LCA study of the Pilot Measure and Pilot Energy Strategy (PES) for Ilmajoki Municipality

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Content

Introduction

European Union has set an ambitious target for greenhouse gases emission reduction to reduce the impact of the energy sector on global warming. The set goals foresee a decrease of 40% by 2030 and 80 – 95% by 2050. It is thus essential to address efforts in the residential sector as it is responsible for 40% of the current total energy demand. In this perspective district heating and cooling play, an essential role as centralized management for space heating/cooling has proven to be an effective way to reduce energy intensity (CO_2/kWh). Furthermore, in 2017 the European Commission highlighted the relevance of moving towards a circular economy in energy systems, especially related to the use of waste energy and waste-to-energy, as inputs for reducing or avoiding landfilling and the use of non-recyclable and hazardous waste materials.

The integration of renewable energy sources and the use of more efficient heat generation equipment when compared to individual heating Green House Gas (GHG) emissions from the district heating sector can reduce the overall amount of GHG emissions within the process. These features contribute to the reduction of both climate change and other environmental issues (Bartolozzi, et al., 2017). One of the main benefits for centralized heat generation is the possibility to generate both electricity and heat in cogeneration plants simultaneously. The effect is to increase the overall efficiency and decrease the primary energy consumption when comparing to conventional heating plants or condensing power plants. The use of excess industrial heat as a thermal source for district heating can reduce overall fuel consumption. However, the main challenge to overcome is the decrease of heat losses occurring when the heat is transmitted for long distances.

The decrease of residential building heat consumption arises the necessity of changing the operational conditions of district heating systems. New buildings have higher energy efficiency performance; therefore, heat density in newly built areas decreases. One of the lately discussed solutions for district heating companies to adapt to the new conditions is oriented towards the reduction of the supply water temperature. The low temperature district heating system concept provides innovative solutions in all the district heating system components – i.e. heat source, heating network and heat consumer. Low temperature district heating systems can lower energy losses, utilize excess industrial heat more efficiently, balance the renewable energy in the electricity grid and have strong economic potential if adequately implemented. Estimations on low temperature district heating showed a possible reduction of heat loss by 75 % comparing with medium temperature district heating system (Li, 2014).

The future urban development aims to achieve better environmental performances; however, research evaluating the environmental impacts related to this kind of infrastructure from a life-cycle perspective is still in its primary stage.

There is a lack of holistic approach to assessing the potential transition of District Heating Systems (DHS) to environmental sound DHs including both the possible use of renewable sources and the overall refurbishment of the technological DH system concept in terms of energy production, distribution systems and end of life. Moreover, there is a lack of benchmarking scenarios necessary to optimize the DH environmental performance also from an eco-design perceptive.

In this direction, the concept of the Life Cycle Assessment could be an essential quantitative method to cover this gap.

Several studies are dealing with LCA on DH (Persson, 2006), (Perzon, 2007), but only a few of them provide a complete environmental assessment of a DH network. This aspect shows a lack of involving the evaluation of the effect of a specific neighborhood, including all the DH parts starting from the energy plant (e.g. CHP) to the final heat exchangers in the substations.

Other studies implementing LCA, have been focused on specific types of fuels used within a particular DH system rather than the overall technological system itself (Persson, 2006).

Some LCA studies present comparisons of different scenarios taking into account diverse type of fuel for the energy plant (e.g. waste incineration with the combustion of biomass or natural gas) (Eriksson, 2007). In specific in the study of Eriksson et al. (2007) is highlighted how the use of natural gas in CHP plants is an alternative of interest if marginal electricity has a high fossil content. The study of Persson (Persson, 2006) found a benefit for large DH in terms of the better arrangement of highly efficient burning and flue gas treatment. Specifically, in this context, the use of LCA provides an added value on defining optimization process towards specific environmental criteria (Bardouille, 2000).

The previous lacks justify the selection of LCA approach as a useful and practical tool to be integrated into every infrastructure designing phase including (Low Temperature) DH to facilitate the passage of optimal environmental and viable solutions by using a set of specific environmental criteria. This way will support a more global vision within the environmental assessment highlighting which systems, subsystems or section of the DH present the most significant impact and to further better (re)design or reframe the whole infrastructure with higher environmental performances. The results from an LCA made for a DH system should be able to:

- define an updated data inventory of all DH subsystems to be eventually used as further benchmarks;
- clarify which subsystems and part of a district heating system are effecting the most to the overall environmental performance of the infrastructure;
- Provide alternatives based on eco-design perspectives implementable in Municipality Energy strategies, including SECAP and compare them with business-as-usual DH scenarios (e.g. distribution network using natural gas or 3rd generation type of DH system).

The LCA results may be of interest for energy planner and energy companies, engineers, DH operators, public officials and decision-makers including municipal planning merging the environmental perceptive within new or updated planning processes for urban infrastructural development.

The Life cycle assessment proposed in this report is based on the Pilot energy strategy for Low Temperature District Heating System implementation for Ilmajoki Municipality.

This document thus represents a consistent guideline on how to perform LCA specifically addressed to the implementation of eco-design principle for the construction of new or renovation of existing DH system. The specific inventory utilised to evaluate the overall eco-profile of certain energy strategy implemented in Low Temperature DH are reported both in the Annexes and as excel tables.

1. DH in the Context of Sustainability

From all levels of the energy sector there is a clear consensus that the decarbonisation of Europe`s energy supply relies on the expansion of district heating as well as increasing the share of renewable energy and waste heat (Svendsen S., 2017). The district heating network connects buildings in different areas of cities and other settlements so that the heat can be supplied from different centralized boiler houses, combined heating plants or several heat production facilities of a lower capacity. This approach allows integrating and combining various heat sources more efficiently.

The district heating system can reduce GHG emissions due to the integration of renewable energy sources and use of more efficient heat generation equipment when comparing to individual heating. These features contribute to the reduction of both climate change and other environmental issues (Bartolozzi, et al., 2017). One of the main benefits from centralized heat generation is the possibility to generate both electricity and heat in cogeneration plants simultaneously. It allows to increase the overall efficiency and decrease the primary energy consumption when comparing to heat generation in heating plants or power production in condensing power plants.

The fuel consumption can also be reduced when excess industrial heat is recovered and used as a thermal source for district heating. Utilisation of the surplus heat flows has been identified as an important goal for the district heating system development. At present, industrial sectors generate large amounts of low-temperature surplus heat, which are mainly discharged into the environment during industrial processes. Research shows that the heat losses from industrial processes are huge (Kapil A, 2012). Another essential source of surplus heat is the various data centres that run continuous cooling processes on servers and other equipment (Wahlroos M., 2018).

In many cases, this thermal energy can be used internally to heat hot water, preheat incoming air in a furnace etc. However, where the remaining heat is with low potential or the company's heat consumption is small, this energy may be passed on to other consumers or district heating network. Such solutions replace the fuel share in heat production, increased efficiency, reduces emissions and costs.

Nevertheless, the distribution heat losses are the main challenge which needs to be overcame when the heat is transmitted within the long distances. Competitiveness of the district heating system derives from a combination of heat generation and supply efficiency conditions (Ziemele, 2017). An important requirement for optimal heat supply is that the demand for heat should be concentrated in order to reduce distribution costs and heat losses.

Due to rapid decrease of residential building heat consumption also arises the necessity of changing the operational conditions of district heating system. Newly built buildings have higher energy efficiency performance therefore heat density in newly built areas decreases. One of the lately discussed solutions for district heating companies to adapt to the new conditions is oriented towards the reduction of the supply water temperature. The low temperature district heating system concept provides innovative solutions in all three district heating system components – i.e. heat source, heating network and heat consumer (Ziemele J., 2016). Low temperature district heating systems can lower energy losses, utilise excess industrial heat more efficiently, balance the renewable energy in the electricity grid and have strong economic potential if properly implemented. Foretime estimations on low temperature district heating showed a possible reduction of heat loss by 75 % comparing with medium temperature district heating system (Li, 2014). In addition, there are other benefits like reduction of boiling risk, reduced thermal stress on materials along the pipeline, utilisation of thermal storage to handle peak loads without oversizing equipment, improving heat-to-steam ratio in steam CHP system to extract more power of the turbine (Imran M., 2017).

From the previously explained background, there is a need to use LCA for the evaluation of the DH environmental sustainability.

2. LCA methodology

A major motivation for developing new DH systems is due to their environmental benefit. In-deed, they can reduce GHG emissions, air pollution, ozone depletion and acid precipitation, among others, by integrating RES, improving efficiency in equipment and moving from individu-al solutions to central heating systems. All products (goods or services) have a life cycle includ-ing: design, development, resources extraction, production, use or consumption, and the end of the life activities (collection, sorting, reuse, recycling and waste disposal) (Rebitzer, et al., 2004). There may exist several production phases, manufacturing of materials required for later production of the analyzed product, transformation of raw materials, energy production, etc.). Conducting all these activities along the life cycle results in an environmental impact due to the resources consumption, emissions of substances into the environment and other environmental exchanges such as radiation or ionization. In the perspective of sustainability, it is necessary to quantify the environmental impacts arising in all of DH development stages and different scenar-ios.

Life Cycle Assessment (LCA) is recognized as the most powerful and widely used tool for under-taking holistic environmental sustainability assessments, as it is capable of assessing product's environmental impacts from the cradle to the grave (Buxel, et al., 2015) using a multicriteria ap-proach. The principle is to compute the materials and energy flow inputs and the emissions at all phases (stages) in the life cycle of a production process. LCA offers a broader perspective and possible use to evaluate a broader range of environmental impact categories, beyond climate change, which is often the usual and only parameter considered when assessing environmental performance, particularly for energy production and distribution scenarios. One of the ad-vantages of LCA is complementing local environmental impact assessments by analyzing the impacts from a global perspective, therefore avoiding the so-called "burden-shifting" (Bartolozzi, et al., 2017). As a result, LCA is understood as a methodological framework to esti-mate the environmental impacts coming from the life cycle of a determined product. These im-pacts can be classified in: climate change, stratospheric ozone depletion, tropospheric ozone creation (smog), eutrophication, acidification, toxicological stress on human health and ecosys-tems, resources depletion, water use, land use, noise, and others (Jolliet, et al., 2003).

