# Life Cycle Assessment (LCA) Study of the Pilot Energy Strategy (PES) for Gulbene Municipality

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# Introduction

The 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 can reduce the overall amount of GHG emissions within the process as compared to individual heating Green House Gas (GHG) emissions from the district heating sector. 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 results in 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 no holistic approach to assess 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 (LCA) 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 neighbourhood, 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). The study of Eriksson et al. (2007) highlights 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 the 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 in Gulbene region. This pilot was aiming to improve district heating systems in Gulbene region to provide a more energy-efficient solution. The study reported in this document assesses and compares existing heat supply situations and problems, including the characterization of each specific energy sources.

This report focuses on the evaluation of the environmental impact using LCA approach of different potential energy strategies of specific Parishes of Gulbene Municipality in fact creating a final ranking of scenarios based on the quantitative evaluation of the overall environmental performances. The authors have included in of each the DH scenarios the fuel-supply chain, the central heating production system, the distribution grid and the final demand.  The results from the study will be clearly described in the next sections.

Finally, this document 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 systems. The specific inventory utilized to evaluate the overall eco-profile of a particular energy strategy implemented in Low Temperature DH is reported both in the Annexes and as excel tables.

# 1. DH in the Context of Sustainability

Under the European climate and energy framework for 2030, Latvia as a member state must pursue a target of above 40 % GHG emission reduction compared with 1990, and a central path towards it is an increase in energy efficiency. As stated in (Ekodoma, 2019) the Latvian National Energy and Climate Plan 2021-2030 settled a goal for 2030 where the share of renewable energy in the final gross consumption is to be equal to 50 %. In the document "Latvia's Sustainable Development Strategy 2030" it is stated that energy independence is a crucial objective for 2030, and self-sufficiency towards energy resources and integration in the EU energy network must be achieved.

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 the heat can be supplied from different centralized boiler houses, combined heating plants or several heat production facilities of 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 the use of more efficient heat generation equipment when compared 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. This concept 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. The utilisation of the surplus heat flows represents an essential 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 important 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 pass to other consumers or district heating networks. Such solutions replace the fuel share in heat production, increased efficiency and reduce emissions and costs.

Nevertheless, the distribution heat losses are the main challenge which needs to be overcome 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 essential requirement for optimal heat supply is the concentration of the demand for heat to reduce distribution costs and heat losses.

Due to the rapid decrease of residential building heat consumption also arises the necessity to change the operational conditions of the 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 – a heat source, a heating network and heat consumers (Ziemele J., 2016). 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 properly implemented. Foretime estimations on low temperature district heating showed a possible reduction of heat loss by 75 % compared to 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, utilization of thermal storage to handle peak loads without oversizing equipment or improving heat-to-steam ratio in steam CHP system to extract more power of the turbine (Imran M., 2017).

In this context, the need to use LCA for the evaluation of the DH environmental sustainability is evident.

# 2. LCA methodology

A major motivation for developing new DH systems is their environmental benefit. Indeed, they can reduce GHG emissions, air pollution, ozone depletion and acid precipitation, among others, by integrating RES, improving efficiency in equipment and moving from individual solutions to central heating systems. All products (goods or services) have a life cycle including: 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 scenarios.

Life Cycle Assessment (LCA) is recognized as the most powerful and widely used tool for undertaking 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 approach. 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 advantages 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 estimate the environmental impacts coming from the life cycle of a determined product. These impacts can be classified in: climate change, stratospheric ozone depletion, tropospheric ozone creation (smog), eutrophication, acidification, toxicological stress on human health and ecosystems, 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 material 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 objective 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 collection 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 Interpretation, several elements are considered: identification of significant issues based on results, evaluation of consistency and sensitivity checks, and discussion of conclusions, limitations and recommendations.

# 3. Goal and Scope

Gulbene region comprises the Gulbene town and 6 more parishes. Nowadays they have installed District heating systems working under what can be called third-generation technology state of the art for many district heating systems currently operating in North and Easter Europe. Nevertheless, under the seeking to meet the aforementioned plans, Gulbene region has started to work towards a more energy-efficient performance by the development of a Low Temperature District heating network, initially implemented in the Belava parish (Feofilovs, et al., 2019). Under the Pilot Energy Strategy (PES) proposed for Gulbene region and developed within the framework of LowTEMP project, other 6 Parishes including Gulbene Municipality have been considered for developing low temperature also called fourth generation district heating (4GDH) systems. These development scenarios were compared with initial studies as baseline scenarios; thus, it was possible to assess the technical and economic feasibility for different future development scenarios (Ekodoma, 2019). However, the environmental load of possible future scenarios should be analyzed and compared to the nowadays heat production and distribution practice, to quantify the impact change in different areas of concern from the proposed development options.

## 3.1 Goal definition

The goal of this study is to assess the environmental impacts of the baseline scenario for the current DHS in Gulbene region and compare it with possible future designs where temperature profiles in the distribution network are lowered. The study will also include the effects of insulation improvements from buildings retrofitting as part of a new Low Temperature District Heating system (LTDH).

The main objective is to evaluate the effects towards the transition from a 3GDH system to a 4GDH system. The LCA study provides, in junction with economic assessment, a reliable decision-making tool providing consistent thresholds for the section of the optimal technological solution in line with "Latvia's Sustainable Development Strategy 2030".

## 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. The attributional model is used for this study to evaluate the environmental load of the DHS baseline scenario with the proposed upgrade to a LTDHS future 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 across the pipelines that comprise the distribution network, resulting in heat losses reductions, or in the boiler house, are also not considered other than the ones explicitly discussed within the project.

Among the different scenarios comprised in (Ekodoma, 2019), some of them evaluate not only the reduction in the temperature profile across the network but also the inclusion of new customers, decoupling of some buildings while maintaining the same temperature profile for the supply and return lines of the DH network. Within this study, only scenarios falling under the definition of LTDH were analyzed and compared to the baseline scenario.

For the baseline scenario the current technology, data for calculations, fuels and networks described in (Ekodoma, 2019) were used for modelling activities as part of the background data. Foreground data were obtained from (Feofilovs, et al., 2019) ad further assumed that similar infrastructures are encountered or developed in the other Gulbene's parishes. The distribution network temperature is usually considered as 70°C for the supply pipelines and 45° for the return lines, although each parish has its temperature schedule. In the system boundaries section, more information regarding infrastructure of each parish and scenario will be described in detail.

## 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 howlong/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 different Gulbene's parishes and municipality including infrastructural works as are necessary for heat distribution in each scenario. This assumption includes any construction or renewing work required either for the baseline or future scenarios, such as boiler house construction or maintenance, the deployment of required new pipelines and heat pumps installation or refurbishment and insulation materials for the customer's buildings.

## 4. System Boundaries

The project concerns 6 different parishes including Gulbene town within Gulbene municipality. These parishes are located at the northeast of Latvia in the Vidzeme region and the heating season in accordance with previous Cabinet Regulation No. 338 "Regulations on Latvian Construction Standard LBN 003-15 "Building Climatology" in Gulbene is 209 days, but the average outdoor air temperature is -1.4° C (Ekodoma, 2019). The duration of the heating season is based on the assumption that the heating in the buildings is switched on when the average five-day outdoor air temperature is below 8° C and accordingly switched off when the five-day average temperature is above 8° C.

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 energy needed for it. 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 solar plants, heat pumps and accumulation tanks are also considered in terms of 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. Replacement of equipment such as recirculation pumps during the lifespan of the project are considered.

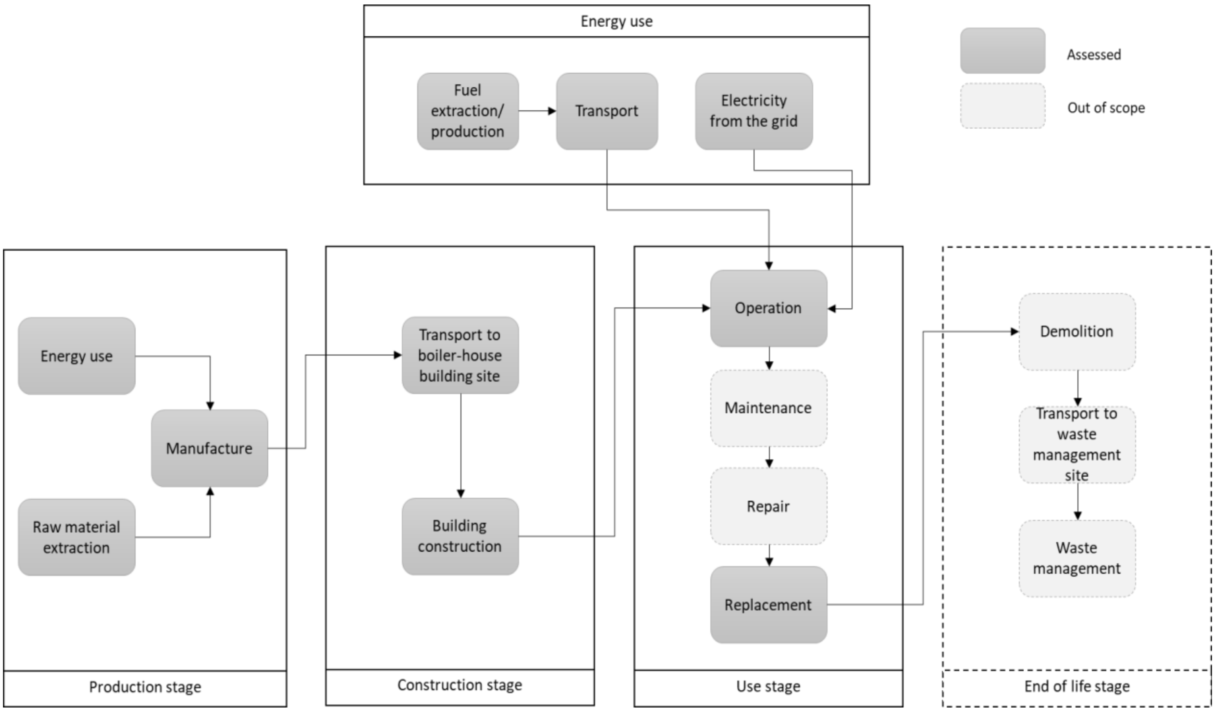



Figure 1. System boundaries on the supply side

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 at all in this study, as the useful life of a DH system depends on many variables such as governmental policies, the technological diffusion of new technologies, rate of change in population (demand side), and maintenance of the network and boilerhouse.

Regarding the boundaries in the demand side is assumed that buildings required a tailored refurbishment to reduce the specific heat consumption in terms of kWh/m2 per year. The end of life cycle is not considerd in this study.

