C demand) and integrated with renewable H&C systems. Synchronization of energy performance action and switch to renewable is key and should be tailored to each pathway to ensure appropriate design and heating system efficiency.
- **Actions to refurbish the existing DHC infrastructure, where feasible**. For the pathways where DHC is still relevant (all but the LHC pathway), refurbished DHC infrastructure is required to reduce heat/cool demand as well as increase renewable integration in the DHC system.
- **Actions to develop the required new DHC infrastructure, where appropriate**. For the pathways where DHC is still relevant and further developed (all but the LHC pathway), highly performant infrastructure (4th or 5th generation) is required to reduce heat/cool demand as well as increase renewable integration in the DHC system.
- **Empower local authorities to play an active role in H&C decarbonization**. All local authorities (cities, municipalities) play a crucial role in the planning of H&C systems. Empowering them with clear guidance on H&C decarbonization planning, dedicated financing and administrative support plays a key role in encouraging them to play an active role in H&C decarbonization.
- **Set up a level playing field and create a market for renewable alternatives**. These actions should be tailored to the pathways' focused alternative H&C technologies to create a level playing field with traditional fossil-based H&C technologies (and possibly bio-based heating system for the All-Electric pathway) in order for these alternative technologies to achieve economies of scale. Market development on the Estonian territory is crucial for some technologies to compete (e.g. HP in Estonia are still costly, only a market ramp up would lead to prices aligned with international markets).
- **Actions to empower industry and household consumers to decarbonize H&C systems**. H&C consumers (industry and households) require empowerment, beyond the energy renovation activities, in order to be well-informed and encourage to participate in H&C decarbonization. They should all be provided technical assistance to ensure well-informed choices, in line with their needs and socio-economic situation. Dedicated actions would be required for low-income households.

- **Actions to strengthen professional skills in the H&C market**. The shortage of skilled labor required for decarbonizing heating and cooling needs to be addressed in terms of improving skills within the existing H&C supply chain. All professionals should be considered.
- **Mobilize and mainstream financing and funding**. Given that various actions include different financing schemes for the H&C sector and consumers, actions are required to ensure that the necessary financing and funding are efficiently mobilized and mainstreamed, on the long term (and not only until 2027, end of the RRP).

2.2 Pathway advice

Overall pathway recommendation is made based on the comparison of overall scenario outputs (performance indicators). The overview of the scenario performance is presented in Table 2-3**.** Scenario performance is quantified by the overall scenario performance score. For the overall scenario score, the performance indicators scores are multiplied by the given performance indicator's weight and then the sum of these scores is divided by the total number of the performance indicators. Indicator weights have a range 1-5 (indicator with weight 5 being the most important one) are assigned based on their sensitive nature to the scenario deployment (weights assigned by project teams' expert opinion).

Table 2-3. Pathway performance indicators

Indicator	***BAU***	***All electric***	***DHC***	***LHC***	***Tech. neutral***	***Weights***
New installed capacity (GW) (2022-2050)	1.9	3.866	2.197	2.7	2.248	1
Input energy/Fuel consumption (TWh)	13.4	7.1	12.1	10.6	11.5	5
Biomass dependency (use) by 2050 (TWh)	12.99	0	11.37	7.93	9.99	5
GHG emissions in 2050 (kt $CO_{2eq.}$)	12	0	0	0	0	5
Total investment requirements (2022-2050)	€17,621M	€19,066M	€18,789M	€18,027M	€17,837M	1
Average heating costs for households in 2050 (EUR/MWh)	62	97	62	74	68	5
Average cooling costs for households in 2050 (EUR/MWh)	113	112	114	113	110	3
Impact of fuel prices on H/C prices (*Elasticity)	0.59	0.53	0.54	0.62	0.58	5
Impact of technology investment costs on H/C prices (*Elasticity)	0.08	0.14	0.10	0.08	0.09	2
H&C activities as % of GDP in 2050	3.5%	3.2%	3.8%	3.0%	3.4%	2
Employment in 2050 due to HC activities (jobs)	16367	15216	18064	14133	16004	2
Scenario risk perception by stakeholders	Low to medium	Medium risky	Less risky	Riskier	Moderately more risky	5
Overall score	**10.8**	**13.1**	**12.8**	**10.7**	**12.3**	
Overall scenario ranking	**4th**	**1st**	**2nd**	**5th**	**3rd**	
CAPEX vs. Fuel driven options						
Average heating costs for HH in 2050 (EUR/MWh) - 2021** fuel prices	62	97	62	74	68	
Average heating costs for HH in 2050 (EUR/MWh) - 2022** fuel prices	94	105	87	102	92	
Increase in average heating costs based on fuel cost increase (EUR/MWh)	**32**	**8**	**25**	**28**	**24**	
Legend (Indicator score by colour)						
Colour	🟩	🟦	🟨	🟧	🟥	
Score	**1**	**2**	**3**	**4**	**5**	

**Elasticity: Sensitivity result parameter e.g., Elasticity 0.5 means that, when the fuel prices increase by 1% the price for H/C will increase by 0.5%*

***Electricity (based on average Nord pool prices for the first 2 quarters of 2022): 137 EUR/MWh*

***Biomass (growth rate based on the firewood price comparison of 2022 2nd quarter data with 2021 2nd quarter data): 2.5 times price increase (22 EUR/m3 in 2nd quarter in 2021 vs. 55 EUR/MWh in 2nd quarter in 2022)*

Based on the overall scenario performance scores, we recommend utilising the mix of **All-Electric and DHC scenario to achieve carbon neutral heating and cooling in Estonia**, which would mean:

- Electrifying the existing DHC, by integrating large scale heat pumps;
- Deploying new DHC, mainly in urban areas with high energy use density, but also in some semi-urban areas or more dense rural areas (e.g. village centrums);
- Complementing the supply with individual HP, in urban areas (where DHC are not applicable) and in non-urban areas;
- Leveraging the highest mix of energy sources, by using:
    - Massive RES-electricity for efficient DHC & individual HP (assuming a ramp up of RES in the electricity mix);
    - A mix of solar, geothermal and bioenergy to supply DHC (complemented by large HP);
    - Bioenergy for small share of individuals (where neither DHC, nor HP are applicable), based on locally produced resources.

Even though the All Electric may seem to be the expensive option in some aspects, when looking at the cost for final consumers, its combination with the DHC scenario allows to leverage several advantages:

- Adapting to the local situation and specific needs, as none of the scenarios could on their own comply with all specific needs and constraints. In some places it may be more effective to deploy new DHC, or to refurbish existing DHC, while in other places deploying heat pumps may be more appropriate and cost-effective option;
- Increasing the number of options to decarbonise DHC, by speeding up the improvement of their performance, deploying large scale heat pumps to supply DHC and leveraging the use of low temperature energy sources (solar, geothermal, or waste heat). The availability of local RES resources should also be used as a criterion for the deployment or refurbishment of DHC;
- Strengthening the resilience of the energy mix, given the fact that the All Electric is mainly CAPEX-driven, while the other 3 scenarios rely mainly on bioenergy cost, and are therefore fuel-driven. Fluctuations of energy prices on international markets will have a higher impact on bio-based scenarios. In the current context of the Ukraine-Russia crisis, prices have increased significantly, especially for bioenergy. Electricity prices have also increased significantly, but given the higher efficiency of heat pumps and hence lower electricity use, the price volatility has a higher impact on bio-based scenarios, while All Electric is less sensitive to price shocks;
- Combining different types of employment, with activities in installing new systems (e.g. new heat pumps) and at the same time operation and maintenance of large scale systems (e.g. DHC);
- Reducing significantly the pressure on biomass feedstocks, giving leeway to the deployment of a bioeconomy, and use of the same resource for material purposes, in order to maintain or improve the sustainability impact of its use;
- Building on existing assets, by the refurbishment of the existing DHC, where improving their performance is technically feasible;
- Maximising the energy efficiency principle, thanks to the high share of heat pumps (which is the most efficient regarding primary energy use);
- Reducing the electricity grid reinforcement, by deploying DHC to reduce the distributed installations of heat pumps, but also thanks to the fact that DHC can provide more

effective flexibility services to the electricity system than a portfolio of small scale systems;
- Keeping the lowest cost for energy consumers on the long term, thanks to the flexibility to choose the most cost effective option (between DHC and All Elec), and given the fact that increasing use of biomass feedstock due to a raising bio-economy will increase the pressure on bioenergy prices.