Methodologies to implement an LCA vary among studies, but the most common one remains to be the LCA ISO standard 14040 and 14044. The ISO 14040 (1997) describes the principles and framework for LCA, while the ISO 14044 presents requirements and guidelines to perform it. According to the framework found in ISO 14040, a complete life cycle, with its associated mate-rial and energy flows is called product system. Then, collecting, tabulating, and performing a preliminary analysis of emissions and resource consumption is called Life Cycle Inventory (LCI). Most of the times it is necessary to calculate and interpret indicators of the potential impacts associated with the exchange of such flows with the natural environment, thus, performing a life cycle impact assessment (LCIA).

In ISO 14044, the main four steps included in the LCA methodology are described: goal and scope, life cycle inventory, life cycle impact assessment and life cycle interpretation (International Standard, 2006). Defining the goal and scope is the first step in an LCA, the objec-tive is to make clear the purpose and intended audience of an LCA study and which phases of the production processes are analyzed. Due to the iterative LCA nature, the scope is susceptible to redefinitions during the study. The goal and scope must define the intended application, the product system, functional unit (FU), system boundaries, LCIA methodology, assumptions and limitations, and some other data requirements. The second step is the LCI, where inventory is gathered and quantified according to the defined FU. In this step, the stages and the data collec-tion and calculation techniques are described in detail. The third step, the LCIA, includes the collection of indicator results for the different impact categories, which together represent the LCIA profile for the product system. Such results are categorized in the aforementioned impact categories. It is at this point, where sensitivity analysis can be performed to determine how changes in data and methodological choices may affect the results. Finally, in the Life Cycle In-terpretation, several elements are considered: identification of significant issues based on re-sults, evaluation of consistency and sensitivity checks, and discussion of conclusions, limitations and recommendations.

3. Goal and Scope

Kurikka and Ilmajoki municipalities in the region of South Ostrobothnia are currently working under standard third generation District heating systems (3GDH), using mainly woodchips and sod peat as fuels in heat only boilers with different installed capacities (1 – 6 MW).

For Ilmajoki, three different perishes can be distinguished: Administrative area, Koskenkorva and Rengonharju. While for this municipality, the next replacement investment is forecasted by 2027, the situation in Kurikka is different, with one of the boilers reaching its end of life in 2022.

3.1 Goal definition

The goal of this study is to assess the environmental impacts of the baseline scenario for the current DHS in Koskenkorva parish and Kurikka municipality and a future development scenario where waste heat from an industrial distillery will be used as energy source for a LTDH system. The main objective of the project is to assess the effects of the transition from a 3GDH system to a 4GDHS. The LCA study will provide, in junction with economic assessment, a reliable making decision tool providing consistent thresholds for the section of the optimal technological solution in line with national energy-related emission reduction targets in Finland.

3.2 Scope

Scope definition requires clearly describing the function and functional unit, system boundaries, methodology, and data requirements sufficiently to address the stated goal. As said before, an attributional model is going to be performed for this study to evaluate the environmental load of the DHS baseline scenario with the first steps towards the proposed upgrade to a LTDHS future scenario. Within this transitional phase, surplus heat from a distillery will be used as heat source for heat pumps to feed the District heating network at the same temperature as in the baseline scenario. The time frame of the study only includes existing technologies and described technologies in this project.

Hence, the effect of new technologies will not be taken into consideration. Future trends in insulation improvements resulting in heat losses reductions in the distribution network, boiler house or demand side, are also not considered other than the ones explicitly discussed within the project.

For the baseline scenario the current technology, data for calculations, fuels and networks described in (LowTEMP, 2019) and (Poyry, 2018) were used for modelling activities as part of the background data. Foreground data was obtained directly acquired in cooperation with the LowTEMP partner Thermopolis. The distribution network temperature is assumed as 105°C.

For the future scenario, where surplus heat from a distillery in Koskenkorva parish would be used as heat source for running a series of heat pumps, the background data were obtained from (Poyry, 2018) and SimaPro databases. Foreground data were obtained from the LowTEMP partner Thermopolis.

3.3 Functional Unit

A functional unit (FU) is a measure of the performance of the functional outputs of the product system, and its primary purpose is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. The definition of a functional unit must hence include both quantitative aspects to avoid subjectivity when subsequently defining an equivalent scenario to be compared. The functional unit thus is oriented to provide a consistent quantitative comparison of alternative ways of providing a function. In a functional unit defines aspects of the quality of a certain function provided and quantifies the quantitative aspects of the same function, answering to questions like "what?", "how much?", "for how long/how many times?", "where" and "how well?". Especially for complex products or processes, that may differ in a number of qualitative aspects (e.g. two cars of different levels of comfort), is important that the equivalence of the "functional unit" is carefully defined to ensure valid and defendable comparisons and even more so for comparative assertions disclosed to the public.

For this study, the functional unit is the operation and maintenance of DH system over an assumed time horizon for delivering the required heat demand of Koskenkorva parish and Kurikka municipality including infrastructural works required for heat distribution in each scenario. This includes, any construction or renewing work required either for the baseline scenario, such as boiler house replacement in 2027, or the deployment of the required new pipelines and heat pumps installation for the future scenario.

4. System Boundaries

The project concerns only the scenarios mentioned for the Ilmajoki administrative area and Koskenkorva parish in the Ilmajoki municipality. These villages and cities are located in the region of South Ostrobothnia in Finland. Ilmajoki is one of the 18 municipalities in the region of South Ostrobothnia. The system boundaries comprehend the construction of boiler houses, including energy and raw materials required for all equipment and accessories, the transport of materials for construction and the required energy. Within the assemblies for the boiler house, nodes, pumps, taps and DH pipeline network, materials and equipment susceptible of replacement during the lifespan of the project are also included. Construction of heat pumps and accumulation tanks are also considered, as elements, energy and processes required for their construction.

As can be seen in Fig. 1, for the operational phase, the fuel and electricity required to run the thermal boiler house, pumps, and other equipment is accounted, including the extraction and transport of fuels. Nevertheless, operations related to maintenance and repairs are not included due to its intrinsic feature of uncertainty and to avoid overestimated impacts. The replacement of equipment during the lifespan of the project (e.g. recirculation pumps) are considered in the model.

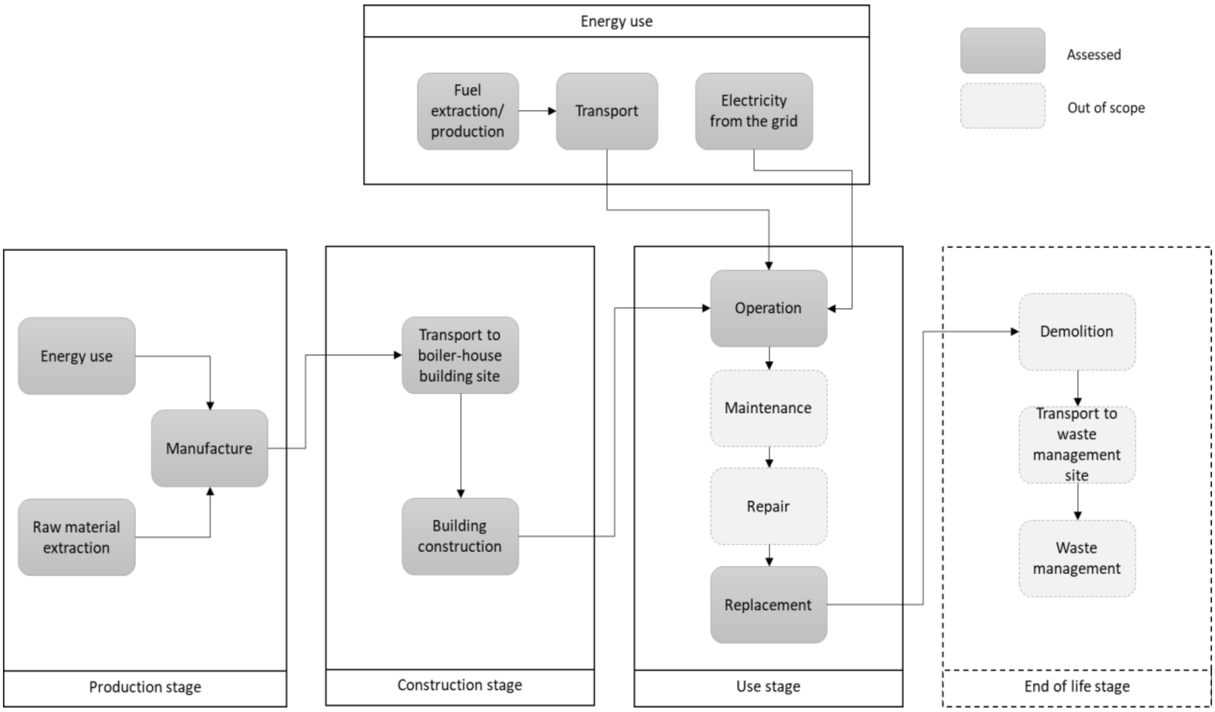


Figure 1. System boundaries on the supply side

The service life or intended time horizon is for 25 years from 2020, hence only available technologies at the moment of writing this document are considered within the study. The end of life stage is not considered in this study, as the useful life of a DH system depends on many variables such as governmental policies, technological diffusion of new technologies, rate of change in population (demand side), and maintenance of the network and boilerhouse.

Within the boundaries, the decommissioning phase of the DHS is not included, only waste treatment processes available in the Ecoinvent 3 database are accounted. Electricity consumption is assumed as taken from the national grid.

4.1 Geographical boundaries and scenarios description

For the whole Ilmajoki municipality, district heating is generated in three different areas. The largest one, and most heat consuming area, is the central area of Ilmajoki (administrative area) while the parishes of Koskenkorva and Rengonharju are smaller heat networks.

The whole model accounts for two main parts, one for the Ilmajoki administrative area, and another one for the Koskenkorva parish. At this moment (2019), both areas have independent heating systems powered by boiler houses using different types of fuels, but it is planned that both parishes in the future will besupplied by waste heat feeding heat pumps in order to provide district heating to the residential and administrative buildings in a large share of the municipality.

4.1.1 Ilmajoki administrative area

District heat in Ilmajoki is generated in heat-only boiler production units, which are split around the heating network. Apart from the network located in the administrative area of Ilmajoki municipality, there are two smaller heat networks that are not connected to the main heat network. In addition, each network has adequate reserve and peak load boiler units.