## 4.1 Parishes boundaries and scenarios description

For each selected Parish different and independent heating systems were considered for the definition of alternatives of low temperature concept to be modelled according to the LCA metod.

## 4.2 Gulbene town

Gulbene district heating system (DHS) consists of interconnected boiler house and CHP plant, heating network and energy consumers. Nowadays more than 68 % of the total energy delivered to consumers, is purchased from the CHP plant by the SIA "Vidzemes enerģija". The remaining heat is produced in either a 4.5-6.0 MW woodchip boiler depending on the required demand. Data for heat purchase and production in 2018 can be seen in Table 1.

TABLE 1. DH HEAT PRODUCTION AND SUPPLY

| Parameter | 2018 |
|---|---|
| Produced heat, MWh per year | 9819 |
| Purchased heat from CHP, MWh per year | 21031 |
| Total, MWh per year | 30850 |
| Heat losses, MWh per year | 6330 |
| Heat losses, % | 21% |
| Delivered to consumers, MWh per year | 24520 |
| Wood chip consumption, $m^3$ per year | 15585 |
| Energy from fuel, MWh per year | 12624 |
| Average efficiency | 78% |

Gulbene DH already produces all its heat from renewable energy sources - biomass, but for efficient use of fuel it is necessary to ensure maximum heat production efficiency.

Wood chips are used as fuel in the boiler house of SIA "Vidzemes Enerģija". The average moisture content of woodchips is 40-60%. This means that much of the heat produced is consumed to evaporate moisture from the fuel. Evaporated moisture is released into the atmosphere in the form of flue gases. Installation of a condensation type economizer or flue gas condenser is an option to increase the efficiency of heat production. The return water from the district heating network is used as heat carrier in the economizer. Upon entering the economizer sections, the water warms up by "picking up" the physical and condensing heat of the flue gas and returns to the total return of the heating network, which combines the return water of the entire heating network (Blumberga, 2011).

The use of solar energy was analyzed (Ekodoma, 2019) as an alternative to increase the share of renewable energy in the energy balance. Solar energy can be used to produce both, thermal energy through solar panels and electricity only from Photo Voltaic (PV) solar panels. As the available heat surplus from the wood processing plant is to be used primarily in the city of Gulbene, the installation of a solar collectors for heat production during the summer period is not considered.

In order to cover the boiler house's electricity demand during summer time, the required solar panel area was calculated (Ekodoma, 2019) based on the monthly consumption of summer boiler house electricity and global solar radiation in the Vidzeme region, which has been determined according to meteorological observations. The optimal output of the solar power plant would be 170 kW, provided by the installation of an effective area of 1000 m2 panels. Such an area of solar panels with average solar radiation and total efficiency of 17%, could produce 168 MWh of electricity per year. Two scenarios were assessed in this study for Gulbene town to evaluate the potential increase the use of renewable sources and improving the overall efficiency of the boiler house.

a. Scenario 1. In this scenario, the heat is supply by a woodchip boiler. The heating system operates with the current temperature mode. Scenario 1 assumes that two new woodchip boilers (1.5 MW and 3.5 MW) are installed in the existing boiler house with automatic woodchip feed and additionally integrated storage tanks for optimum boiler operation and daily load balancing. The scenario assumes that the boiler house has a 1.5 MW flue gas condenser that can recover the energy consumed to evaporate the moisture and expel it to the atmosphere due to the high temperature of the flue gas. In equivalent projects in Latvia conditions, 10-15% of the boiler capacity can be recovered. In addition to installing woodchip boilers, the installation of a 170 kW solar power plant to cover the electricity consumption of the boiler house is being evaluated (see

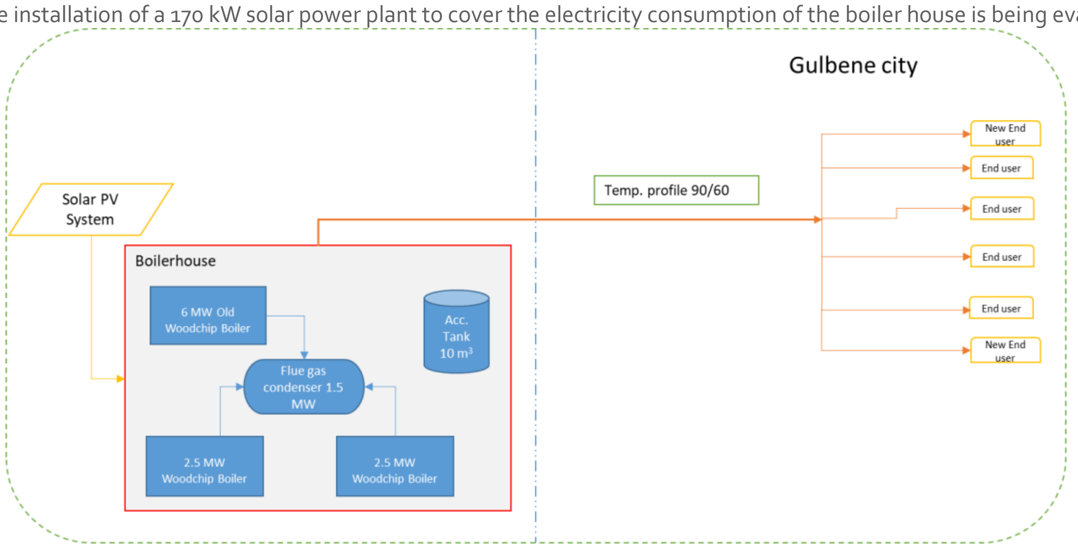



Figure 2). It is predicted that a 1000 m2 solar panel effective area will be installed and almost all solar electricity (162 MWh) can be directly used for self-consumption.

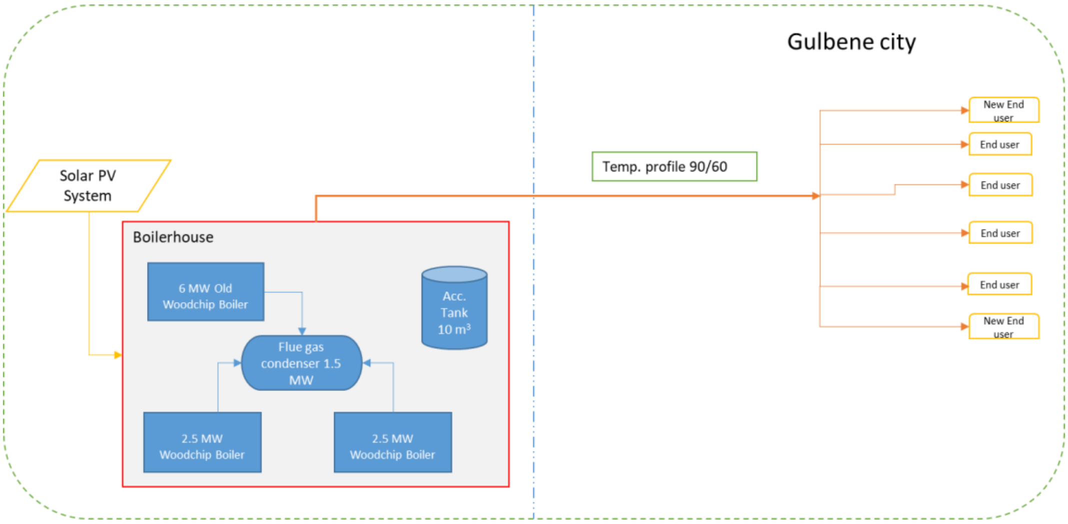



Figure 2. Geographic boundaries for scenario 1 (Gulbene town)

b. In scenario 2 it is assumed that the temperature of the heating network will be lowered to 70/45 °C, the heat loss will decrease by 1300 MWh/year. It is assumed that the heat consumption of buildings due to the connection of new consumers will increase respect to Scenario 1. As a result, there is no need to increase the capacity of the boiler house. It is assumed that in this scenario the flue gas condenser (2.4 MW) could recover about 20% of the thermal energy. It is assumed that a 1.5 MW baseload boiler will be installed, which would produce nearly 11 GWh a year. In addition, a 3 MW woodchip boiler is installed for the base load during the heating season (around 11 GWh per year), and the existing boiler would cover the remaining peak load (2444 MWh or 8%). The flue gas condenser would produce 6 GWh per year. As in the first scenario, it is assumed that the solar panel field will be used to generate electricity for the boiler house. See

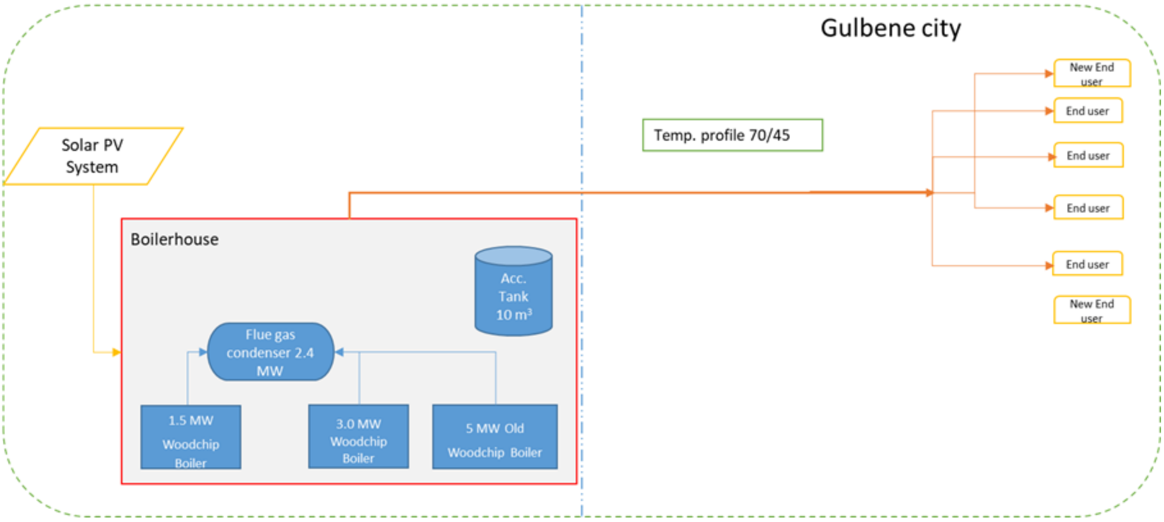



Figure 3:

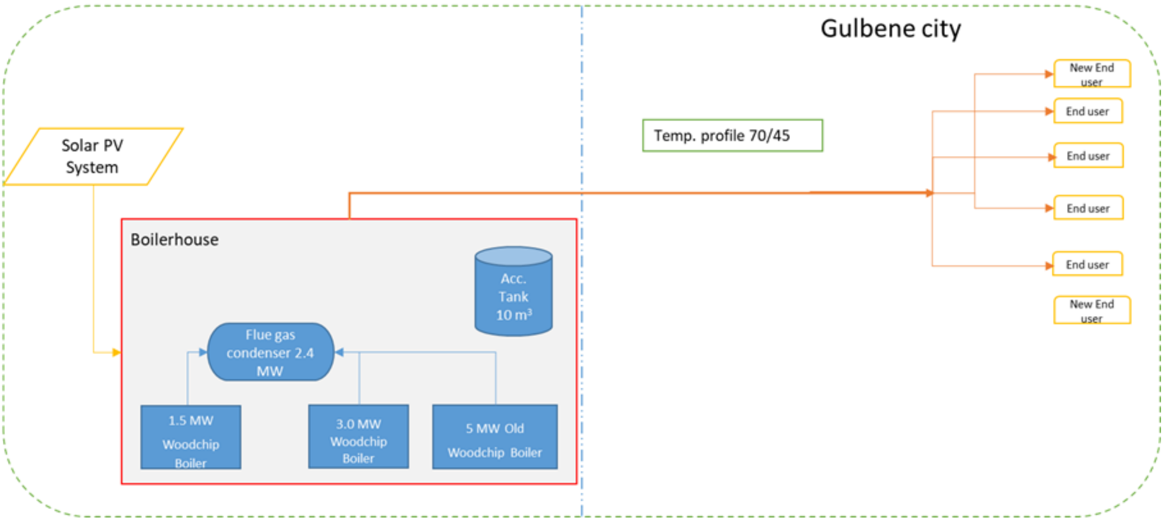



Figure 3. Geographic boundaries for scenario 2 (Gulbene town)

## 4.3 Stari village in Daukstu parish

At the moment, the heat demand in this village is supplied by one of the three installed 0.5 MW fire-wood boilers to cover the demanded heat. In 2018, around 900 MWh of heat were produced in the boiler house during the heating season. The boiler house is already operating in a reduced temperature regime in which maximum flow temperature reaches 63° C at ambient air temperature of -25 °C.


Figure 4), as only 5 consumers are connected to it - three apartment buildings, the parish administration building and the cultural centre. The total heated area is 5232 m² and the average specific heat consumption for space heating in residential buildings is 157 kWh/m² per year.

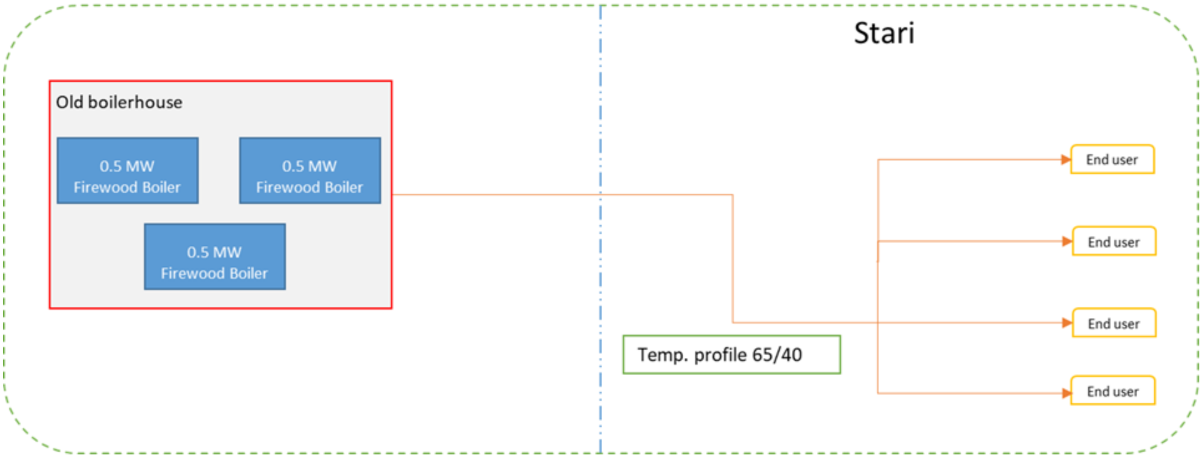



Figure 4. Geographic boundaries for baseline scenario (Stari village)


Figure 4, was modeled in this study along with the LowTemp scenario discussed in (Ekodoma, 2019) and summarized as follows.

LowTemp scenario: It assumes that three DH-connected apartment buildings will be insulated, and that total heat consumption will decrease. Further calculation of benefits and costs assumes that the specific heat consumption of these buildings for heating from the existing one would decrease to 90 kWh/m², which is following the Cabinet of Ministers Regulation No. 383 "Requirements for reconstruction and renovation of buildings". As a result, the total heat consumption in the DH would be reduced to 575 MWh. In this case, the heat consumption density would drop to 1.02 MWh/m² and the maximum peak load would be 300 kW. In this scenario, it is assumed that an automatic pellet boiler with a capacity of 250 kW with an accumulation tank is installed in the boiler house, as seen in

Figure 5.

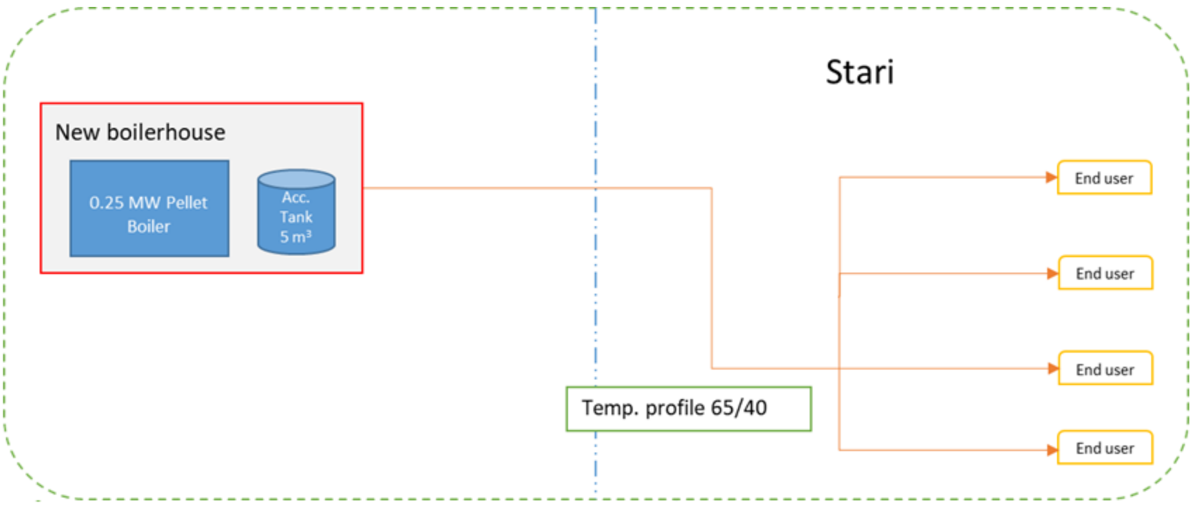



Figure 5. Geographic boundaries for LowTemp scenario (Stari village)

## 4.4 Litene parish

In Litene, currently, two 0.25 MW pellet boilers are installed to produce thermal energy to provide heat to five buildings. The boiler house produces heat only to cover space heat consumption leaving aside hot water preparation. The average heat production in Litene is 587 MWh per year.

The estimated amount of heat loss is 54 MWh or 9% of the total heat production. The flow and return temperatures of the heating are estimated at 75/55 ° C, the system boundaries for the current scenario can be seen in Figure 6.

According to the analysis performed on the heat load curve in (Ekodoma, 2019), the maximum heat load reaches 228 kW.

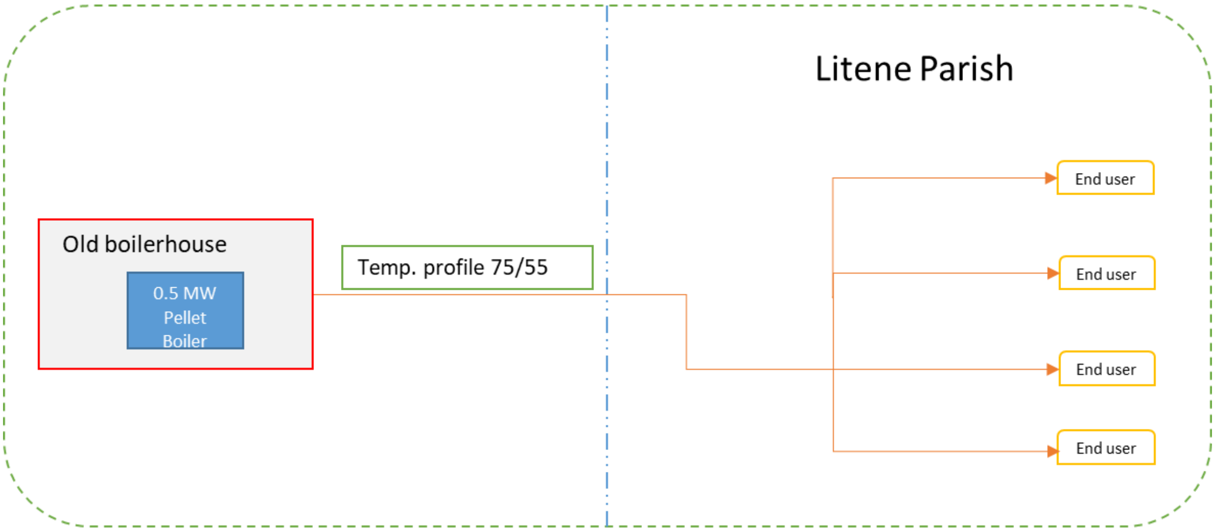



Figure 6. Geographic boundaries for baseline scenario (Litene parish)

For the LowTemp scenario, it is assumed no new customers are connected to the DH network, but some refurbishments in existing buildings are implemented increasing the energy efficiency. After such measures, total heat demand is reduced to 120 MWh. Due to the aforementioned increase in energy efficiency, it will be possible to reduce the heat supply temperature to 60° C without replacing the building's internal heating systems. The heat load for this scenario is reduced to 180 kW.