This mix of All Electric and DHC scenarios will require important investments, compared to the two other scenarios (LHC and Technology neutral), which rely on the existing heating appliance stock, and therefore require lower investment in the short term. However, the replacement of these existing heating appliances will become inevitable over the 30 coming years, consequently reducing the difference between the investment needs of the All Electric/DHC scenarios and the other scenarios. We assume full decarbonisation of the electricity system by 2050. If for the climate-neutral electricity strategy, a less renewable pathway is selected for electricity generation, we would then recommend increasing slightly the share of DHC (moving more from All Electric to DHC).

3 Answers to additional study questions

Based on the results of the previous project deliverables, the study questions are answered in Table 3-1.

Table 3-1. Answers to the additional study questions

Questions	**Answer**
1. What are the sources of the energy in carbon neutral heating and cooling system?	Renewable electricity sources, biomass, solar thermal energy, geothermal energy, waste heat (heat recovered from, sewage water, seawater, rivers, lakes, data centres, and electrolyser stacks) and surplus heat sources (excess industrial heat) in combination with the suitable heating and cooling technologies are the most promising energy sources for carbon neutral heating and cooling.
2. What (if anything) could replace biomass usage in the carbon neutral heating and cooling?	If biomass materials' sustainable/carbon-neutral status is to be changed in the future. In that case, the status quo will result in heat pumps favouring the most market-ready energy-efficient heating option. Then irrespective of the selected scenario, high level of integration of electrified solutions will take precedence (both in local and at district level technologies). Heat pumps are versatile and offer high efficiency levels even in cold temperatures. Just 25%[18] of the energy used by a heat pump installed in a single house or apartment building is provided by electricity, with the remaining 75% being generated by the environment through the ground, water or air (depending on the type of HP system). Owing to this fact, large HP installations for services/commercial buildings or for district heating systems can take advantage of different waste heat streams as an input (sewage water in W/W HPs, lake/sea water, mine water, industrial low exhaust air etc.). Owing to the stated technology benefit, All-electric scenario will require 6.5 TWh of electricity (2.583 TWh for building sector's H&C demand and 3.9 TWh for industrial heating demand) where Estonia heating and cooling will completely shift to the electrified solutions.
3. Which of the used technologies seem to be the most sustainable considering the whole supply chain?	At district heating and cooling level, the technologies which can be used in combination with the waste/surplus heat sources (e.g., air-to-water, water-to-water heat pumps, and absorption chillers) seem to be the most sustainable considering the whole supply chain. At the local heating and cooling level, for consumers in urban areas, air to air and air to water heat pumps and for non-urban areas ground source heat pumps (in addition to the A/W and W/W HPs) are a viable sustainable option given the fact that ground source heat pumps required large excavation areas which usually in urban areas are hard to acquire. Shallow geothermal well fields (<500m) in Narva and Mardu and groundwater geoenergy in Narva region also present the promising domestic energy sources for geothermal heat pumps but the technical feasibility is yet to be determined (ongoing project managed by Geological survey of Estonia[19]).**Error! Bookmark not defined.**
4. What should be the needed regulatory framework for such a vision to be accomplished?	Since establishing a sustainable, competitive and secure energy market has been the aim of the EU energy policy in recent decades, the Estonian heating and cooling system also needs to restructure in this line. This could mean that transition to a carbon-neutral HC system should be implemented in Estonia by gradually opening the HC market through an appropriate policy and regulatory framework. Such a framework must include but is not limited to: • Assess and map the potential HC suppliers and consumers for achieving to highest stakeholder involvement. • Design market tools for stimulating stakeholders to contribute to HC supply (e.g., via an unbundled and liberalized market where the price is defined competitively) • Facilitate renewables integration into the production network. • Development of strategic heating and cooling plans (mutually reinforcing local and national actions, mainstreaming sustainability as a critical principle, defining the scope and purpose). • Integrating low-temperature supply into existing buildings and district heating networks.

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[18] Typically achievable coefficient of performance (COP) of 4. Meaning, one unit of input electricity gains 4 units of produced heat.

[19] https://www.egt.ee/en/fields-activity-and-objectives/resources-earths-crust/geothermal-energy

Questions	Answer
	• Provide a proper structure for protecting socially vulnerable groups, especially from monopoly, while it avoids market distortion and facilitates investment in the HC market. Such a goal can be achieved via a high level of transparency in the pricing structure since consumers will lose trust in the district energy operators without transparency and reliability. This could lead to weak operation and potentially enter a negative cycle with disconnections, increasing pricing and lack of satisfaction. • Considering the geothermal issue described under question no 3, it is essential that the framework facilitates the fuel switch to geothermal energy, and the laws and regulations governing the licensing of geothermal and water resource extraction play a key role. Given the limited use of geothermal and water resources, there are possibly policy loopholes for their specific utilization for heating and cooling in Estonia. Developing a dedicated and streamlined geothermal and/or water (sea and river) licensing regime could attract more investment and facilitate the development of projects. Critical recommendations for a regulatory framework for geothermal DH are proposed by the GEODH project (Regulatory Framework for Geothermal District Heating in Europe)[20].
5. What are the needed technologies that must be further developed?	**Research and innovation priorities for building sector:** 4. Develop solutions to accommodate fluctuating supply and demand from renewable energy sources, especially combined with large-volume seasonal heat storage for DHC infrastructure. Invest in new storage technologies (e.g., underground sand batteries[21]). which serve will serve can be used for sector coupling (power and heat sectors). 5. Test Estonian geothermal resources with operational pilots (a project from the Geological survey of Estonia is underway). 6. Foster research into solar thermal technologies to provide both clean electricity and heat in large quantities. **Research and innovation priorities for industries:** 4. Design high-temperature (up to 200°C) heat pumps for industrial use – one of the main potential game-changing technologies. 5. Apply technology's integration approach when designing industrial heating solutions. Integrate thermal energy storage (TES) technologies with other thermal technologies. For instance, waste heat recovery and concentrated solar power (CSP) storage[22], in a modular manner to satisfy different industrial needs. 6. Develop solutions that can help couple the heat sector with the electricity sector.
6. What are the measures (guiding principles – inherent benefits) that direct the consumers and producers to use demand response measures? What is the impact of such a vision in terms of energy efficiency compared to the situation in 2020?	During the summer, heating is needed primarily for domestic hot water, but in winter, the need for heating can be extensive. Under the normal load, district heating is produced in an increasingly eco-friendlier way. Still, the heat during consumption peaks is generally produced in backup heat plants powered by fossil energy sources. Implementation of demand response measures can reduce the extent of these peaks by using artificial intelligence-based smart control systems on the consumer side to reduce the temperature levels at times of high district heating grid load. AI-based smart control systems will encourage the consumers to be able to save energy during the time intervals when the heated space is not occupied and will reduce the temperature to the minimum just to keep the space warm enough. In short, the peak shaving effect of the demand response measures can direct the producers, and the reduced energy bills can direct the consumers to use demand response measures. Demand response measures will help to establish low-temperature district heating areas, which in return have several benefits in a district heating system, such as increased electrical output from CHP-plants, increased heat recovery from industrial excess heat and geothermal heat, and an increased coefficient of performance if heat pumps are used in heat generation.