At the administrative area of Ilmajoki, district heat is produced by two boilers named KPA1 and KPA2 which are fed only with solid fuel. While boiler KPA1 is a 4.0 MW, KPA2 is a 6.0 MW boiler Both of them are grate boilers and both are equipped with flue gas scrubbers and are fired with woodchips, sod peat and milled peat. In Table 1, it can be seen the total fuel consumption in both main boilers and the reserve or peak one which basically uses light oil and in energy terms, represents around 1 % of total heat produced. The most common fuel is woodchips with 68 % of total heat production followed by peat with near 31 %.

TABLE 1. FUEL CONSUMPTION PER YEAR FOR DH (REF. 2018) IN ILMAJOKI ADMINISTRATIVE AREA.

Type of fuel	Amount [ton][1]
Sod Peat	4896.7
Woodchips	6661.4
Oil [2]	11.1

In Figure 1, all the steps included within the model for this LCA were shown, however it is important to mention, most of these processes are allocated according to the "point of substitution" approach from Ecoinvent database in the operational step, especially those related to the energy use including all its activities such as fuel extraction/production, transport and the electricity generation for later use. The operational step can include many sub-process and actors, which is why the boundaries for this main step must be clearly defined within at this point, to avoid over expanding the system to areas out of the scope. As can be seen in Figure 2, the operational phase does not include activities at the end user side (see dashed line), only activities required for the heating production and distribution

[1] Calculated using standard LHV and data from (Poyry, 2018)
[2] For backup boilers

are within the boundaries.

The building construction (boiler houses, pipelines and nodes) step in the construction stage (see Figure 1) is the other key point of substitution, where all raw material extraction, energy use for manufacture of intermediate products (pipes, pumps, etc.) and subsequent transport to the boiler house site are accounted.

4.1.2 Koskenkorva parish

District heating in Koskenkorva is provided by two small boilers with a capacity of 1 MW each. As in Ilmajoki case, these two boilers are solid fuel fed, been able to burn woodchips, sod peat or milled peat. However, only woodchips are used for heat production, with an annual consumption of 971.3 ton in 2018, equivalent to a heat production of 3700 MWh.

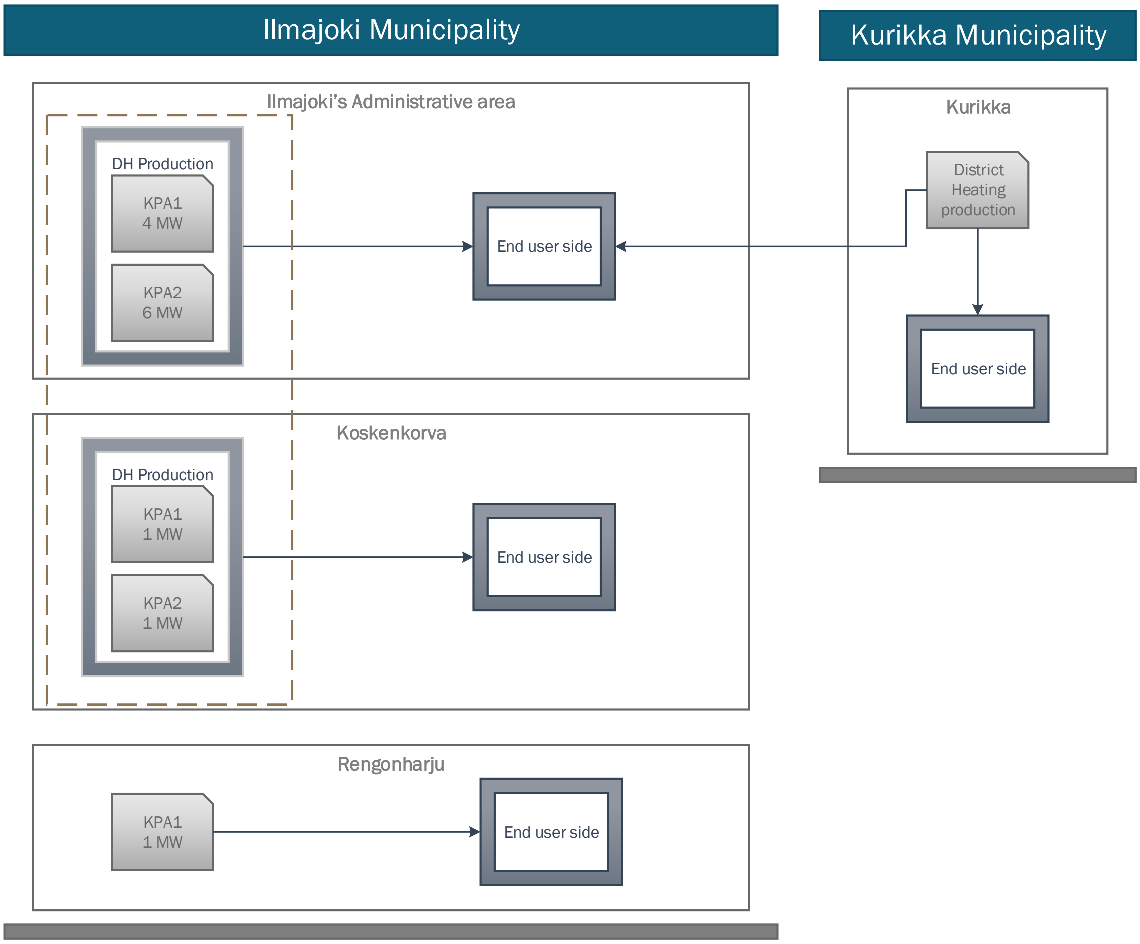


Figure 2. System boundaries for the baseline scenario.

As with the Ilmajoki's administrative area, for the Koskenkorva Parish, only baseload boilers are taken into account for the modelling. Similar like in the study (LowTEMP, 2019) and (Poyry, 2018) the reserve boilers haven't been used for district heat production in the last 3 years and no other type of fuel has been burned but woodchips.

4.1.3 Future scenarios description

Within Koskenkorva parish exist a distillery located just nearby the district heating plant. The distillery generates waste heat which is currently been cooled by using blowers. The resulting usable heat is contained in the cooling water produced at an average rate of 200 m^3/h and at 29° C, and the utilization capacity corresponds to 8500 hours per year (Poyry, 2018). According to those preliminary results, flowrate and temperature will allow for a series of heat pumps designed using a COP 3.1 - 3.3, to increment the temperature up to 95° C, which would be enough to cover the actual ΔT profile, with a supply temperature between 80 - 90° C (see Figure 3). This way, the resulting water becomes an energy carrier able to feed the heat pumps to reach the desired temperature at the user end side.

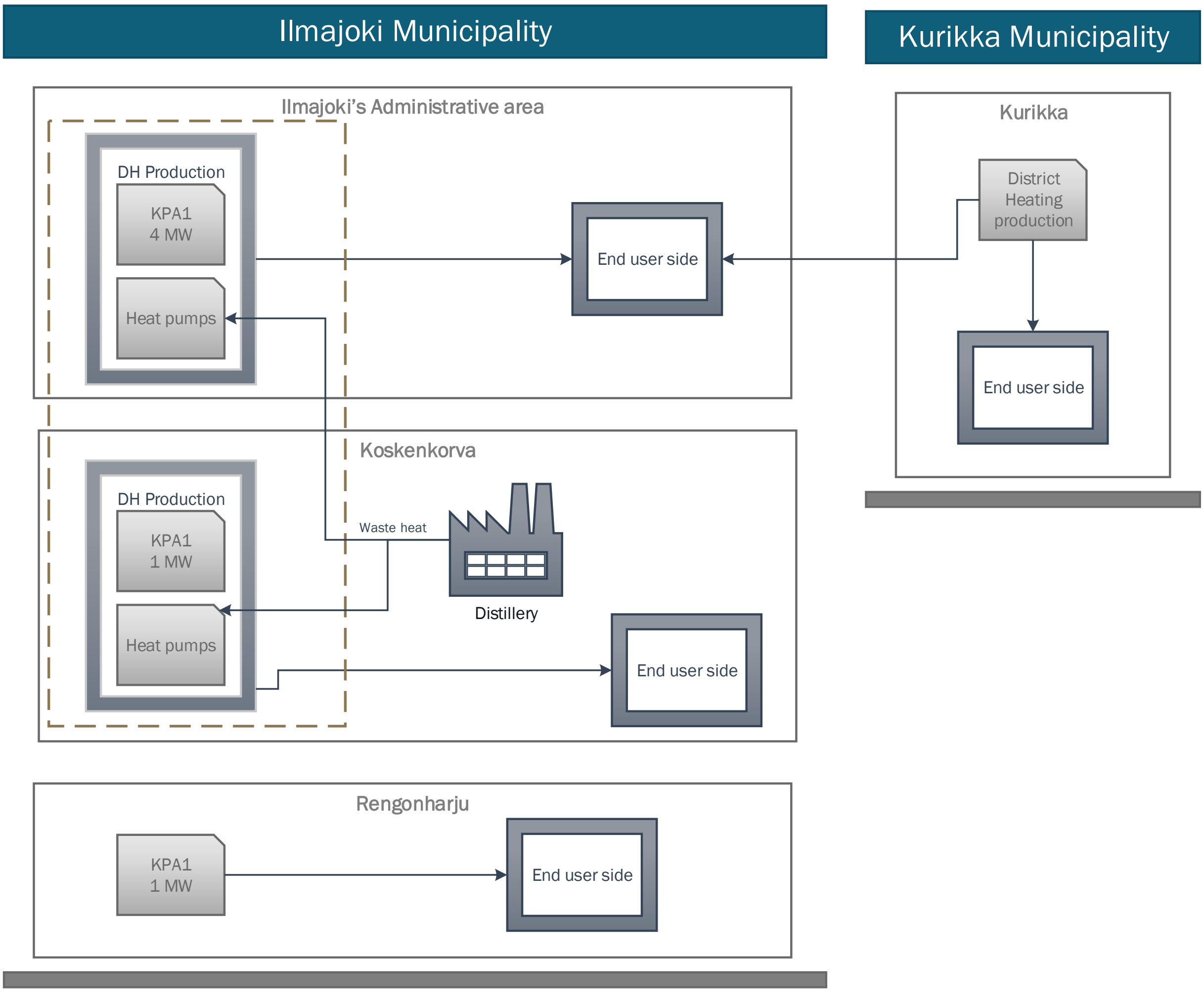


Figure 3. System boundaries for the future development scenario

For the preliminary evaluation, a total annual production of 3.3 GWh and 38.7 GWh of thermal energy were assumed as desired for Koskenkorva and Ilmajoki parishes respectively. The total reachable installed capacity for the heat pumps in Koskenkorva parish was of 730 kW, while 5860 kW for Ilmajoki's Administrative area. In order to integrate the heat waste from the distillery into the DH system, a new distribution pipeline sector with a total length of 650 m would be required.