### TABLE 2. ASSUMPTIONS AND CALCULATED VALUES FOR THE ANALYZED SCENARIOS

| Parameter | Base scenario | LowTemp scenario |
|---|---|---|
| Temperature graph, °C | 75/55 | 60/40 |
| Heating area, m² | 3276 | 3276 |
| Average specific heat consumption, kWh/m² | 163 | 126 |
| Total consumption of buildings, MWh per year | 533 | 510 |
| Loss of thermal energy, MWh per year | 54 | 45 |
| Proportion of heat losses, % | 9% | 8% |
| Total heat produced, MWh per year | 587 | 556 |
| Length of heating circuit, m | 277 | 277 |

| | | |
|---|---|---|
| Consumption density of heat energy, MWh/m | 2.12 | 1.49 |

In Fig. 7 it can be seen how the only difference with the baseline scenario is the reduction in the temperature schedule for DH network after the refurbishments works in some buildings have been performed.

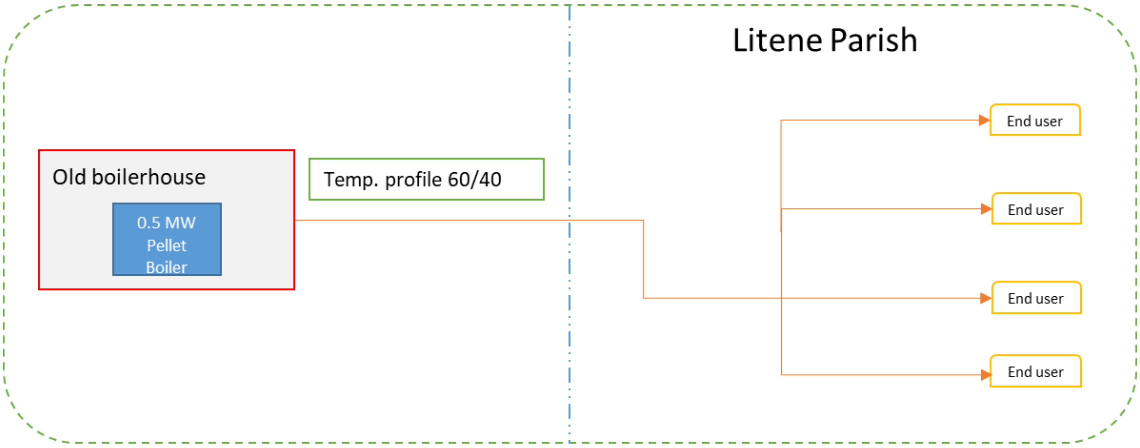



Figure 7. Geographic boundaries for LowTemp scenario (Litene parish)

## 4.5 Lejasciems parish

At this moment, there exist two woodfired boilers with a capacity of 1.0 and 1.5 MW installed in the boiler house delivering thermal energy at the Lejasciems DH system (see Fig. 8). However, only one of them is operating during the heating season. The maximum heat load output was calculated in 0.7 MW. During the whole heating season, the boiler house produces 1656 MWh of thermal energy to feed a total heated are of 9587 m². The average specific heat consumption in buildings for heating is 150 kWh/m².

The total length of the DH network in this parish is 974 m with an average pipe diameter of 95 mm. It was estimated a total heat loss of 253 MWh alongside the whole DH system, which means 15 % of total heat generated.

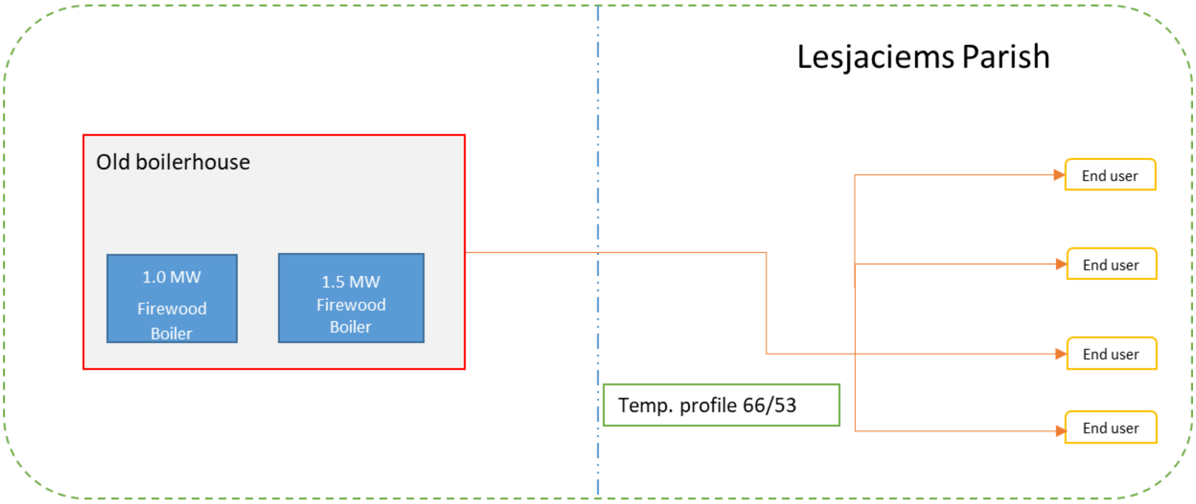



Figure 8. Geographic boundaries for baseline scenario (Lejasciems parish)

LowTemp scenario: This scenario assumes that all buildings with a specific heat consumption above 150 kWh/m2 are refurbished by insulation improvements. It is estimated that the specific heat consumption will be decreased to 90 kWh/m$^2$ and the total heat consumption would be reduced by almost 500 MWh and the maximum heat load would be 418 kW. This new insulation measures increasing energy efficiency and new heating units, allow the temperature profile to be reduced to 60/45 °C. Most changes and differences from baseline scenario to the greenest one, can be seen in Table 3.

The new alternative foresees a new type of container pellet boiler house closer to the consumers. This adopted solution solves the issues to have boiler house located far from end user side, and the pipeline network poorly insulated. This solution adds 100 m of new DH network connected to a section of the existing pipelines.

In Table 3, it can be seen how the total heat losses reach 18 % due to a lower amount of heat production and consumption.

TABLE 3. CALCULATED VALUES FOR ANALYZED SCENARIOS IN LEJASCIEMS PARISH

| Parameter | Base scenario | Scenario 2 |
|---|---|---|
| Fuel used | Firewood | Pellets |
| Installed boiler power, kW | 2500 | 400 |

| | | |
|---|---|---|
| Heat network temperature graph , °C | 66/53 | 60/45 |
| Length of heating network, m | 974 | 847 |
| Volume of accumulation tank, m³ | n/a | 5 |
| Heat produced, MWh per year | 1656 | 1063 |
| Loss of thermal energy, MWh per year | 253 | 150 |
| Heat sold, MWh per year | 1404 | 913 |
| Heat consumption density, MWh/m | 1.7 | 1.1 |
| Specific heat losses, % | 15% | 18% |

The new DH system for Lejasciems can be seen in

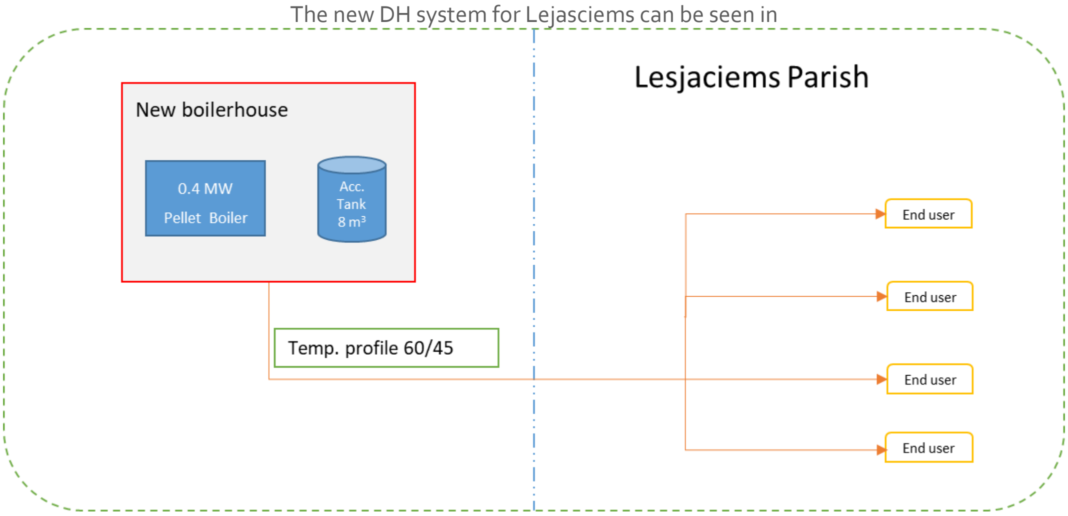



Figure 9. including an accumulation tank for covering peak loads and increasing total efficiency.

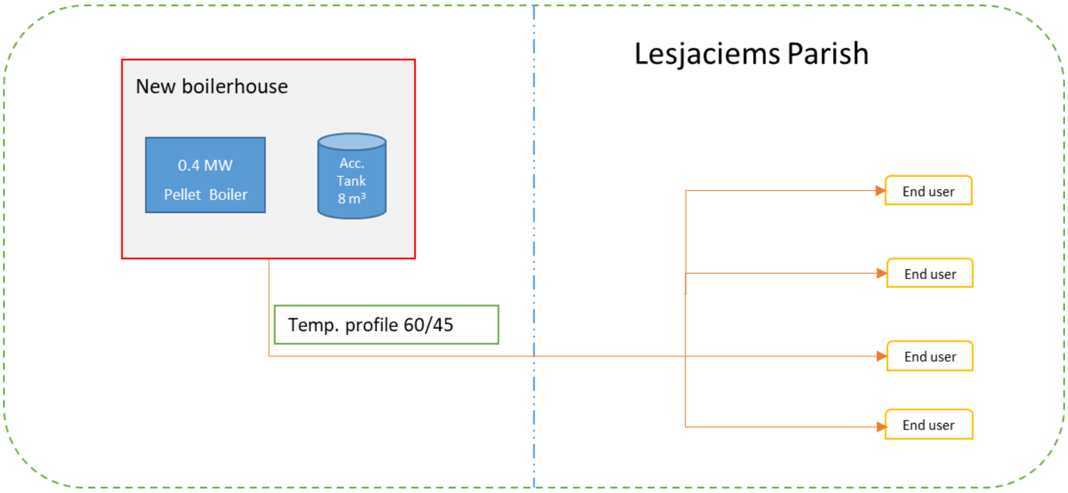



Figure 9. Geographic boundaries for LowTemp scenario (Lejasciems parish)

## 4.6 Lizums parish

The thermal energy used in this parish is purchased from a nearby wood chips cogeneration plant. Gulbene Municipality provides heat transfer via circulation pumps located in Lizums boiler house. Within this boiler house Orion-3H1 boiler manufactured in 2007 with a 1.5 MW capacity (see