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[20] http://geodh.eu/wp-content/uploads/2012/07/D-3.5-GEODH-Regulatory-Framework-17-02-2014.pdf

[21] https://polarnightenergy.fi/technology

[22] https://www.solarpaces.org/how-csp-thermal-energy-storage-works/

Questions	Answer
7. What are the basic measures to provide sustainable heating and cooling?	Reducing dependency on fossil fuel sources via pushing demand response measures and increased rates of building renovations are the most important measures to provide sustainable heating and cooling.
8. What are the key aspects of carbon neutral heating and cooling economics?	Including renewable sources (solar thermal, geothermal, seawater etc.) in the district heating and cooling systems will put an additional charge on the final consumers if not appropriately managed, as deploying these technologies will require significant investment costs. Nonetheless, these technology options are most viable for the Estonian regions with dense heating and cooling network consumption densities (e.g., Tallinn and Tartu). Nevertheless, it is rather challenging to make an innovative business model for the areas with small district heating networks having very low consumption densities.
9. How to make the most of the energy market integration benefit towards the carbon neutral heating and cooling? How to maximize joint result of heating and cooling sectors?	'Open District heating concept', can help achieve the promising benefits of energy market integration towards carbon neutral heating and cooling. The concept of open district heating provides the flexibility for different market participants to participate openly in the system with the possibility to couple district heating and cooling systems (e.g., utilizing waste heat from grocery stores to heat the nearby buildings as modern systems for cooling stores' chilled and frozen sections can be directly connected to district heating and cooling networks so that all excess heat is recycled)[23].
10. What are the reasonings when developing new regions in district heating?	When the DH push is under consideration, multiple constraints and social factors must be considered. The DH share in the overall demand can be expanded by adding new consumers on the existing lines or adding new customers in areas where DH was not present before, and a new network must be constructed. Several district heating companies in Estonia (during the stakeholder discussions) mentioned that the first step in district heating coverage expansion is adding more customers to the existing DH networks before developing the new regions.
11. If and on which conditions, it is reasonable to divide operator of the grid from production? Which version has better security of supply? The role of energy system integration in both versions?	Separating production from transmission and distribution for a vertically integrated utility company is considered a key measure in liberalizing the electricity market through increased competition. Production is considered suitable for competition in a well-functioning electricity market. However, this is less common in the heat market. Like the deregulation of electricity and natural gas markets in many countries, the participation of the private sector in DH market, challenges the natural monopolistic characteristics of the district heat companies with more competition. The district heating network can be a platform which can utilise surplus or waste heat. Taking an example from "Open District Heating"[23], data centres, supermarkets, restaurants, and industries can sell their excess heat into the network, thus the network can provide a service where they will buy heat from different sources. The competition authority may choose to regulate third party access in a non-discriminatory way. The actual costs of transmission and distribution will vary significantly depending on the characteristics of local sites. This information gap can complicate the harmonization of conditions and standards regarding third-party access. To ensure rapid development and the security of supply in an open district heating system, the following points must be considered first: • The regulatory authority in Estonia should make low-grade excess heat visible in energy statistics. For this, there is a need to develop guidelines to help local authorities assess and report the potential for district heating and any additional costs of using excess heat. Heat resource mapping is expected to identify industrial clusters and assess heat supply and demand across regions. This will allow the assessment of transmission distances between excess heat producers and district heating networks. • Estonia should enhance the utilization of low-grade excess heat as a structural energy efficiency measure. The national regulatory authority can develop a guideline on cost-benefit analysis of a range of clean heat solutions. The country must consider multiple options for integrating heat and power sectors so that the system costs and benefits can be better understood. This will support the market with a scientifically sound analysis to promote improvement in the energy efficiency of district heating. • The government needs to improve third-party access to district heating networks. The key measures include promoting transparency of heat network

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[23] https://www.opendistrictheating.com/about/open-district-heating-how-it-works/

Questions	Answer
	pricing and enforcing the competition of heat production. It is also important to establish least-cost heat procurements and enhance investors' appetite for clean heat options.
12. On what conditions the grid is necessary and what are the functions for the grid? What are the necessary changes in consumer choices? Which version helps better to avoid energy poverty?	A district heating and cooling grid (network) is necessary to utilize the large volumes of the technically available waste or surplus energy, reducing the dependence on the conventional energy production systems, ensuring efficient use of power, and for energy market integration via sector coupling. These objectives cannot be achieved without the presence of the district heating and cooling networks. Multiple factors drive consumer choices, but low-cost options and the security of supply can be counted as the main drivers. Due to the recent energy crisis in 2022, energy prices are increasing rapidly. Consumers need to change the energy consumption patterns via employing property (building) renovations to reduce the energy demand of the buildings, demanding smart meters for district heating to kickstart the demand response measures. Keeping in mind that the deployment of energy-efficient decentralized (local) heat production technologies requires individual investment costs against the new investment costs being divided in a dense district heating network, the district heating networks present a better option to avoid energy poverty.
13. Is the low temperature key character in carbon neutral heating?	Lowering the required heating temperature directly reduces the need for heat produced in the district heating plants. It also helps to bring down the peak demands during the winter season. Low temperature is also the key to reaching the 4th and eventually 5th generation of district heating which presents a high level of energy efficiency and offers opportunities to the market participants to become a part of the heat selling market.
14. Is there a need to redefine district/local heating considering the optimum solution in carbon neutral heating and cooling?	The market for heating and cooling will grow organically, but measures like significant incentives for building renovations to achieve energy efficiency in buildings, legislation and regulatory frameworks for the local companies and businesses to sell their excess heat at market price will help to find an optimum solution for carbon neutral heating and cooling.
15. What is the optimal length of the heating grid in various occasions (dense demand, low temperature grid, etc.)?	When the DH push is under consideration, multiple factors, constraints, and social factors must be considered. The DH share in the overall demand can be expanded by adding new consumers on the existing lines or adding new customers in areas where DH was not present before, and a new network must be constructed. The real situation cannot be predicted, but a simplification can be made to have an idea about the DH infrastructure expansion when a push towards DH takes place. To see the expansion of DH pipelines while maintaining the heat consumption densities, the DH supply line lengths can be calculated by dividing the heat demands with the average heat consumption density of the current DH infrastructure (i.e., 2.66[24] MWh/m). Based on the explained methodology, after the heat coverage shift from local heating to DH, the overall length should increase from ~1,591 (2021) km to ~2,355 km by 2050. By utilizing the same methodology, the DH network's length (km) shrinkage for the LHC scenario and the comparison with the other scenarios is presented in the following graph:

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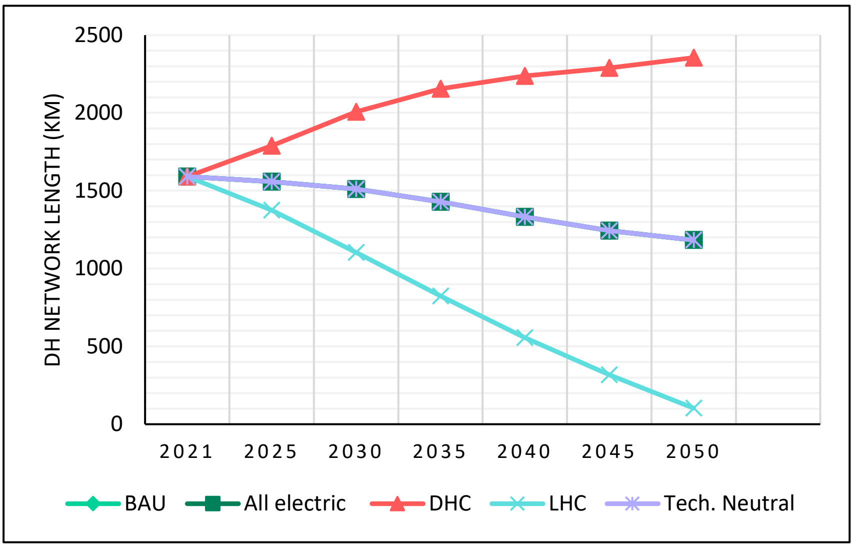
[24] Heat consumption density of Estonian DH network communicated by competition authority of Estonia.

<table>
<tr><th>Questions</th><th>Answer</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td>16. What are the advantages of district heating compared to local heating in carbon neutral heating and cooling, considering relevant business models?</td><td>District heating provide opportunities to integrate surplus or waste heat, provide the opportunity to use Power-to-heat concepts, can provide and ‘Heat as a service’ concept by employing open district heating.</td></tr>
<tr><td>17. What might be the impact of the development of building materials to the production and consumption of a building and might such developments play a role in using the district grid?</td><td>Different building materials can affect heating and cooling consumption. The effect of using advanced and innovative building materials can be divided into two parts: materials that cut down energy consumption and materials that produce energy that can directly be utilized for heating and cooling. In both cases, the buildings connected to district heating will have reduced energy consumption, and consequently, the heat consumption density of such district heating lines can decrease significantly.</td></tr>
<tr><td>18. What might be the possible share of the locally produced energy in the field of heating and cooling considering the development of building materials?</td><td>Building integrated photovoltaic (BIPV) can be used in Estonian building stock to produce decentralized electricity, which in return can further support the deployment of heat pumps and other electrical technologies. Modules replace genuine construction elements such as roof tiles and cladding materials. They also provide building owners with a new way to comply with the increasingly stringent energy-related building criteria. Energy generators blend in aesthetically with the surroundings and contribute substantially to the energy transition when PV modules are integrated into the building envelope[25]. BIPV can cover up to 10% of the required building energy on a typical day in summer[26]. **The annual average of BIPV geographical potential of Estonia**[27] **is 637 kWh/square meter[28], that means having a 100 square meter roof installed with BIPVs can potentially produce 63.7 MWh electricity per year**. If an installation of 10% on the total building stock for different market participant is assumed, the collective electricity production with BIPV by 2050 is presented in the following table.
<table>
<tr><th>Building type</th><th colspan="2">2030</th><th colspan="2">2050</th></tr>
<tr><td></td><td>Installation area (mil. m²)</td><td>Electricity production (GWh)</td><td>Installation area (mil. m²)</td><td>Electricity production (GWh)</td></tr>
<tr><td>Single houses</td><td>28.84</td><td>1837</td><td>31.59</td><td>2012.2</td></tr>
<tr><td>Apartment buildings</td><td>25.47</td><td>1622.3</td><td>29.62</td><td>1886.6</td></tr>
</table></td></tr>
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[25] https://www.solarmarkt.ch/de/solarwissen/bipv.

[26] Yoo, Seung-Ho & LEE, EUN-TACK & LEE, JONG-KEUK. (1998). Building Integrated Photovoltaics: A Korean Case Study. Solar Energy - SOLAR ENERG. 64. 151-161. 10.1016/S0038-092X(98)00115-7.

[27] For Tallinn

[28] Gholami, Hassan & Røstvik, Harald & Steemers, Koen. (2021). The Contribution of Building-Integrated Photovoltaics (BIPV) to the Concept of Nearly Zero-Energy Cities in Europe: Potential and Challenges Ahead. Energies. 14. 6015. 10.3390/en14196015.

<table>
<tr><th>Questions</th><th>Answer</th></tr>
<tr><td></td><td><table><tr><td>Services /commercial</td><td>28.71</td><td>1829.1</td><td>41.64</td><td>2652.2</td></tr></table></td></tr>
<tr><td>19. What are the possible connections and effect of mobility for the carbon neutral heating and cooling?</td><td>The increasing use of electric vehicles could help to decarbonise the economy. Battery electric vehicles (BEVs) using electricity produced from renewable energy can be used as rolling storage. The concept of Vehicle to Grid (V2G)[29], Vehicle to Home (V2H)[30] and Vehicle to Building (V2B)[31] employ the use of batteries in BEVs to supply electrical energy to ensure a better coupling between energy generation and consumption to reduce the peak demand.
The following table exhibits the electrical energy provision potential of BEVs in Estonia for 2030 and 2050, assuming if all BEVs are connected to buildings in providing electrical energy. The potential is calculated for discharging all the BEVs in 2030 and 2050 for one cycle and 25 cycles (to highlight the contrast). The discharged electricity from the BEVs can be utilized in buildings for different applications including for heating and cooling.
<table>
<tr><th>Number of cycles</th><th colspan="2">2030</th><th colspan="2">2050</th></tr>
<tr><th></th><th>Number of cars</th><th>Energy provision (GWh)</th><th>Number of cars</th><th>Energy provision (GWh)</th></tr>
<tr><td>1</td><td>97,500</td><td>4.7</td><td>600,000</td><td>22.0</td></tr>
<tr><td>25</td><td>97,500</td><td>117.5</td><td>600,000</td><td>551.7</td></tr>
</table></td></tr>
</table>

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[29] https://www.virta.global/vehicle-to-grid-v2g

[30] https://blog.wallbox.com/why-bidirectional-charging-is-the-next-big-thing-for-ev-owners/#:~:text=V2H%3A%20Vehicle%20to%20Home,embedded%20within%20the%20EV%20charger.