In Figure 4, the estimated annual heat load for Koskenkorva parish is displayed, been covered mainly by heat pumps and by a solid fuel boiler during the period with lower temperatures.

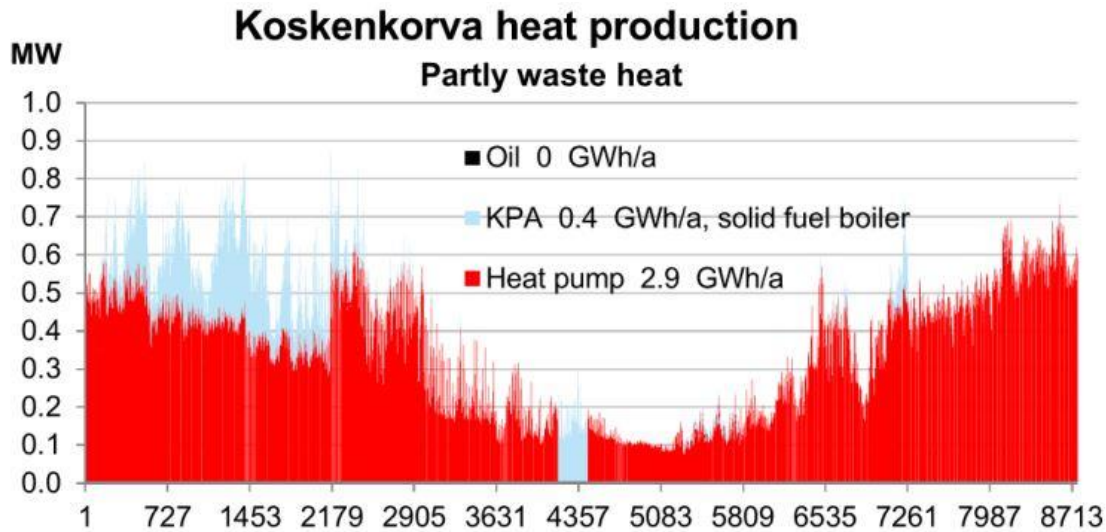


Figure 4. Future scenario for Koskenkorva heat production (LowTEMP, 2019).

The total forecasted heat load for Ilmajoki's administrative area plus Koskenkorva parish can be seen in Figure 5, with a total thermal energy production of 42 GWh per year. As shown, 32 GWh are to be produced by the use of heat pumps using the heat waste from the distillery and the remaining 10 GWh by the currently working solid fuel boilers.

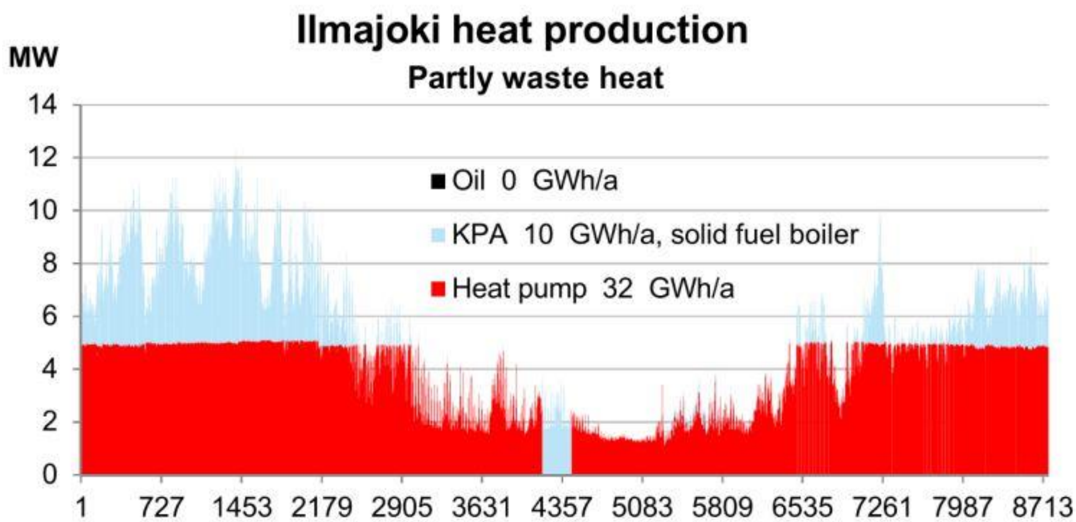


Figure 5. Future scenario for Ilmajoki heat production (LowTEMP, 2019).

Within the boundaries for the future scenario, the same approach as for the baseline scenario is considered regarding decommissioning, transport of materials, waste treatment and electricity consumption. The heat production and fuel consumption in the distillery are not considered within the boundaries (see Figure 3) as it is interpreted as use of waste heat, that otherwise would be cooled in cooling towers under the private facilities. On the other hand, the heat pumps energy consumption and operation are accounted just as the heat production from the boiler house covering the extra load during the coldest period. Finally, it must be mentioned that the intended time horizon for LCA is 25 years.

4.2 Assumptions and Limitations

Here are listed a summary of assumptions and limitations found after reviewing the available DH data for all scenarios.

Among the limitations that apply for all parishes and scenarios, the main one to consider is the technology deployed in them, as only currently available at commercial level ones are considered. Most data used for modelling was found in the Ecoinvent database 3.5, and decommissioning or waste treatment for baseline scenarios are not considered. Some materials used for the assemblies might account for waste scenarios and would be mentioned when it happens.

To account for the whole impact of the assembly and operation of the district heating network, construction materials, equipment and raw materials are included for all scenarios, this means that construction phase is within the boundaries. Nevertheless, this construction phase and all activities and materials are subjected to the data availability, which is limited due to future scenarios are still under study.

For baseline scenarios:

- Only base load boilers are used.
- No changes in insulation technologies along network were considered maintaining the same heat losses trends.
- After any equipment replacement or maintenance, and renovation, the same boiler technology is used, using the same fuel type and consumption.
- A low calorific value of 3.5 MWh/ton of woodchips is used for calculations.
- A boiler efficiency of 89% is used for the whole-time horizon (LowTEMP, 2019) in Koskenkorva parish and 94% for Ilmajoki's solid fuel boilers.
- Calculations for the amount (ton) of fuel consumption were carried out considering previously mentioned values.
- No decommissioning phase was considered.

For LowTemp scenarios:

- Steady production and heat demand profile during the study lifetime.
- New distribution network for the surplus heat of 6.5 km using DN200 pipelines.
- A Coefficient of performance of 3.2 is assumed for the heat pumps in a series arrangement.
- The same DH distribution network is used during this transitional phase.
- Same distribution temperatures profiles and no changes in current ΔT between supply and return lines.

- No decommissioning phase was considered.

5. Life Cycle Inventory

DH infrastructure data of Ilmajoki municipality were not available, and only data regarding general aspects was available (network length and pipe types, thermal capacity as well as fuel consumption, thermal capacities and thermal energy generated). For this reason most of the infrastructure data were gathered from the (Feofilovs, et al., 2019) and adapted to the size or length of Ilmajoki administrative area and Koskenkorva parish.

The main technical data were gathered from certificates of manufacturers and then grouped into the corresponding material and processes within the Ecoinvent 3 database. Some DH assemblies have an equivalent input object in the Ecoinvent 3 database, but many do not. Such missing equipment, apparatus or accessories missing in the database, were entered as the amount and materials required for its production, including the process necessary to construct the assembly.

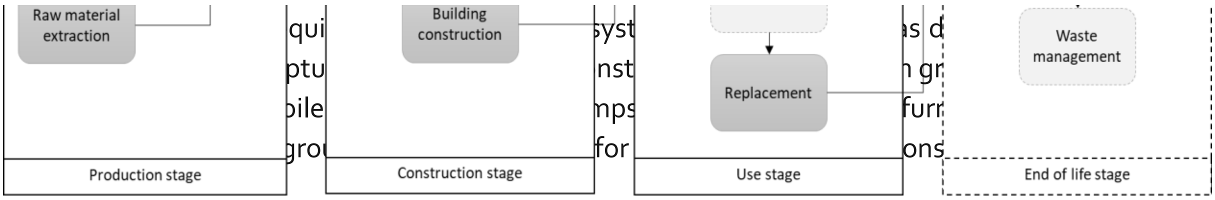


Figure 1) as selected objects from Ecoinvent 3 database correspond to items allocated at the point of substitution (APOS). Thus, the use stage, including operation of the DH assemblies, and the energy use phase which contains the fuel extraction or production, transport to boilerhouse and electricity or other energy use, is part of another "assembly" within the model, named "operational phase" in this LCA model. Detailed inventory tables can be seen in Annex 1.

A general example on how the assemblies were designed for inventory input is shown in Table 2. Then a summary of stages into the particular parish which is modeled in SimaPro is shown in Table 3.

TABLE 2. OPERATIONAL PHASE FOR ILMAJOKI BASELINE SCENARIO

Materials or Assembly	Amount	Unit
Peat {GLO}| market for | APOS, U	4896.7	ton
Wood chips, dry, measured as dry mass {RER}| market for | APOS, U	6661.4	ton
Light fuel oil {Europe without Switzerland} | market for | APOS, U	11.1	ton
Processes	**Amount**	**Unit**
Heat, district or industrial, other than natural gas {RoW}| heat production, hardwood chips from forest, at furnace 5000kW | APOS, U - LOWTEMP - Ilmajoiki	44700	MWh
Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, light fuel oil, at boiler 100kW condensing, non-modulating | APOS, U - LOWTEMP Ilmajoki	538	MWh

As can be seen in Table 3, assemblies such as DH pipelines, and nodes, are adjusted to the size or length of the specific parish. The operational phase stage is entered, considering Table 2, which is the inventory of fuels and materials required for a year of operation under the scenario described in the 4.1 section.

The end user side, or required building renovation assembly, was not modelled since the temperature profile is not yet to be reduced for this study. The future scenario to model only considers the reuse of waste heat from distillery as heat driver for the heat pumps arrangement in each parish.