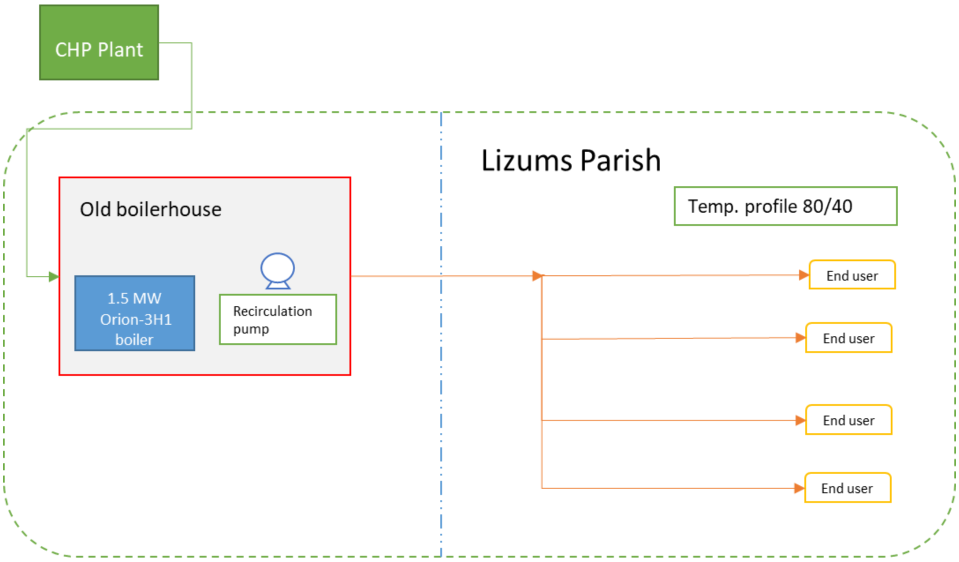



Figure 10. Geographic boundaries for baseline scenario (Lejasciems parish)

) is installed.

The heat amount purchased in 2018 for district heating was 2094 MWh. The average specific heat consumption for heating of all buildings is 166 kWh/m2 per year. Based on the information on the amount of purchased heat, the heat load of Lizums DH is calculated at 860 kW. The total DH network length is 1523 m, excluding the part connecting the CHP plant with the recirculation pump in the boiler house. The calculated heat loss is around 479 MWh (23 %) of the heat purchased.

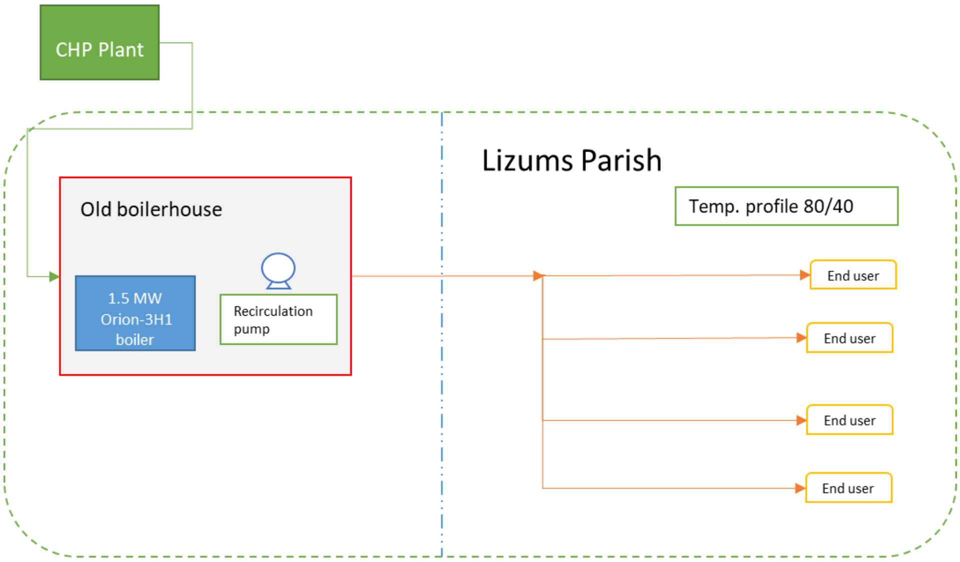



Figure 10. Geographic boundaries for baseline scenario (Lejasciems parish)

LowTemp scenario: In this scenario, new consumer connections are not considered, but it is assumed that part of the buildings are renovated resulting in a heat consumption reduction. The resulting specific heat consumption after refurbishment is assumed to be 90 kW/m² per year. The scheme for new boundaries can be seen in Figure 11.

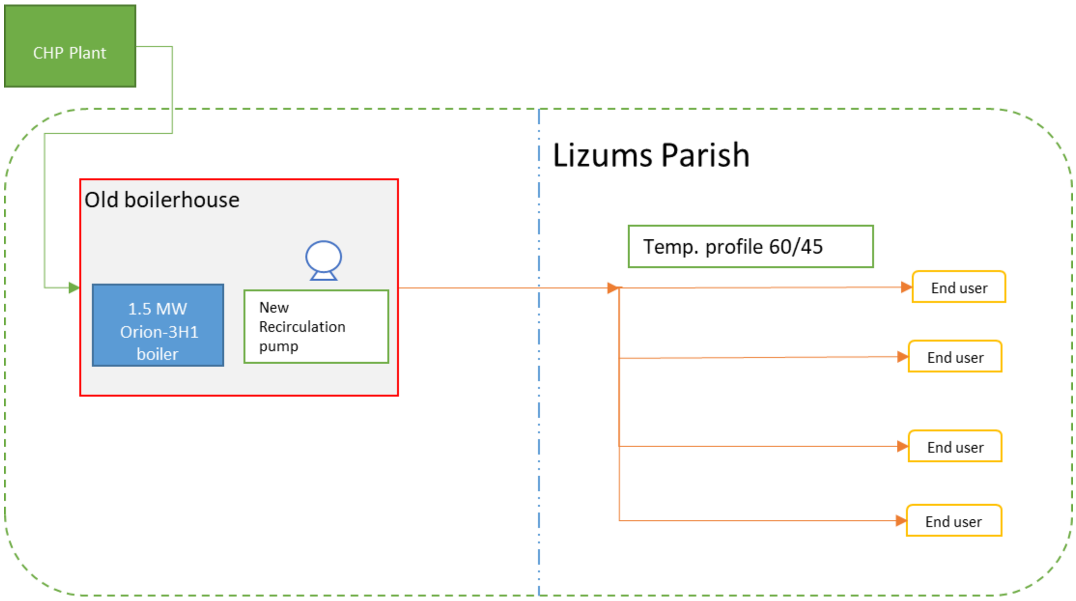



Figure 11. Geographic boundaries for LowTemp scenario (Lejasciems parish)

After refurbishment is done, the total heat purchased to the CHP plant would be reduced to 1186 MWh under a new temperature network profile of 60/45 °C due to the new conditions in the apartments to accept LowTemp DH systems. The heat losses under this new scenario are estimated at 254 MWh per year (21 %). This scenario assumes the replacement of recirculation pump (Figure 11) and the construction of automated heating systems which are usually installed in the distribution network nodes.

## 4.7 Galgauska parish

Currently, there is no district heating system in Galgauska village. The heated in the buildings is provided individually by wood fired boilers. For this small parish, two scenarios are analyzed for delivering thermal energy to cover the heat demand in an area of 5673 m2.

In the first scenario (

Figure 12.a), a firewood boiler plus an accumulation tank are installed in a boiler house with a total

capacity of 350 kW. To deliver the thermal energy to the buildings in the village, a 460 m long distribution network must be constructed, for both development scenarios.

In scenario 2 (

Figure 12.b), the main difference when compared to the previous scenario, is a lower heat distribution temperature. In contrast to the first scenario, a temperature profile of 75/55 °C is used, for the second one, a more consistent one with the definition of 4GDH is used (60/40 °C).

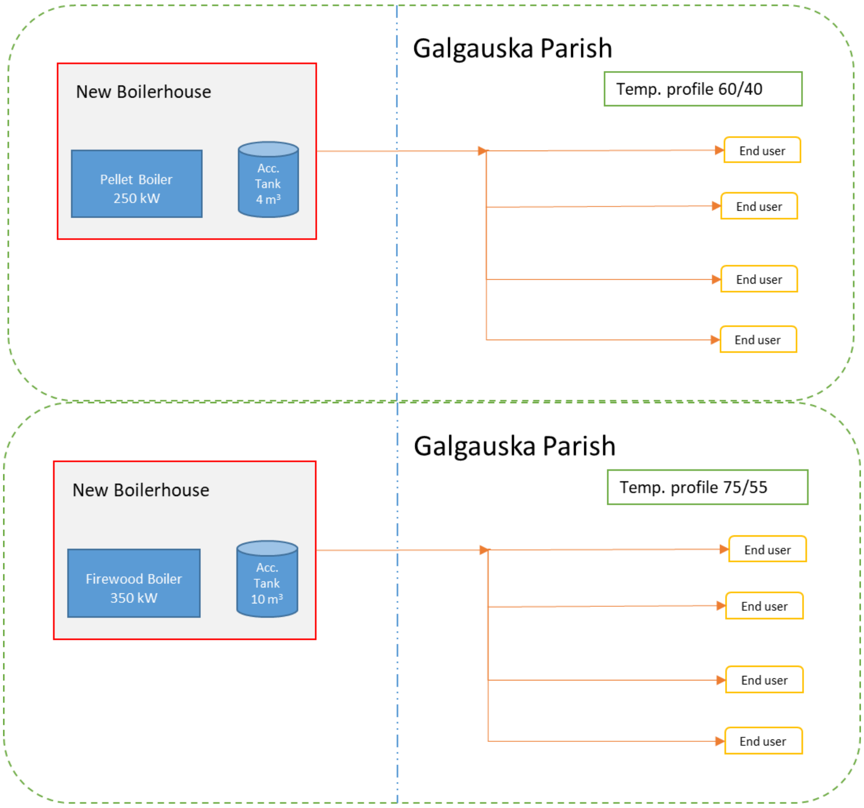



Figure 12. a) Geographic boundaries for first scenario (Galgauska parish); b) Geographic boundaries for LowTemp scenario (Galgauska parish)

## 4.8 Ranka parish

Currently, there is no DH system in this parish, and heat is generated and distributed individually in using wood fired boilers in some building and furnaces in others. The total heated area is 7240 $m^2$, and hot water is prepared also locally by electric boilers. As in previous parishes, two scenarios are analyzed; in the first scenario a DH system is implemented using a single woodchip boiler, and it is assumed all buildings in the parish (10) are connected under usual temperature profile (see

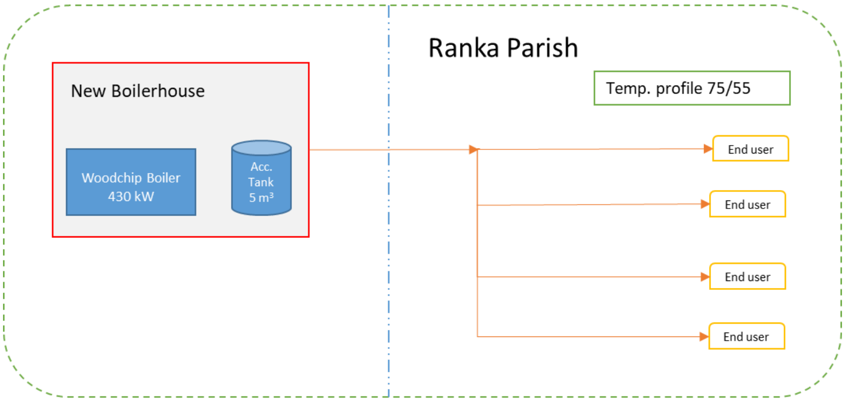



Figure 13).