[31] https://sinovoltaics.com/learning-center/electric-vehicles/what-is-vehicle-to-building-charging-v2b/

Annex A.1 – Indicative timeline and roles of the proposed actions

Figure A - 1 Timeline for actions for the All-Electric pathway

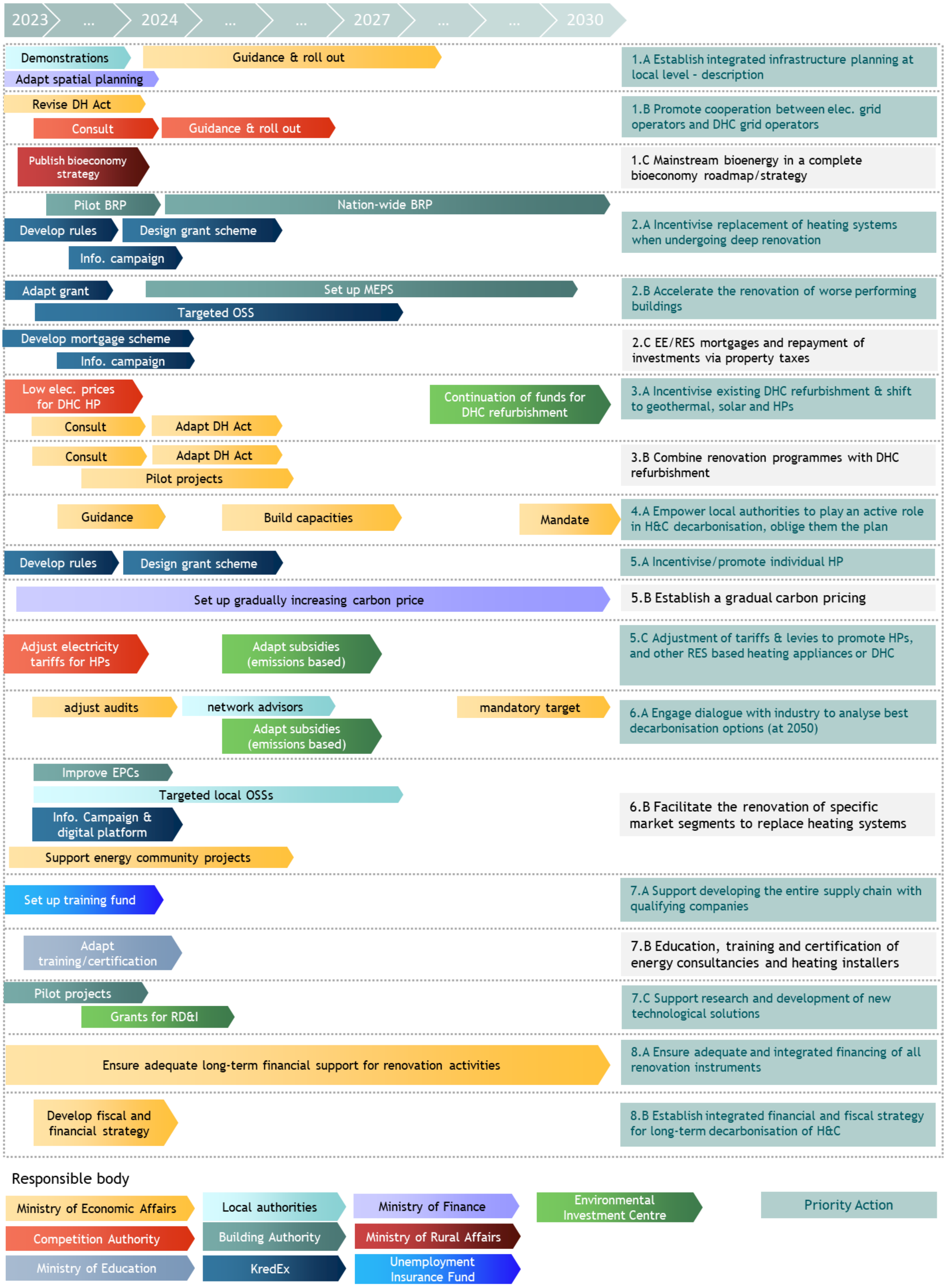