TABLE 3. ILMAJOKI BASELINE SCENARIO MODEL

Material/Assemblies in SimaPro	Amount	Unit
Old Boilerhouse	2	p
Old District heating Pipelines	51.5	p
DH nodes	51.5	p
Boiler's pumps, taps, heat m., exch. & flow device	2	p
Node's pumps and taps	51.5	p
Pipeline's pumps, taps, heat meters, exch., flow d	51.5	p
Ilmajoki Baseline Scenario Op. Phase	25	p

Use stage (operational phase) specific inventory assembly per parish and other infrastructure assemblies within the construction and production phase, represent the full scenario used in the model as seen in Table 3. Therefore, similar tables were elaborated for Koskenkorva parish, and are to be found in Annex 1. The word "p" it means one unit of the proposed material referred to the FU.

6. Life Cycle Assessment Results

The LCI gathered was used for the simulation in SimaPro in accordance with the defined functional unit in section 3.3. The following results are presented for each parish, for the baseline scenario and for the proposed future model. First, the environmental impact assessment is presented at midpoint level (kg of substance equivalent) in tables where specific midpoint categories results can be observed, and then a characterisation graph is presented for comparing the environmental toll of each assembly within the construction phase and operational phase. After analysing the midpoint categories, a damage assessment is shown, in terms of Eco-indicator points, kPt, in relation to the Functional unit. This damage assessment presents results in the main four areas of concern evaluated within the IMPACT 2002+ methodology: human health, ecosystem quality, climate change and resources. Finally, for the parishes and different scenarios evaluation, hotspots are identified by comparing the Life Cycle stages and their total environmental burden. This result are found in the next subsection for both parishes/areas.

6.1 Life Cycle Assessment Results for Ilmajoki administrative area – LCIA

6.1.1 Ilmajoki administrative area - baseline scenario

In Table 4, the total kg per substance, which express the amount of a reference substance equalizing the impact of the analyzed pollutant under the midpoint category, is presented for the current state scenario with reference to the functional unit. It means, those are the environmental impacts of building and operating a DH system under current conditions for 25 years.

TABLE 4. CHARACTERISATION RESULTS FOR THE ADMINISTRATIVE AREA (BASELINE SCENARIO)

Impact category	Unit	Total	Op. Phase	Construction
Carcinogens	kg C_2H_3Cl eq	2,287,216	1,961,322	325,894
Non-carcinogens	kg C_2H_3Cl eq	12,703,955	12,444,051	259,904
Respiratory inorganics	kg PM2.5 eq	368,008	360,345	7,663
Ionizing radiation	Bq C-14 eq	8.30E+08	7.91E+08	3.88E+07
Ozone layer depletion	kg CFC-11 eq	4.7	4.4	0
Respiratory organics	kg C_2H_4 eq	61,046	58,087	2,959
Aquatic ecotoxicity	kg TEG water	9.65E+10	9.44E+10	2.11E+09
Terrestrial ecotoxicity	kg TEG soil	3.50E+10	3.43E+10	7.61E+08
Terrestrial acid/nutri	kg SO_2 eq	6.66E+06	6.58E+06	82,872
Land occupation	m2org.arable	2.37E+07	2.37E+07	82,658
Aquatic acidification	kg SO_2 eq	985,831	962,073	23,758
Aquatic eutrophication	kg PO_4 P-lim	53,216	50,291	2,924
Global warming	kg CO_2 eq	5.29E+07	4.83E+07	4.65E+06
Non-renewable energy	MJ primary	2.08E+09	2.01E+09	6.94E+07
Mineral extraction	MJ surplus	3.31E+06	1.89E+06	1.42E+06

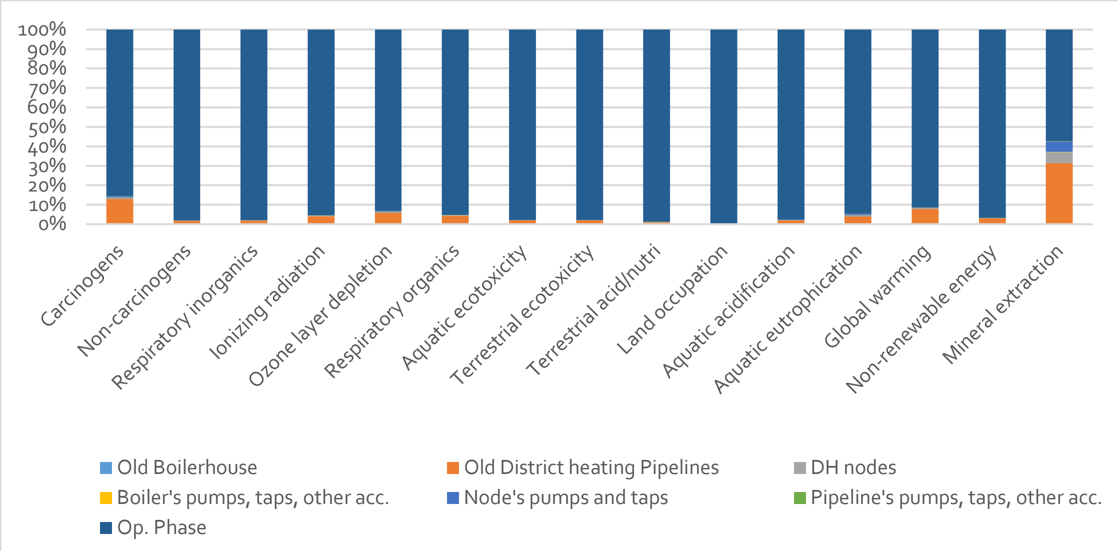


Figure 6 shows in a clear way, the share of assembly in the different impact categories. As seen, the operational phase is the major environmental impact for all categories.

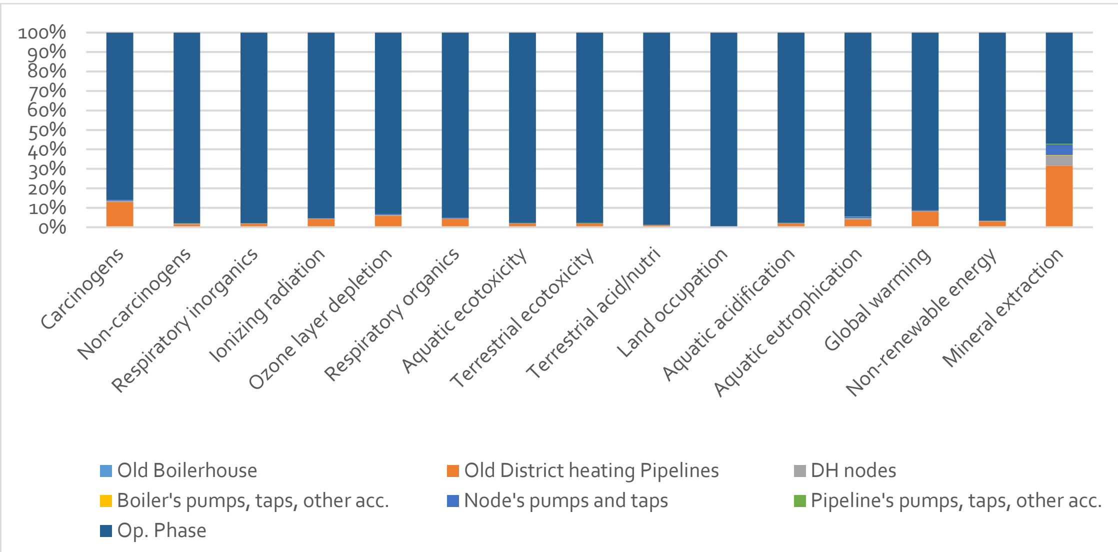


Figure 6. Characterisation comparison between assemblies for the administrative area - baseline scenario.

The weighted damage assessment per area of concern is presented in Figure 7, displaying every single assembly considered within the scenario model. The operation phase is followed far behind by the pipeline network, and all other assemblies are practically negligible if compared with these two hotspots. The most impacted area of concern is human health with a total score of 42.28kPts, followed by the ecosystem quality with 22.97 kPts, resources and climate change with 13.7 and 5.34 kPts, respectively.

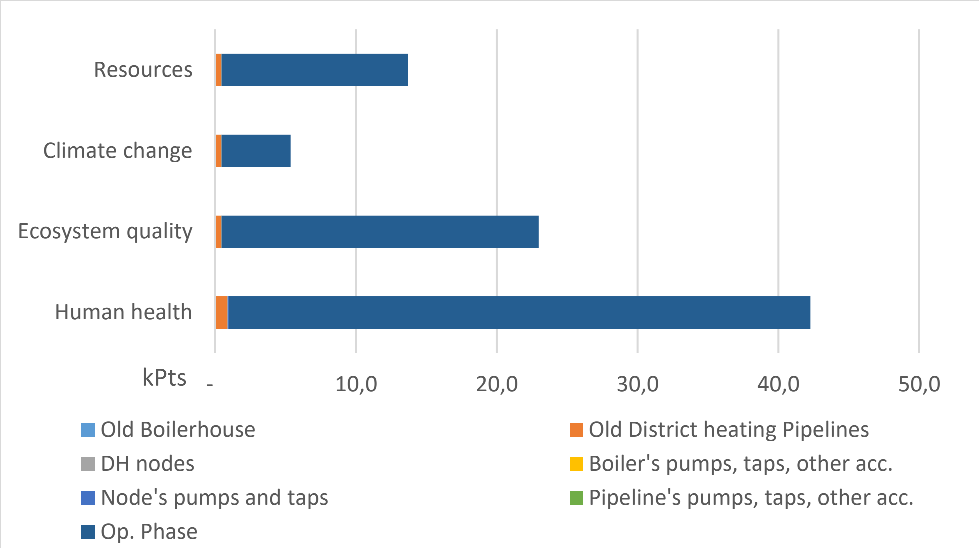


Figure 7. Damage assessment for the administrative area - baseline scenario.

6.1.2 Ilmajoki administrative area – future scenario

In Table 5, midpoint category characterisation is presented for the future scenario with reference to the adopted functional unit.