Figure 13. Geographic boundaries for first scenario (Ranka parish)

In the second scenario, a lower temperature schedule is designed (allowing a decrease in the maximum heat load from 430 to 300 kW. In this low temperature DH system, a pellet boiler in a container boiler house is presumed and only six buildings would be connected.

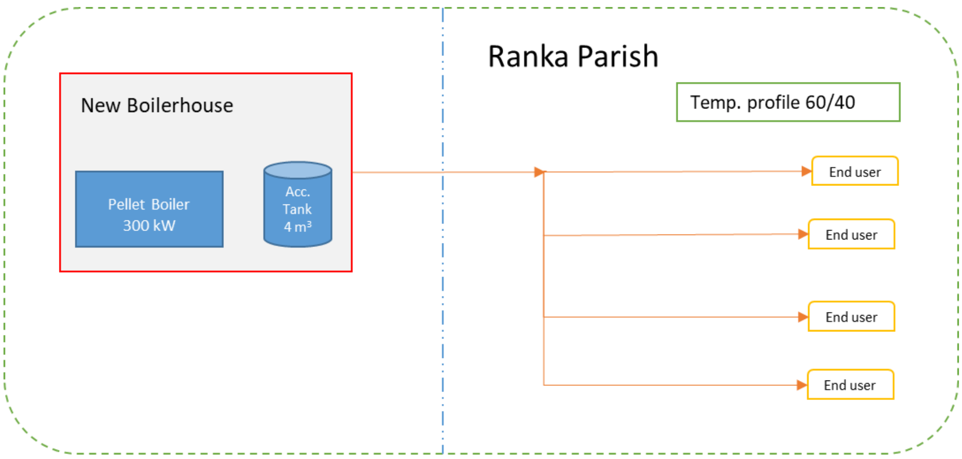


Figure 14. Geographic boundaries for low temp scenario (Ranka parish).

In Ranka parish, as in Galgauska, the construction of heating networks would be necessary, a factor that it is considered within the Life Cycle Inventory. For the first scenario 440 m of heating networks would be required while for the second scenario, the length is reduced to 221 m due to fewer building connected to the grid.

Detailed information regarding each parish, its geographical boundaries, heat load calculations, and scenarios development can be found in (Ekodoma, 2019). However, main general assumptions are described in the next section.

## 4.9 Assumptions and Limitations

Here are listed a summary of the assumptions and limitations found after reviewing the available DH data for all scenarios in the different parishes subject to model at Gulbene region.

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 data base 3.0, and decommissioning or waste treatment for baseline scenarios are not considered.

In order 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 assumption means the construction phase is within the boundaries as seen in

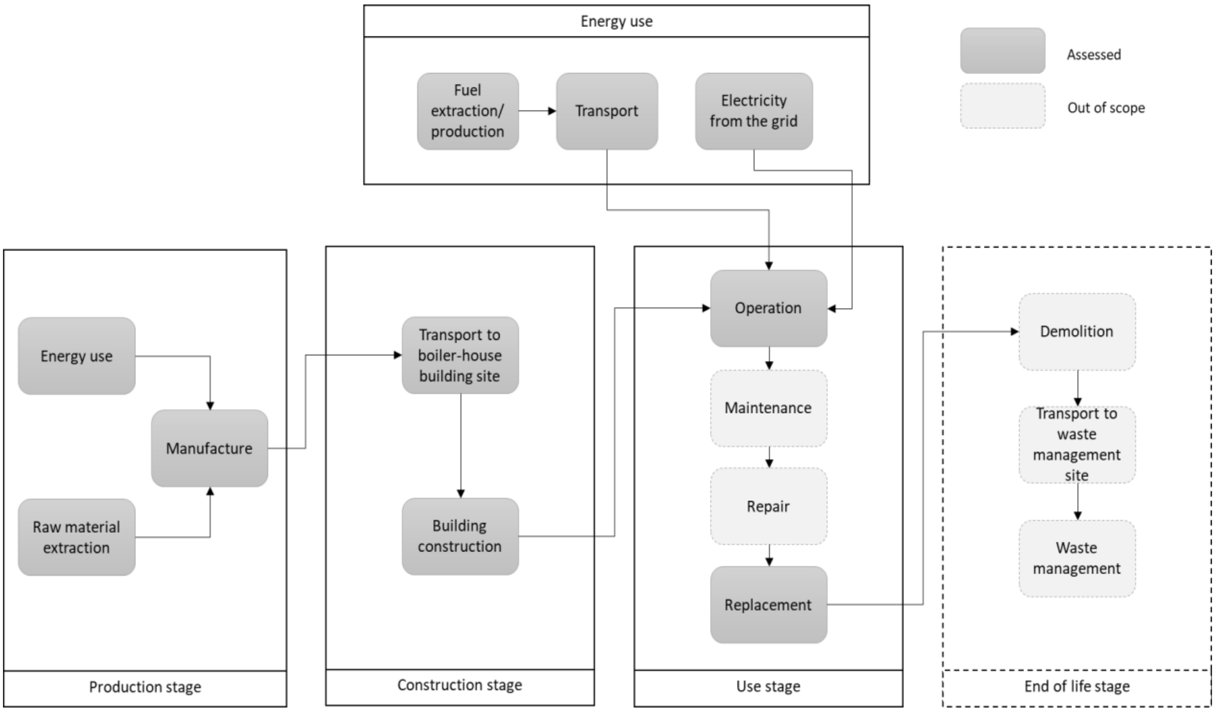


Figure 1. Nevertheless, this construction phase and all activities and materials are subjected to the data availability, which is limited due to all future scenarios are only proposals at the time this study was made, so detailed plans for reconstruction of boilerhouse is not available. The distribution network, nodes, taps and pumps suffer from the same lack of information, as only in some parishes basic data regarding pipeline diameters and length is available, hence, it was necessary to use the assembly data gathered in (Feofilovs, et al., 2019) for Belava parish, and use the same record for the modeled parishes in this study. This assumption is made since Belava is a parish within Gulbene region and it is included in the Pilot energy strategy documents.

For baseline scenarios:

- Only base load boilers are used;
- No changes in distribution network temperature profiles or ΔT between supply and return lines;
- No changes in insulation technologies along network, maintaining same heat losses trends;
- After any equipment replacement or maintenance, and renovation, 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);
- Calculations for amount (ton) fuel consumption were carried out considering previous mentioned values;
- No decommissioning phase was considered.

For LowTemp scenarios:

- Annual production for district heating of 3.3 GWh;
- Steady production and heat demand profile during the study lifetime
- Heat pumps heating capacity of 730 kW;
- 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 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.

# 5. Life Cycle Inventory

DH infrastructure of each parish varies among each other mainly in terms of the type of boiler, fuel and furnace, and boiler size. Infrastructure data used information directly from the LCA study developed for Belava parish (Feofilovs, et al., 2019). The main boiler house structure was adjusted accordingly to the size or length for each principal parts and accessories (i.e. DH nodes, valves, pumps, etc.) (Ekodoma, 2019). Future renovation or refurbishment of these structures is not yet available and economic feasibility for most of the projects is still an ongoing work.

As described in the LCA of the Pilot energy strategy report for Belava, the data for common assemblies 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 equipment, apparatus or accessories missing in the database, were entered as the amount and materials required for its production plus the process required to construct the assembly.

The whole inventory gathered for the LCA on the PES was divided into stages, for organization and conceptual purposes. For the construction stage, the main groups, basic for any DH system are pipelines, boilerhouse, DH nodes, pumps and accessories, furnaces and accumulation tanks. Other assemblies were built accordingly for each parish and scenario model, such as solar plant, furnaces, accumulation tanks and containers (for small capacity pellet boilers when necessary). It must be mentioned that these groups only account for production and construction stage (see

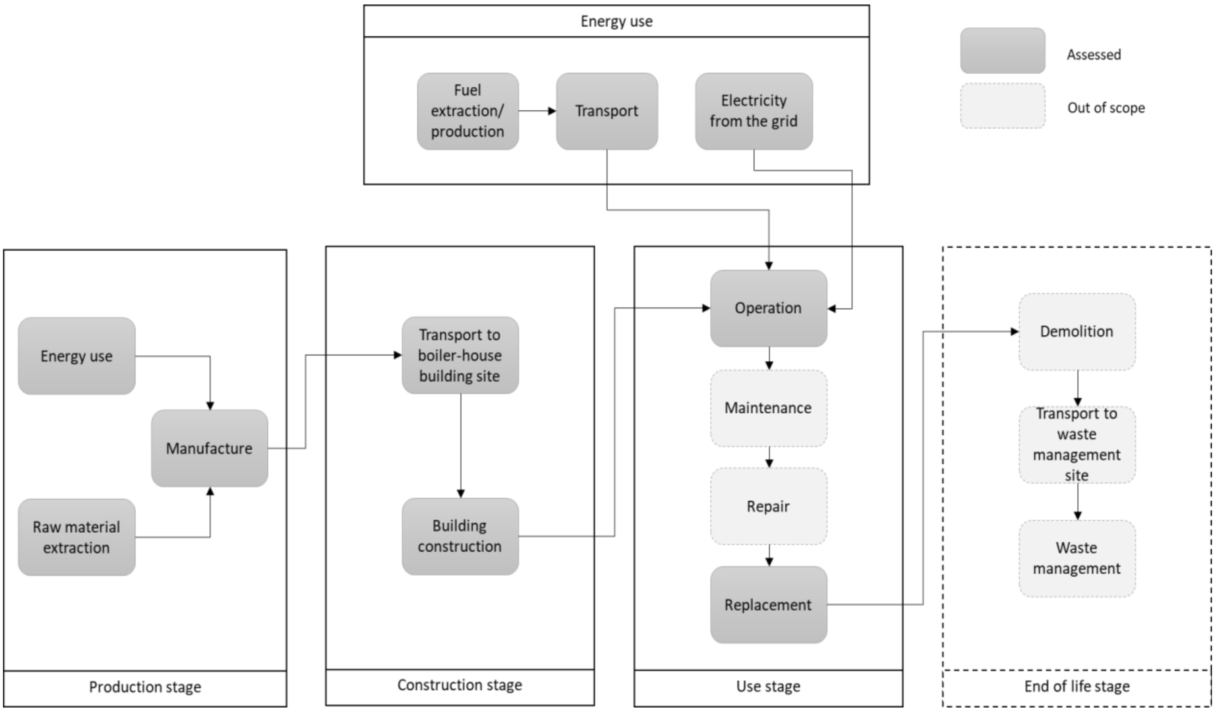


Figure 1) as selected objects from Ecoinvent 3 database correspond to items allocated at the point of substitution (APOS). Thus, the use stage, including operation of the DH assemblies, and the energy use phase which contains the fuel extraction or production, transport to boilerhouse and electricity or other energy use, is part of another "assembly" within the model, named "operational phase" in this LCA model. The same approach was used for the user side, with the building refurbishment required for accepting low temperatures under the future LowTemp scenarios. 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 4. Then in Table 5, it is shown a summary of stages into the particular parish which is modeled in SimaPro.