Figure A - 2 Timeline for actions for the DHC pathway

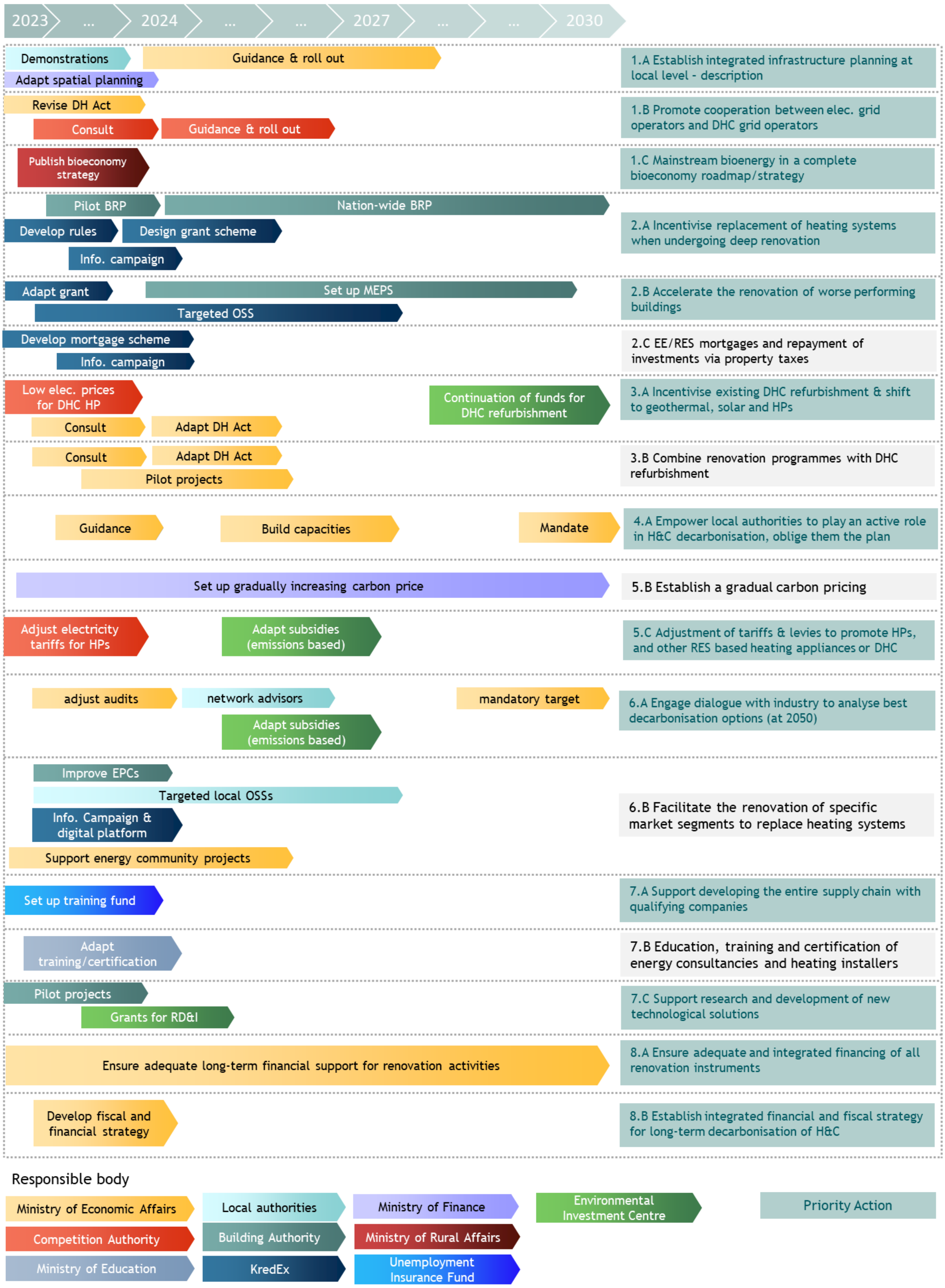


Figure A - 3 Timeline for actions for the LHC pathway

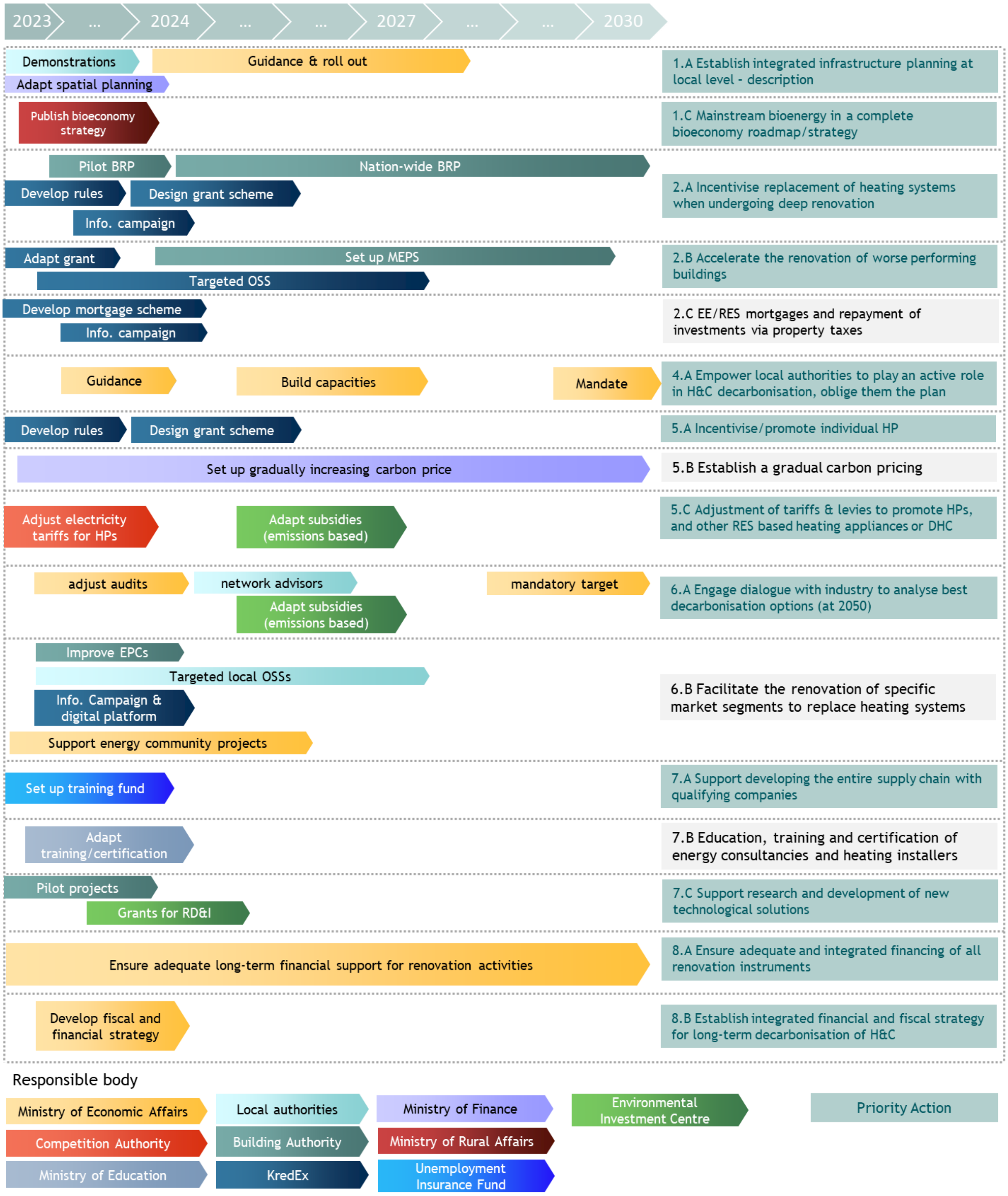
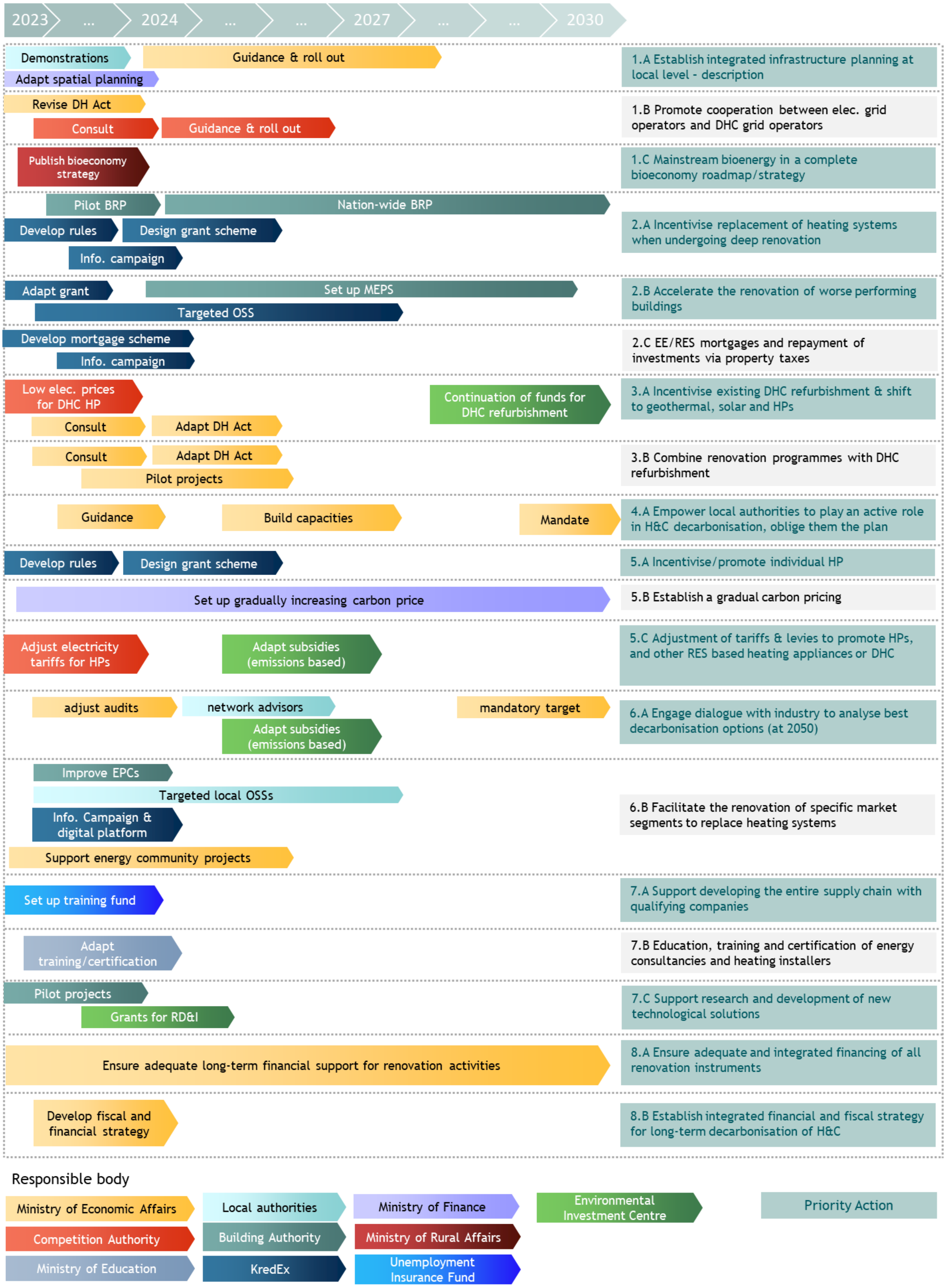
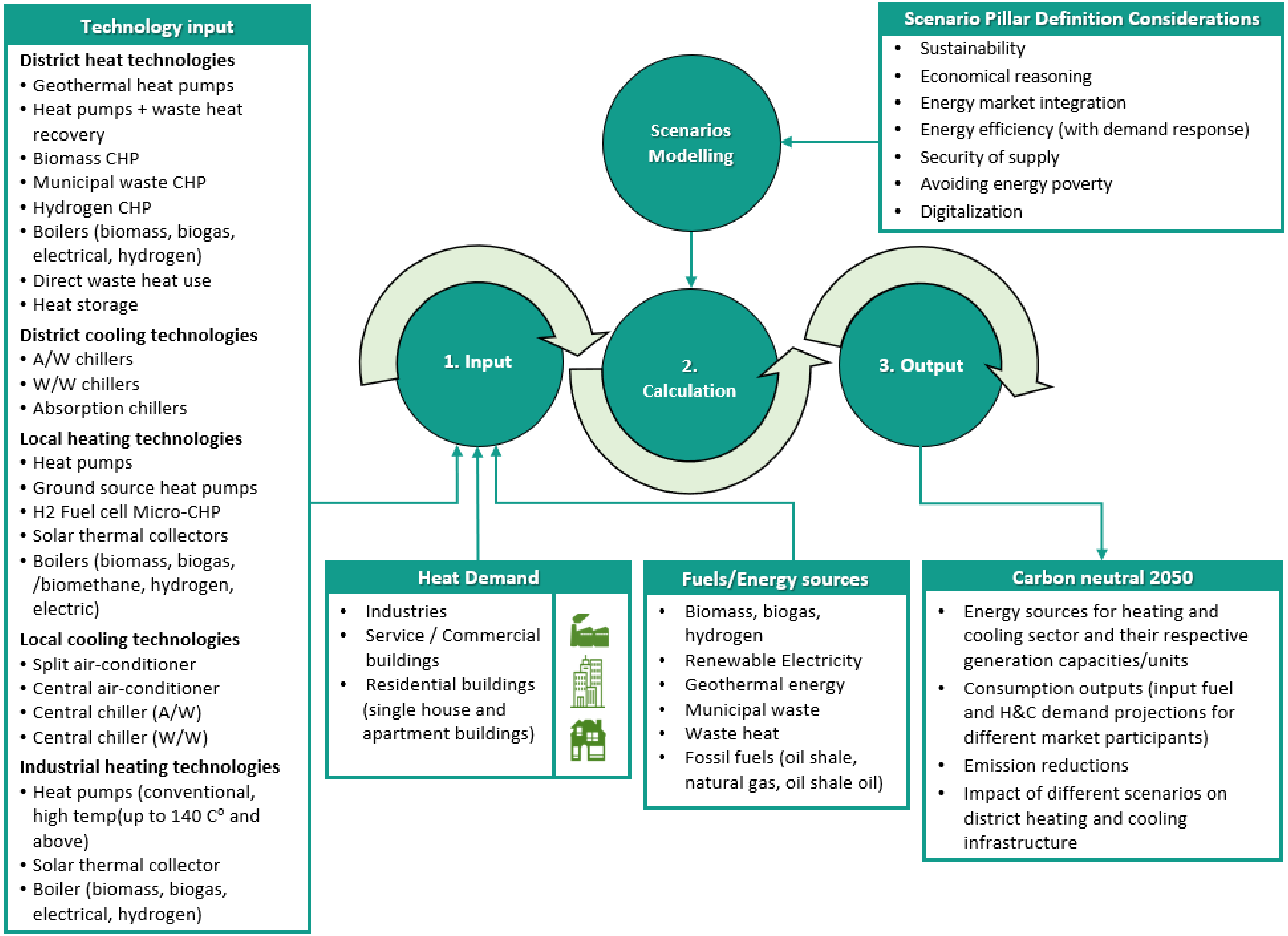