TABLE 5. CHARACTERISATION RESULTS FOR THE ADMINISTRATIVE AREA (FUTURE SCENARIO)

Impact category	Unit	Total	Op. Phase	Construction
Carcinogens	kg C2H3Cl eq	1,172,014	846,534	325,480
Non-carcinogens	kg C2H3Cl eq	4,437,441	4,177,973	259,469
Respiratory inorganics	kg PM2.5 eq	132,469	124,824	7,645
Ionizing radiation	Bq C-14 eq	8.74E+09	8.70E+09	3.88E+07
Ozone layer depletion	kg CFC-11 eq	13.56	13.24	0.32
Respiratory organics	kg C2H4 eq	29,895	26,939	2,955
Aquatic ecotoxicity	kg TEG water	3.24E+10	3.03E+10	2.11E+09
Terrestrial ecotoxicity	kg TEG soil	1.12E+10	1.04E+10	7.60E+08
Terrestrial acid/nutri	kg SO2 eq	2,284,478	2,201,770	82,708
Land occupation	m2org.arable	1.20E+07	1.20E+07	8.25E+04
Aquatic acidification	kg SO2 eq	433,464	409,755	23,709

Aquatic eutrophication	kg PO_4 P-lim	27,442	24,522	2,920
Global warming	kg CO_2 eq	6.39E+07	5.92E+07	4.65E+06
Non-renewable energy	MJ primary	2.01E+09	1.94E+09	6.93E+07
Mineral extraction	MJ surplus	4.69E+06	3.28E+06	1.41E+06

Figure 8 shows the share of each assembly in the different impact categories. As seen, the operational phase is again the major environmental impact. Still, its share has diminished for certain impact categories, because of the fuel consumption reduction due to waste heat utilisation with the new heat pumps.

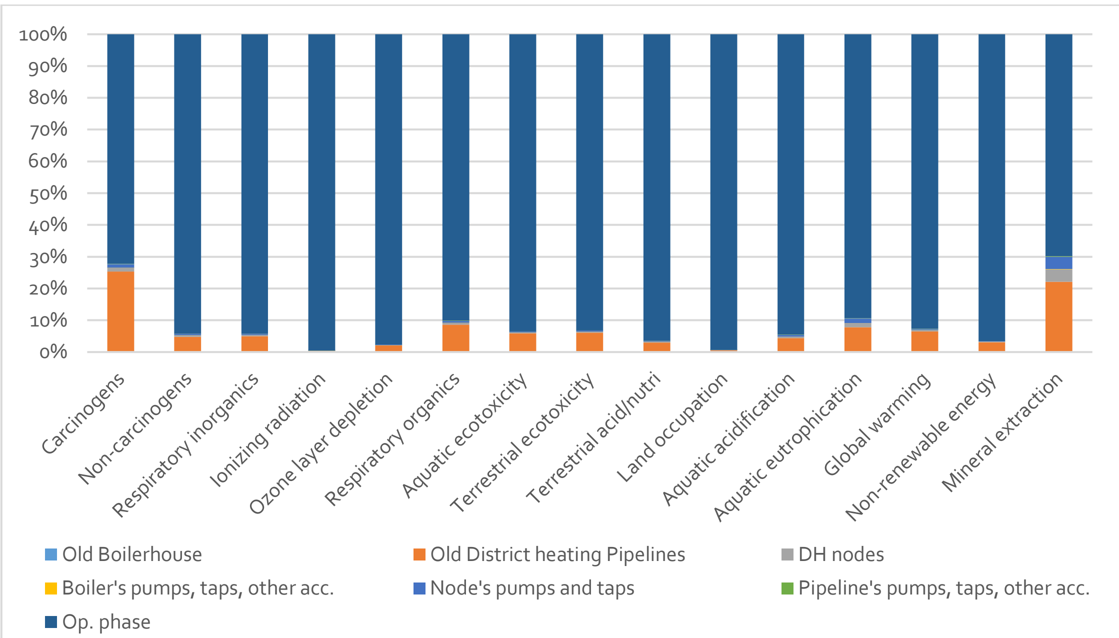
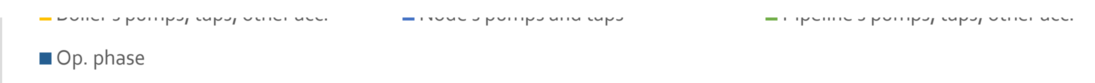


Figure 8. Characterisation comparison between assemblies for the administrative area -future scenario



in (see

Figure 9), displaying every single assembly considered within the scenario model. The most impacted area of concern is the human health with a total score of 15.6 kPts, followed by resources with 13.3 kPts, then the ecosystem quality with 7.7 kPts, and at last, climate change with 6.5 kPts.

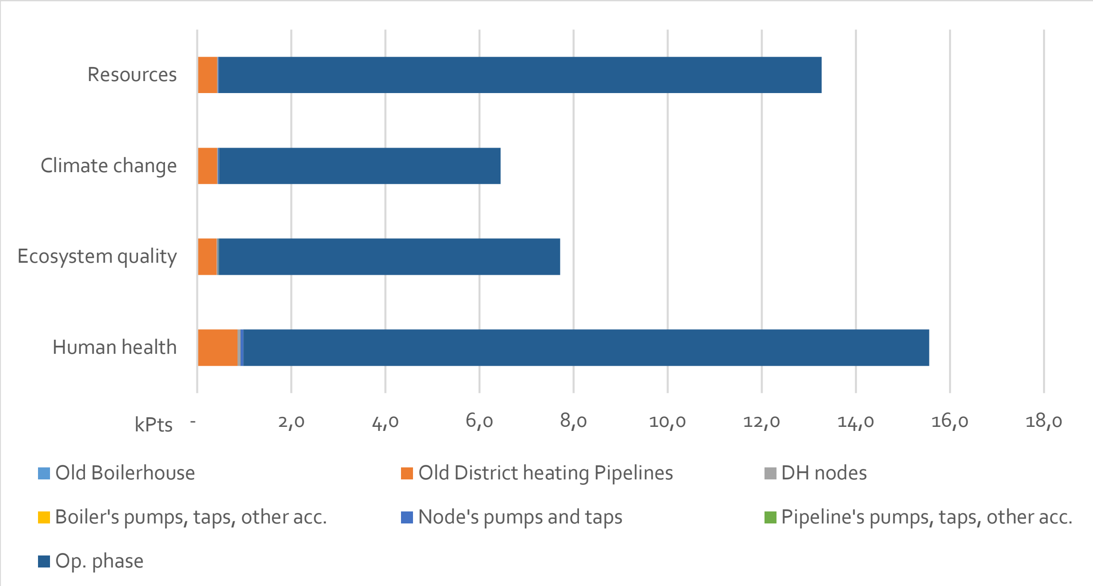


Figure 9. Damage assessment for the administrative area – future scenario.

6.2 Life Cycle Assessment Results for Koskenkorva parish

Koskenkorva parish was the only parish remaining to be evaluated for its environmental impact under this study.

6.2.1 Koskenkorva parish - baseline scenario

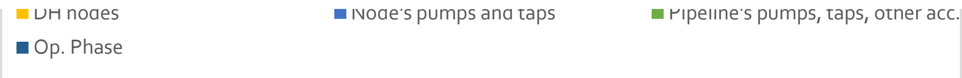
In Table 6, the midpoint category results are presented for the current state scenario with reference to the functional unit.

TABLE 6. CHARACTERISATION RESULTS FOR STARI PARISH (BASELINE SCENARIO)

Impact category	Unit	Total	Op. Phase	Construction
Carcinogens	kg C_2H_3Cl eq	248,066	204,904	43,162
Non-carcinogens	kg C_2H_3Cl eq	1,136,494	1,101,887	34,607
Respiratory inorganics	kg PM2.5 eq	34,371	33,343	1,029
Ionizing radiation	Bq C-14 eq	9.69E+07	9.18E+07	5.16E+06
Ozone layer depletion	kg CFC-11 eq	0.57	0.53	0.04
Respiratory organics	kg C_2H_4 eq	7,535.48	7,143.14	392.34
Aquatic ecotoxicity	kg TEG water	8.59E+09	8.31E+09	2.79E+08
Terrestrial ecotoxicity	kg TEG soil	3.11E+09	3.01E+09	1.01E+08

Terrestrial acid/nutri	kg SO2 eq	597,859	586,782	11,078
Land occupation	m2org.arable	3,426,773	3,415,737	11,036
Aquatic acidification	kg SO2 eq	90,788	87,609	3,179
Aquatic eutrophication	kg PO4 P-lim	5,043.3	4,654.2	389.1
Global warming	kg CO2 eq	5.49E+06	4.87E+06	6.19E+05
Non-renewable energy	MJ primary	1.02E+08	9.25E+07	9.21E+06
Mineral extraction	MJ surplus	409,841	215,969	193,872

Figure 10 shows the share of each assembly in the different impact categories. As seen, the operational phase is the major environmental impact in this scenario for all categories. In the mineral extraction, it is worth to notice that the construction of pipeline network carries 35% of the total impact for this category.



is presented in

Figure 11, displaying all the assemblies considered in the model for this parish.

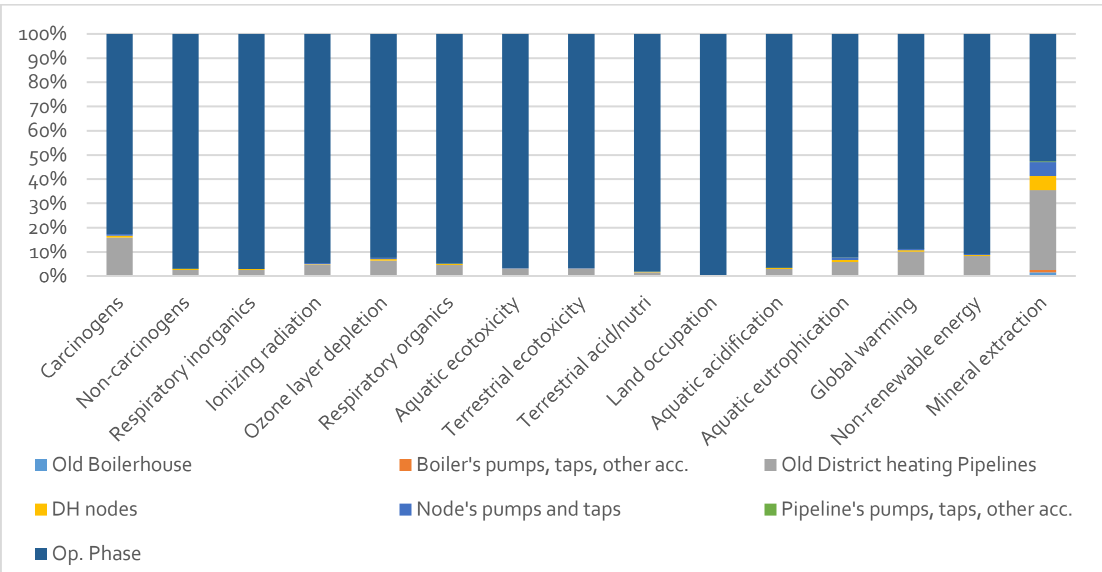


Figure 10. Characterisation comparison between stages for Koskenkorva - baseline scenario.