TABLE 4. OPERATIONAL PHASE FOR STARI LOWTEMP SCENARIO

| Materials or Assembly | Amount | Unit |
|---|---|---|
| Roundwood, parana pine from sustainable forest management, under bark {GLO}\| market for \| APOS, U | 1194 | $m^3$ |
| **Processes** | **Amount** | **Unit** |
| Heat, district or industrial, other than natural gas {CH}\| heat production, hardwood chips from forest, at furnace 300kW \| APOS, U | 900 | MWh |
| Electricity, medium voltage {LV}\| market for \| APOS, U | 23.1 | MWh |

As can be seen in Table 5, assemblies such as DH pipelines, and nodes, are adjusted to the size or length of the specific parish taking as base, the assembly inventory from Belava parish. The operational phase stage is entered according to Table 4, which is the inventory of fuels and materials required for a year of operation under the scenario described in the 4 section.

The end user side, or required building renovation assembly, comprehend the materials required for lowering the average specific heat consumption in a determined building from the current state, down to the desired one in order for the inhabitants to enjoy the same temperature comfort than achieved under the actual 3rd generation DH systems working in Gulbene region, with supply lines between 75-90 ⁰C and return lines around 55-60 °C. The principle is simple, the better the insulation, the lower the heat permeability is (or heat losses), resulting in a lower specific heat consumption per square meter. Typical materials for building refurbishments towards 4GDH, and their environmental impact when used in these projects, are listed in (Stephan, et al., 2013) (De Angelis, et al., 2013) and (Bull, et al., 2014). The average specific heat consumption for each parish in Gulbene region is reported in the study from (Ekodoma, 2019). In the same report are calculated the specfic heat consumption required for future low temperatures DH scenarios accordingly with the intended new temperature, i.e. 65-45 ⁰C for supply and return lines respectively. In order to create a material inventory for the refurbishment activities in the potential buildings under a possible 4GDH future scenario, research on previous projects for building renovations in Latvia was made, finding two projects with similar specific heat consumption values to the ones in Gulbene region (125 – 180 kWh/$m^2$) (Pakere, 2019).

TABLE 5. STARI LOWTEMP SCENARIO MODEL

| Material/Assemblies | Amount | Unit |
|---|---|---|
| *New Boiler House - No furnace* | *1* | *p* |
| *Old District heating Pipelines* | *0.61* | *p* |
| *DH nodes* | *0.61* | *p* |
| *Boiler's pumps, taps, heat m., exch. & flow device* | *1* | *p* |
| *Node's pumps and taps* | *0.61* | *p* |
| *Pipeline's pumps, taps, heat meters, exch., flow d* | *0.61* | *p* |
| *Stari LowTemp  Scenario Op. Phase* | *25* | *p* |
| *Building renovation ($m^2$)* | *2353.3* | *p* |
| *Intermodal shipping container, 20-foot {GLO}\| market for \| APOS, U* | *1* | *p* |
| *Furnace, pellets, with silo, 300kW {GLO}\| market for \| APOS, U* | *0.83* | *p* |
| *Hot water tank, 600l {GLO}\| market for \| APOS, U* | *2.1* | *p* |

A list of materials and amount (kg) required for the renovation of 1 square meter was created. This inventory was then adjusted to the different parishes for the present model (i.e. assembly "***Building renovation***" in Table 5). The model considered two variables: the total heated area and the gap between its current and future or desired specific heat consumption, which is usually between 70-90 kWh/$m^2$ in the modeled parishes. The main assumptions for 1 $m^2$ with the capacity to reduce the specific heat consumption 0 115 kWh/ $m^2$ can be seen in Table 6.

Other assemblies such as furnaces and accumulation tanks are entered in the model independently and according to the foreground data found in (Ekodoma, 2019). Those ones, plus the use stage (operational phase) specific inventory assembly per parish and the building renovation one, make the full scenario to model as seen in Table 5. Two type of inventories are proposed for each parish: one for the baseline scenario and the second including changes to the DH system.

TABLE 6. BUILDING RENOVATION ASSEMBLY

| *Material* | kg/m² |
|---|---|
| Polystyrene, extruded {GLO}\| market for \| APOS, U | 0.62 |
| Adhesive mortar {GLO}\| market for \| APOS, U | 2.36 |
| Gypsum plasterboard {GLO}\| market for \| APOS, U | 5.80 |
| Glazing, double, U<1.1 W/m2K, laminated safety glass {GLO}\| market for \| APOS, U | 0.20 |
| Alkyd paint, white, without solvent, in 60% solution state {RER}\| market for alkyd paint, white, without solvent, in 60% solution state \| APOS, U | 0.34 |
| Stone wool {GLO}\| market for stone wool \| APOS, U | 51.36 |
| Epoxy resin, liquid {RER}\| market for epoxy resin, liquid \| APOS, U | 9.68 |
| Glass fibre {GLO}\| market for \| APOS, U | 0.46 |
| Glued laminated timber, for indoor use {RER}\| production \| APOS, U | 0.01 |
| Orthophthalic acid based unsaturated polyester resin {GLO}\| market for \| APOS, U | 0.06 |
| Steel, chromium steel 18/8 {RER}\| steel production, converter, chromium steel 18/8 \| APOS, U | 0.04 |
| Soil for construction | 64.46 |
| Sand {GLO}\| market for \| APOS, U | 11.49 |
| Polystyrene foam slab for perimeter insulation {GLO}\| market for \| APOS, U | 1.22 |
| Concrete, normal {RoW}\| market for \| APOS, U | 0.04 |
| Acrylic filler {RER}\| market for acrylic filler \| APOS, U | 0.44 |
| Ceramic tile {GLO}\| market for \| APOS, U | 0.19 |

# 6. Life Cycle Assessment Results

The LCI gathered was used for the simulation in SimaPro following the defined functional unit in section 3.3. The results are presented for each parish, for the baseline scenario and for the proposed low temperature scenario. The environmental impact assessment is presented in tables at midpoint level (kg of substance equivalent). Results are further compared among each scenario and for each

Life Cycle stage. Life cycle stages have been divided in three groups: 1) Construction phase including the production stage and transport of materials required for building the DH system, 2) operational phase including the energy use and operational processes for running a DH system, and 3) building renovation accounting for the materials and its transport, for refurbishment at the end user side. After analyzing 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 result in the main four areas of concern evaluated within the IMPACT 2002+ methodology: human health, ecosystem quality, climate change and resources. Finally, within the parishes and scenarios evaluation, hotspots are identified by comparing the Life Cycle stages and their total environmental burden.

## 6.1 Life Cycle Assessment results of Gulbene town

Gulbene town was the first parish to be analyzed since it was expected to account for the highest environmental impact and also due to more detailed information regarding its DH system was available.

### 6.1.1 Gulbene town baseline scenario

In Table 7, the total kg per substance expressing 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 a 3GDH system parameters for 25 years.

TABLE 7. CHARACTERIZATION RESULTS FOR GULBENE TOWN (BASELINE SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 2,193,581.8 | 1,810,144.4 | 383,437.4 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 11,306,975.0 | 10,323,125.0 | 983,850.0 |
| Respiratory inorganics | kg PM2.5 eq | 217,797.7 | 192,801.6 | 24,996.1 |
| Ionizing radiation | Bq C-14 eq | 1,064,686,100.0 | 888,376,630.0 | 176,309,470.0 |
| Ozone layer depletion | kg CFC-11 eq | 8.2 | 6.5 | 1.7 |
| Respiratory organics | kg $C_2H_4$ eq | 82,230.5 | 75,407.9 | 6,822.7 |
| Aquatic ecotoxicity | kg TEG water | 85,397,348,000.0 | 79,757,957,000.0 | 5,639,391,000.0 |

| | | | | |
|---|---|---|---|---|
| Terrestrial ecotoxicity | kg TEG soil | 30,105,989,000.0 | 28,911,149,000.0 | 1,194,840,000.0 |
| Terrestrial acid./nutrif. | kg SO2 eq | 4,100,234.1 | 3,797,342.9 | 302,891.2 |
| Land occupation | m2org.arable | 35,433,318.0 | 35,094,852.0 | 338,466.0 |
| Aquatic acidification | kg SO2 eq | 694,157.2 | 607,936.4 | 86,220.8 |
| Aquatic eutrophication | kg PO4 P-lim | 83,955.6 | 42,914.5 | 41,041.1 |
| Global warming | kg CO2 eq | 59,461,153.0 | 46,083,468.0 | 13,377,685.0 |
| Non-renewable energy | MJ primary | 1,131,206,500.0 | 931,597,050.0 | 199,609,450.0 |
| Mineral extraction | MJ surplus | 6,330,873.6 | 1,906,347.6 | 4,424,526.0 |

Figure 15 shows the share of each life cycle stage in the different impact categories. As seen, the operational phase is the major environmental bearer in this scenario for all categories but mineral extraction.