Figure A - 4 Timeline for actions for the Technology Neutral pathway



Annex B.1 – Technology list and overview of the model structure

Figure B - 1 Schematic of the calculation model *(more on technologies can be found in deliverable 2 report)*



Technology input

District heat technologies
- Geothermal heat pumps
- Heat pumps + waste heat recovery
- Biomass CHP
- Municipal waste CHP
- Hydrogen CHP
- Boilers (biomass, biogas, electrical, hydrogen)
- Direct waste heat use
- Heat storage

District cooling technologies
- A/W chillers
- W/W chillers
- Absorption chillers

Local heating technologies
- Heat pumps
- Ground source heat pumps
- H2 Fuel cell Micro-CHP
- Solar thermal collectors
- Boilers (biomass, biogas, /biomethane, hydrogen, electric)

Local cooling technologies
- Split air-conditioner
- Central air-conditioner
- Central chiller (A/W)
- Central chiller (W/W)

Industrial heating technologies
- Heat pumps (conventional, high temp(up to 140 C° and above)
- Solar thermal collector
- Boiler (biomass, biogas, electrical, hydrogen)

Scenario Pillar Definition Considerations
- Sustainability
- Economical reasoning
- Energy market integration
- Energy efficiency (with demand response)
- Security of supply
- Avoiding energy poverty
- Digitalization

Heat Demand
- Industries
- Service / Commercial buildings
- Residential buildings (single house and apartment buildings)

Fuels/Energy sources
- Biomass, biogas, hydrogen
- Renewable Electricity
- Geothermal energy
- Municipal waste
- Waste heat
- Fossil fuels (oil shale, natural gas, oil shale oil)

Carbon neutral 2050
- Energy sources for heating and cooling sector and their respective generation capacities/units
- Consumption outputs (input fuel and H&C demand projections for different market participants)
- Emission reductions
- Impact of different scenarios on district heating and cooling infrastructure