The operation phase is the main responsible stage for each area of concern in terms of weighted environmental toll. The most impacted area of concern is human health with a total score of 3.9 kPts, followed by the ecosystem quality with 2.1 kPts.

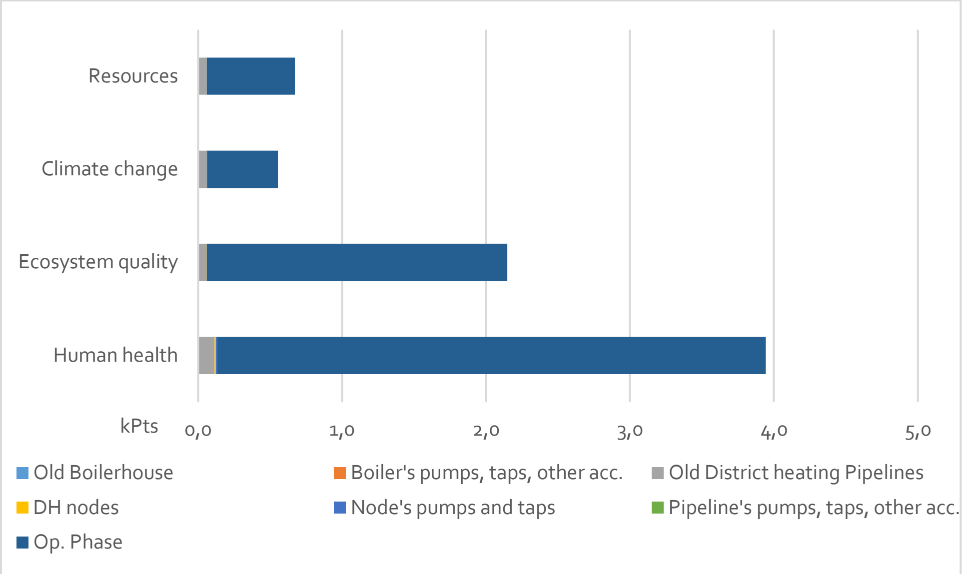


Figure 11. Damage assessment for Koskenkorva - baseline scenario.

6.2.2 Koskenkorva parish – future scenario

In, Table 7 midpoint category characterisation is presented for the future scenario with reference to the functional unit.

TABLE 7. CHARACTERISATION RESULTS FOR KOSKENKORVA PARISH (FUTURE SCENARIO)

Impact category	Unit	Total	Op. Phase	Construction
Carcinogens	kg C_2H_3Cl eq	101,348	53,179	48,169
Non-carcinogens	kg C_2H_3Cl eq	288,335	249,422	38,912
Respiratory inorganics	kg PM2.5 eq	9,470.0	8,320.9	1,149
Ionizing radiation	Bq C-14 eq	8.58E+08	8.52E+08	5.79E+06
Ozone layer depletion	kg CFC-11 eq	1.285	1.236	0
Respiratory organics	kg C_2H_4 eq	2,118.7	1,667.4	451
Aquatic ecotoxicity	kg TEG water	2.07E+09	1.76E+09	311,836,900
Terrestrial ecotoxicity	kg TEG soil	6.96E+08	5.83E+08	112,636,190
Terrestrial acid/nutri	kg SO_2 eq	142,849.4	130,375.0	12,474
Land occupation	m2org.arable	660,828.7	648,486.1	12,343
Aquatic acidification	kg SO_2 eq	31,131.6	27,544.8	3,587
Aquatic eutrophication	kg PO_4 P-lim	2,177.5	1,737.4	440
Global warming	kg CO_2 eq	5.85E+06	5.15E+06	694,505
Non-renewable energy	MJ primary	1.90E+08	1.79E+08	10,392,690
Mineral extraction	MJ surplus	510,478	295,794	214,684

Figure 12 shows the share of each assembly in the different impact categories. The operational phase is the major environmental impact, but due to a reduction in fuel consumption across the project life-time, other assemblies have gained share in several impact categories.

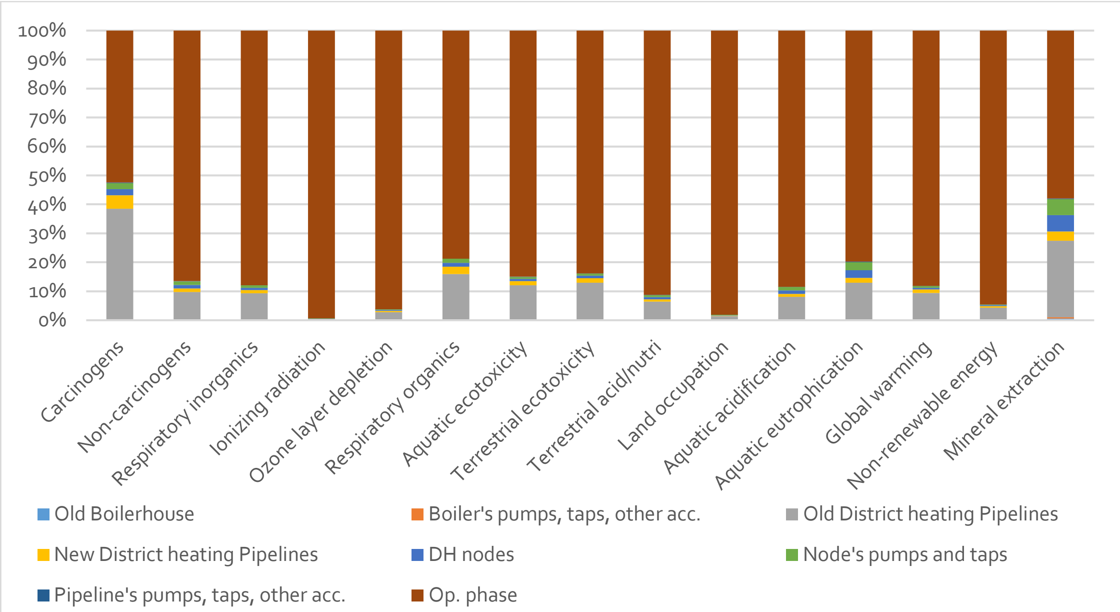


Figure 12. Characterisation comparison between assemblies for Koskenkorva – future scenario.

The weighted damage assessment per area of concern is presented in Figure 13, displaying every single assembly considered for Koskenkorva future DH system model. The operation phase delivers most of the impacts in all areas followed by the pipeline network assembly within the DH construction stage. The most impacted area of concern is resources with 1.3 kPts, followed by human health with 1.1 kPts.

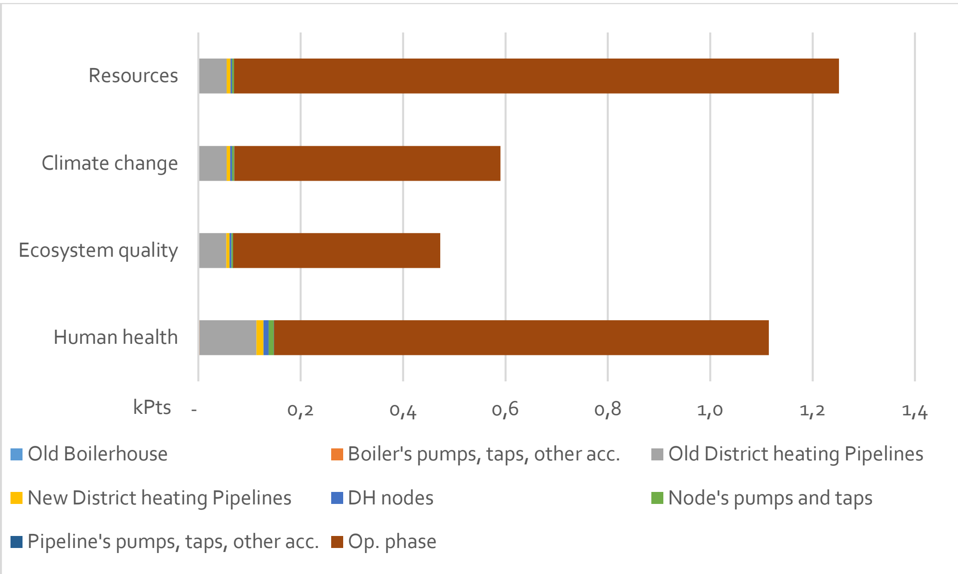


Figure 13. Damage assessment for Koskenkorva- future scenario.

7. LCIA DH comparison and conclusions

The LCA model for two parishes/areas as aggregated in two: 1) current state and 2) future development using waste heat and heat pumps for the DH system already deployed. Table 8 shows the characterized results in terms of released equivalent substances or midpoint level.

TABLE 8. CHARACTERISATION RESULTS COMPARISON BETWEEN DH SCENARIOS

Impact category	Unit	Current scenario	Future scenario
Carcinogens	kg C_2H_3Cl eq	2,535,282	1,273,361
Non-carcinogens	kg C_2H_3Cl eq	13,840,449	4,725,776
Respiratory inorganics	kg PM2.5 eq	402,379	141,939
Ionizing radiation	Bq C-14 eq	9.26E+08	9.60E+09
Ozone layer depletion	kg CFC-11 eq	5.3	14.8
Respiratory organics	kg C_2H_4 eq	68,582	32,013
Aquatic ecotoxicity	kg TEG water	1.05E+11	3.45E+10
Terrestrial ecotoxicity	kg TEG soil	3.81E+10	1.19E+10
Terrestrial acid/nutri	kg SO_2 eq	7,258,220	2,427,327
Land occupation	m2org.arable	27,163,938	12,701,677
Aquatic acidification	kg SO_2 eq	1,076,619	464,596
Aquatic eutrophication	kg PO_4 P-lim	58,259	29,619
Global warming	kg CO_2 eq	58,396,471	69,717,200
Non-renewable energy	MJ primary	2.18E+09	2.20E+09
Mineral extraction	MJ surplus	3,722,157	5,202,701

The implementation of waste heat and heat pumps in the District Heating system brings an environmental benefit in several mid-point categories, except for *Ionizing radiation*, *Ozone layer depletion*, *Respiratory organics*, *Global warming*, *Non-renewable energy* and *Mineral extraction*, where the increase related to the development of the proposed future scenario is 936%, 180%, 19%, 1% and 40% respectively. On the other hand, the remaining ten midpoint categories present an average reduction of 60 %, hence, here, it is necessary to implement a weighted factor in order to clearly display the overall environmental impact. The changes per impact category can be seen in Figure 14.