Annex B.2 – Project summary table

Table B - 1 Summary of the deliverable outcomes

Indicator	DLV	All Electric	DHC	LHC	Technology neutral
Summary		*This is the most ambitious pathway with a full-scale deployment of electricity-based H&C, which results in the highest investment costs for H&C technology development. This pathway has is carbon neutral and completely phases out biomass use. Key actions focus on ensuring adequate, integrated H&C planning, promoting of electricity-based solutions in industry and buildings as well as strengthening capacity in the H&C sector.*	*The pathway is categorised by a focus on district heating and cooling. The pathway is the second most expensive pathway due to the high investment requirements for DHC infrastructure development. Although the pathways result in no carbon emissions by 2050, the pathway has the highest reliance on biomass. The pathway has overall positive socioeconomic impacts and leads to the lowest H&C costs for households. However, the pathway is considered risky by stakeholders as it is considered economically not feasible.*	*The pathway is categorised by a focus on local heating and cooling. The pathway has the second lowest investment needs. Although the pathways result in no carbon emissions by 2050, the pathway is highly reliant on biomass. There are feasibility concerns due to the high spatial requirements and waste of resources due to decommissioning of the existing DHC system.*	*Based on the technology neutrality, different technologies emerge, with a greater deployment of local H&C solutions. Although the pathways result in no carbon emissions by 2050, the pathway is highly reliant on biomass. The pathway has the lowest investment requirements.*
Model description	3	All infrastructure and technologies are based on electric solutions (both district & local). The electricity needs will be covered by renewable electricity and will be added progressively depending on the resource availability, TRL, financial feasibility and access. The technology development mainly consists of heat pumps (A/A, W/W and ground-sourced HPs) in district and local systems. Biomass is faded out by 2050	All possible H&C requirements will be based on district H&C solutions. Energy sources are based on technologies that are considered sustainable and usable for district heating systems. Local heating solution are as limited as possible (only placed where district solutions are not in line with the balance of the pillars).	Mainly single house-based solutions and local autonomous systems. The district grid will be phased out while shifting all the possible demand towards local solutions. Industry needs are integrated through industrial clusters, which allows local solutions to be integrated with industry.	No preference towards any type of infrastructure (local and district) with the flexibility of using any kind of renewable technology, in accordance with the sustainability pillars.
New installed capacity (2022-2050)		3.87 GW	2.20 GW	2.70 GW	2.25 GW
Heat production in 2050					
% District		*24%*	*48%*	*2%*	*24%*
% Local		*42%*	*18%*	*64%*	*42%*
% Industrial		*34%*	*34%*	*34%*	*34%*
Cooling production in 2050					
% District		*6%*	*46%*	*6%*	*6%*
% Local		*94%*	*54%*	*94%*	*94%*
Fuel consumption in 2050		7.1 TWh	12.1 TWh	10.6 TWh	11.5 TWh
Electricity		*6.6 TWh*	*1.9 TWh*	*2.8 TWh*	*2.3 TWh*
Biomass		*0 TWh*	*11.37 TWh*	*7.93 TWh*	*9.99 TWh*
CO_2 emissions in 2050*		0 $ktCO_2$	0 $ktCO_2$	0 $ktCO_2$	0 $ktCO_2$
Expansion of DH network		0 km	764 km	0 km	0 km
Expansion of DC network		33 km	315 km	33 km	33 km
Required heat storage capacity		1311 MW	2610 MW	114 MW	1311 MW
Total investment needs (2022-2050)	4	€19,066M	€18,789M	€18,027M	€17,837M
H&C technologies		*€2,274M*	*€1,038M*	*€1,236M*	*€1,045M*
DHC infrastructure		*€53M*	*€1,012M*	*€52M*	*€53M*
Building renovation		*€16,739M*	*€16,739M*	*€16,739M*	*€16,739M*

Indicator	DLV	All Electric	DHC	LHC	Technology neutral
Average heating costs for households in 2050		97 €/MWh	62 €/MWh	74 €/MWh	68 €/MWh
Average cooling costs for households in 2050		112 €/MWh	114 €/MWh	113 €/MWh	110 €/MWh
H&C activities as % of GDP in 2050		3.2%	3.8%	3.0%	3.4%
Employment in 2050 due to HC activities (jobs)		15216	18064	14133	16004
Avg. change in disposable income		- €389M	- €194M	- €236M	- €162M
Risk analysis	5	Medium risk scenario. Very exposed to electricity grid development and HP technology investment reduction in Estonia	Less risky scenario, overall liked by stakeholders	Riskiest scenario, stakeholders moderately negative about it. Main risks are energy market related (security off supply in economically vulnerable areas and, electricity grid development, and unexpected fuel price increase)	Moderately more risky. Exposed to high energy market risk
Sensitivity analysis - Impact of fuel prices on H/C prices (*Elasticity)	6	0.53	0.54	0.62	0.58
Sensitivity analysis - Impact of technology investment costs on H/C prices (*Elasticity)		0.14	0.10	0.08	0.09
Priority actions (shared priorities in bold)	7	1.A. Establish integrated infrastructure planning at local level 1.B. Promote cooperation between electricity and DHC grid operators 2.A. Incentivise replacement of heating systems when undergoing deep renovation 2.B. Accelerate the renovation of worse performing buildings 3.A. Incentivise existing DHC refurbishment & shift to RES 4.A. Empower local authorities to play an active role in H&C decarbonisation & planning 5.A. Incentivise/promote individual HP when most appropriate option 5.C. Adjustment of markets and fiscal mechanisms to promote RES H&C 6.A. Engage dialogue with industry to analyse best decarbonisation options (at 2050) 7.A. Support developing the entire supply chain with qualifying companies 7.C. Support research and development of new technological solutions 8.A. Ensure adequate and integrated financing of all renovation instruments 8.B. Establish integrated financial and fiscal strategy for long-term decarbonisation of H&C	1.A. Establish integrated infrastructure planning at local level 1.C. Mainstream bioenergy in a complete bioeconomy roadmap/strategy 2.A. Incentivise replacement of heating systems when undergoing deep renovation 2.B. Accelerate the renovation of worse performing buildings 3.A. Incentivise existing DHC refurbishment & shift to RES 4.A. Empower local authorities to play an active role in H&C decarbonisation & planning 5.C. Adjustment of markets and fiscal mechanisms to promote RES H&C 6.A. Engage dialogue with industry to analyse best decarbonisation options (at 2050) 7.A. Support developing the entire supply chain with qualifying companies 7.C. Support research and development of new technological solutions 8.A. Ensure adequate and integrated financing of all renovation instruments 8.B. Establish integrated financial and fiscal strategy for long-term decarbonisation of H&C	1.A. Establish integrated infrastructure planning at local level 1.C. Mainstream bioenergy in a complete bioeconomy roadmap/strategy 2.A. Incentivise replacement of heating systems when undergoing deep renovation 2.B. Accelerate the renovation of worse performing buildings 4.A. Empower local authorities to play an active role in H&C decarbonisation & planning 5.A. Incentivise/promote individual HP when most appropriate option 5.C. Adjustment of markets and fiscal mechanisms to promote RES H&C 6.A. Engage dialogue with industry to analyse best decarbonisation options (at 2050) 7.A. Support developing the entire supply chain with qualifying companies 7.C. Support research and development of new technological solutions 8.A. Ensure adequate and integrated financing of all renovation instruments 8.B. Establish integrated financial and fiscal strategy for long-term decarbonisation of H&C	1.A. Establish integrated infrastructure planning at local level 1.C. Mainstream bioenergy in a complete bioeconomy roadmap/strategy 2.A. Incentivise replacement of heating systems when undergoing deep renovation 2.B. Accelerate the renovation of worse performing buildings 3.A. Incentivise existing DHC refurbishment & shift to RES 4.A. Empower local authorities to play an active role in H&C decarbonisation & planning 5.A. Incentivise/promote individual HP when most appropriate option 5.C. Adjustment of markets and fiscal mechanisms to promote RES H&C 6.A. Engage dialogue with industry to analyse best decarbonisation options (at 2050) 7.A. Support developing the entire supply chain with qualifying companies 7.C. Support research and development of new technological solutions 8.A. Ensure adequate and integrated financing of all renovation instruments 8.B. Establish integrated financial and fiscal strategy for long-term decarbonisation of H&C

Indicator	DLV	All Electric	DHC	LHC	Technology neutral
Environmental and social impacts		Decrease in local/global emissions and no biomass-related environmental impacts. Increased health benefits due to reduced air pollution	Decrease in local/global emissions and increase in related health benefits. However, risk of deforestation due to biomass use and possibly not carbon-neutral when taking the life cycle into account. Local nuisance for residents due to expansion of DHC.	Decrease in local/global emissions and increase in related health benefits. However, risk of deforestation due to biomass use and possibly not carbon-neutral when taking the life cycle into account. Reduction in living space due to installation of local HPs.	Decrease in local/global emissions and increase in related health benefits. However, risk of deforestation due to biomass use and possibly not carbon-neutral when taking the life cycle into account.

Elasticity: Sensitivity result parameter e.g., Elasticity 0.5 means that, when the fuel prices increase by 1% the price for H/C will increase by 0.5%