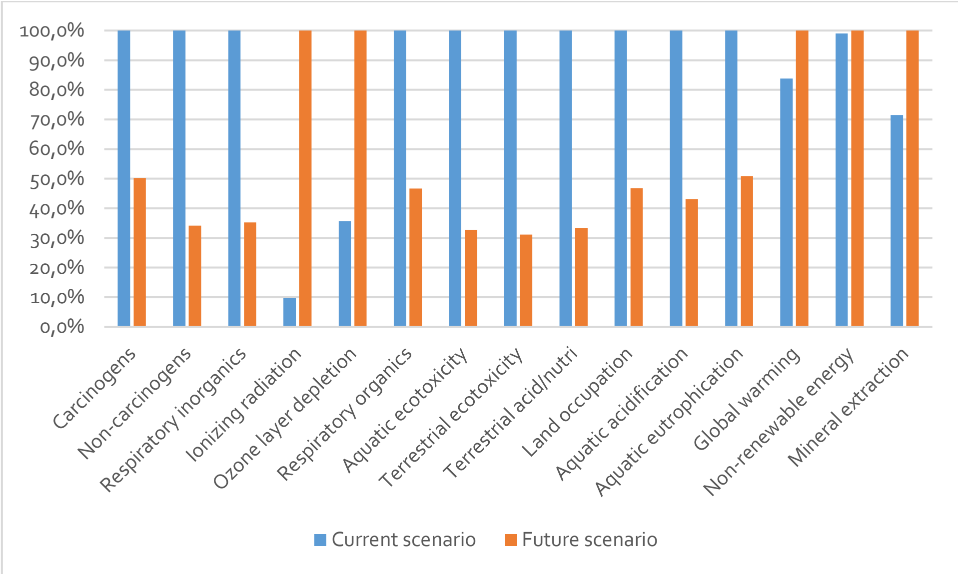


Figure 14. Characterisation comparison between impact categories.

The difference at endpoint categories, or areas of concern, is shown in Figure 15. The human health area is the one with the highest environmental toll, the reduction of moving from the current DH conditions towards implementing waste heat use, is 64%. The total environmental score for human health area under the current conditions in Ilmajoki municipality, deliver 46.2 kPts for the analyzed FU, while under the future scenario, the resulting score is 16.67 kPts. In the ecosystem quality area, the reduction is 67.4%, although, climate change and resources areas show a minor increase from developing the future scenario strategy. For climate change, the raise corresponds to 16.2%, and in the resources area 1.1%.

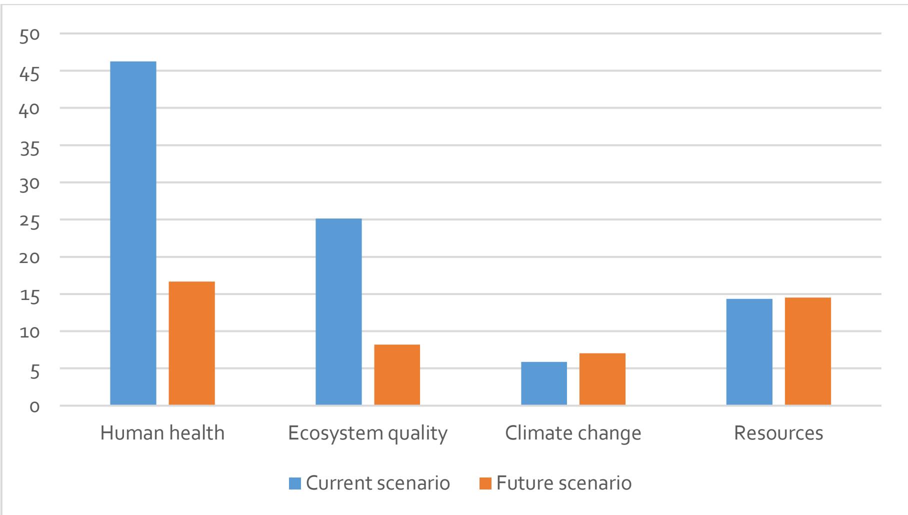


Figure 15. Weighted damage assessment comparison at end point categories.

Finally, the total single score for each model is plotted in Figure 16, where the aggregated results at each area of concern is presented. The current DH system gives a total environmental score of 91.62

kPts, and the future scenario for DH system 46.43 kPts, showing a total reduction of 45.2 kPts, representing an environmental impact reduction of 49.3%.

The environmental benefit of implementing the use of waste heat as driver thermal energy for heat pumps in Ilmajoki DH systems comes mainly from the reduction in the amount of fuel required for the total operation. However, further studies must be carried to evaluate the future impact of 4GDH temperature regimes for the distribution network, once installed the residential and administrative buildings in the parishes (which should be the final goal of bringing into the table using waste heat from other industries.

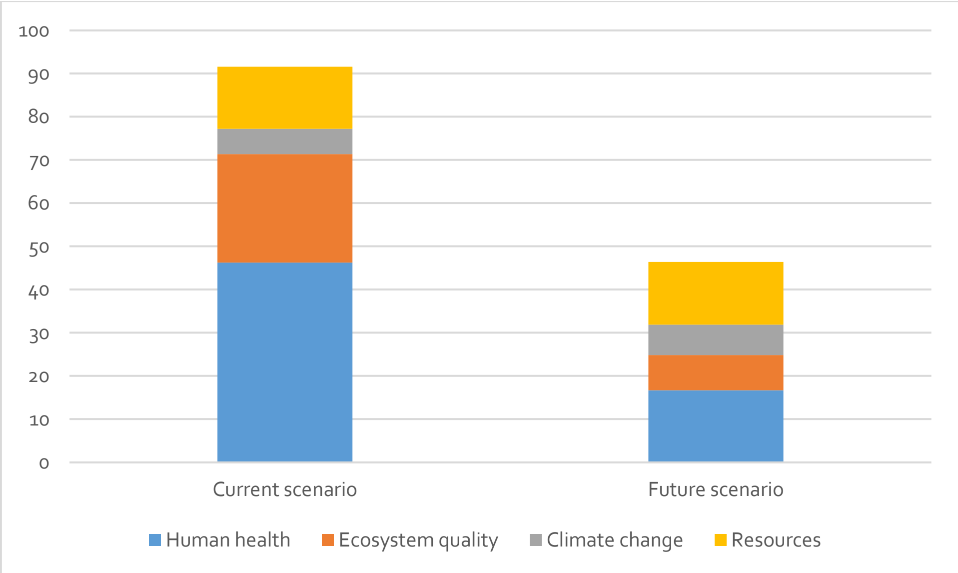


Figure 16. Single score comparison between models.

Authorship

The proposed LCA study has been finalized within the group of activity 4.2 of LowTEMP project with contribution from the partners reported below:

Project Partner	Responsible persons
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Thermopolis (PP9)	Pauli Sneck Sauli Jäntti

1. .

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Annex 1

ITEM INVENTORY FOR ADMINISTRATIVE AREA - OPERATIONAL PHASE (CURRENT SCENARIO)

Material/Assemblies in SimaPro	Amount	Unit
Peat {GLO}| market for | APOS, U	*4896.7*	*ton*
Wood chips, dry, measured as dry mass {RER}| market for | APOS, U	*6661.4*	*ton*
Light fuel oil {Europe without Switzerland}| market for | APOS, U	*11.1*	*ton*
Processes	**Amount**	**Unit**
Heat, district or industrial, other than natural gas {RoW}| heat production, hardwood chips from forest, at furnace 5000kW | APOS, U - LOWTEMP - Ilmajoiki	*44700*	*MWh*
Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, light fuel oil, at boiler 100kW condensing, non-modulating | APOS, U - LOWTEMP Ilmajoki	*538*	*MWh*

ITEM INVENTORY FOR ADMINISTRATIVE AREA - OPERATIONAL PHASE (FUTURE SCENARIO)

Material/Assemblies in SimaPro	Amount	Unit
Wood chips, dry, measured as dry mass {RER}| market for | APOS, U	*2386.2*	*ton*
Processes	**Amount**	**Unit**
Heat, district or industrial, other than natural gas {RoW}| heat production, hardwood chips from forest, at furnace 5000kW | APOS, U - LOWTEMP - Ilmajoki	*9600*	*MWh*
Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, at heat pump 30kW, allocation exergy | APOS, U - LOWTEMP Ilmajoki	*29100*	*MWh*
Electricity, low voltage {FI}| market for | APOS, U	*7911*	*MWh*

ITEM INVENTORY FOR KOSKENKORVA PARISH- OPERATIONAL PHASE (CURRENT SCENARIO)

Material/Assemblies in SimaPro	Amount	Unit
Wood chips, dry, measured as dry mass {RER}| market for | APOS, U	*971.3*	*ton*
Processes	**Amount**	**Unit**
Heat, district or industrial, other than natural gas {RoW}| heat production, hardwood chips from forest, at furnace 5000kW | APOS, U - LOWTEMP - Koskenkorva	*3700*	*MWh*

Material/Assemblies in SimaPro	Amount	Unit
Wood chips, dry, measured as dry mass {RER}| market for | APOS, U	*83.2*	*ton*
Processes	**Amount**	**Unit**
Heat, district or industrial, other than natural gas {RoW}| heat production, hardwood chips from forest, at furnace 1000kW | APOS, U - LOWTEMP Koskenkorva	*400*	*MWh*
Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, at heat pump 30kW, allocation exergy | APOS, U - LOWTEMP Koskenkorva	*2900*	*MWh*
Electricity, low voltage {FI}| market for | APOS, U	*788.4*	*MWh*

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