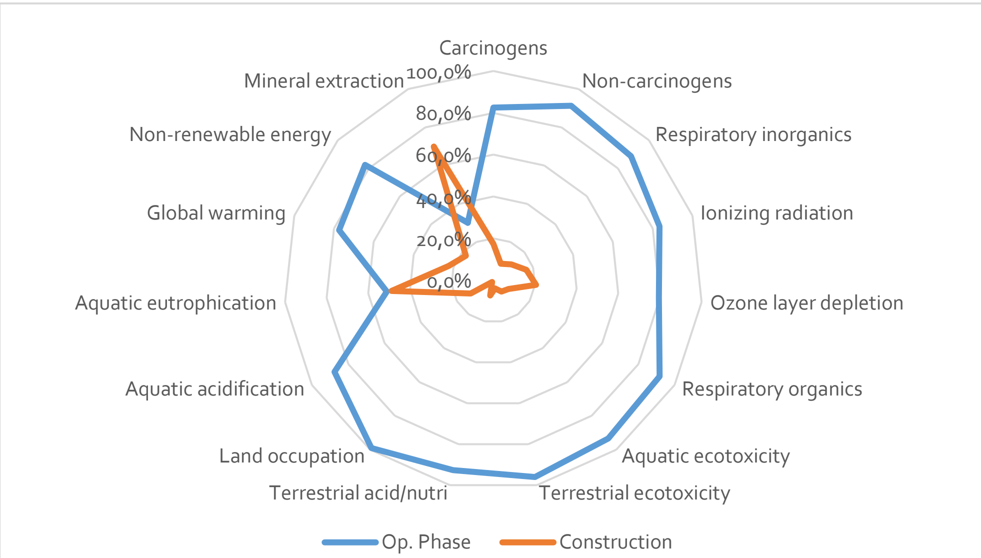



Figure 15. Characterization comparison between stages for Gulbene baseline scenario.

The weighted damage assessment per area of concern is presented in a disaggregated form, displaying every single assembly considered within the scenario model. The operation phase is followed far behind by the solar plant construction, 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 28 kPts, followed by the ecosystem quality with 23.8 kPts, resources and climate change with 8.9 and 6.9 kPts respectively.

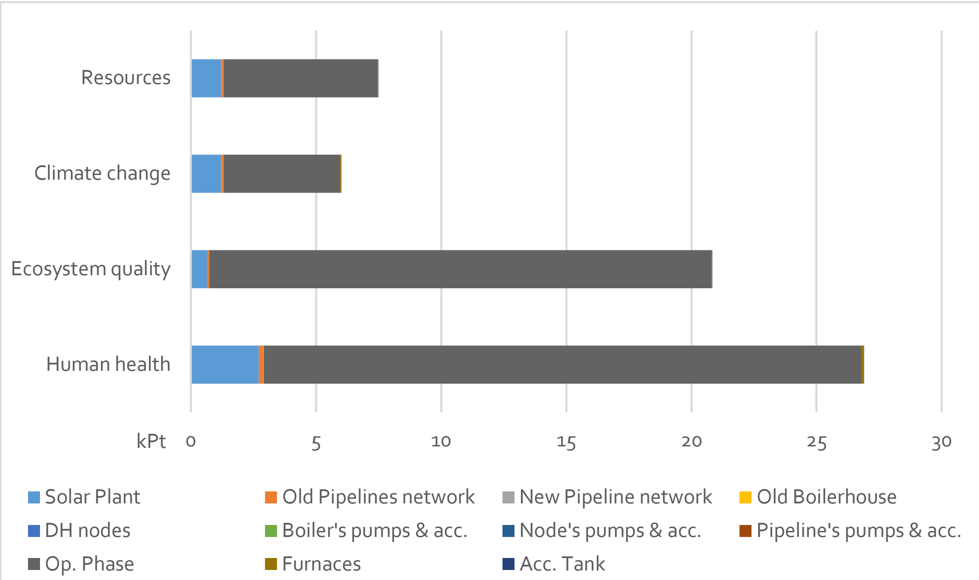


Figure 16. Damage assessment for Gulbene baseline scenario.

A single score graph is presented in Figure 17, where the operational phase (use stage) delivers 54.73 kPts while the whole DH system construction stage 12.97 kPts.

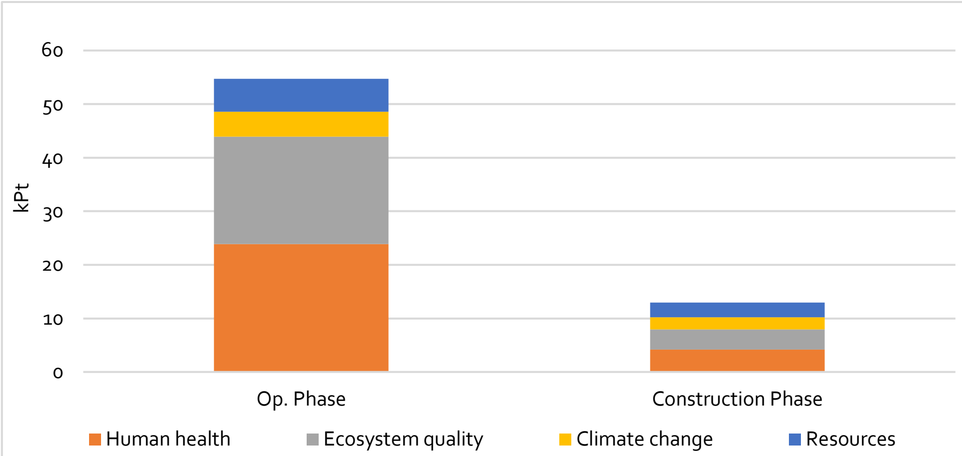



Figure 17. Single score per stage for Gulbene baseline scenario.

### 6.1.2 Gulbene town: LowTemp scenario

In Table 8, midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

TABLE 8. CHARACTERIZATION RESULTS FOR GULBENE TOWN (LOWTEMP SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 2.29E+06 | 1.77E+06 | 3.85E+05 | 1.41E+05 |
| Non-carcinogens | kg C2H3Cl eq | 1.11E+07 | 1.00E+07 | 9.85E+05 | 7.64E+04 |
| Respiratory inorganics | kg PM2.5 eq | 219,212.0 | 188,713.9 | 25,045.0 | 5,453.1 |
| Ionizing radiation | Bq C-14 eq | 1.10E+09 | 8.94E+08 | 1.76E+08 | 2.54E+07 |
| Ozone layer depletion | kg CFC-11 eq | 8.9 | 6.6 | 1.7 | 0.6 |
| Respiratory organics | kg C2H4 eq | 83,806.3 | 73,474.3 | 6,834.9 | 3,497.1 |
| Aquatic ecotoxicity | kg TEG water | 8.35E+10 | 7.73E+10 | 5.65E+09 | 6.39E+08 |
| Terrestrial ecotoxicity | kg TEG soil | 2.93E+10 | 2.80E+10 | 1.20E+09 | 1.33E+08 |

| | | | | | |
|---|---|---|---|---|---|
| Terrestrial acid/nutri | kg SO2 eq | 4,101,656.0 | 3,715,984.3 | 303,497.4 | 82,174.3 |
| Land occupation | m2org.ara-ble | 34,504,652 | 33,988,958 | 337,382.6 | 178,311.4 |
| Aquatic acidification | kg SO2 eq | 711,146.2 | 600,538.6 | 86,544.5 | 24,063.1 |
| Aquatic eutrophication | kg PO4 P-lim | 83,772.7 | 41,730.2 | 41,064.2 | 978.3 |
| Global warming | kg CO2 eq | 6.41E+07 | 4.67E+07 | 1.34E+07 | 3.98E+06 |
| Non-renewable energy | MJ primary | 1.20E+09 | 9.40E+08 | 2.00E+08 | 6.18E+07 |
| Mineral extraction | MJ surplus | 6.54E+06 | 1.86E+06 | 4.44E+06 | 2.34E+05 |

Figure 18 shows the share of each life cycle stage in the different impact categories now, including the building refurbishment in the end user side. As seen, the operational phase is again the major environmental bearer, but its share has diminished for a certain impact categories. The construction stage is responsible for the near 70% of the impact delivered in the mineral extraction category whilst the building renovation has the lowest share in the overall impact categories.

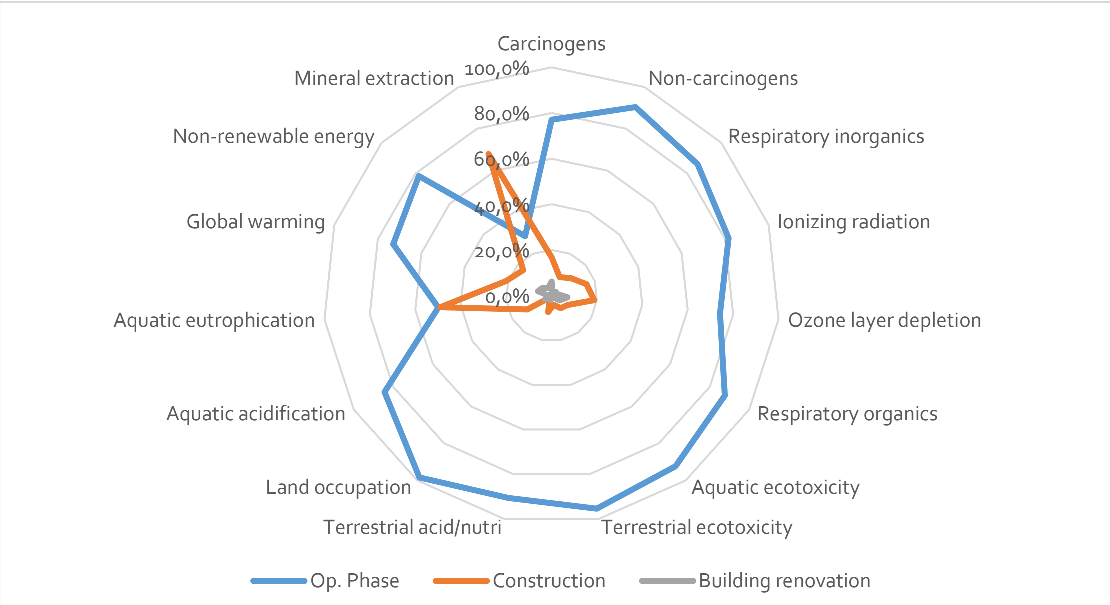



Figure 18. Characterization comparison between stages for Gulbene LowTemp scenario.

The weighted damage assessment per area of concern is presented in a disaggregated form (see

Figure 19), displaying every single assembly considered within the scenario model. The operation phase is followed far behind by the solar plant construction. The most impacted area of concern is human health with a total score of 26.97 kPts, followed by the ecosystem quality with 20.30 kPts, resources and climate change with 7.95 and 6.48 kPts, respectively.

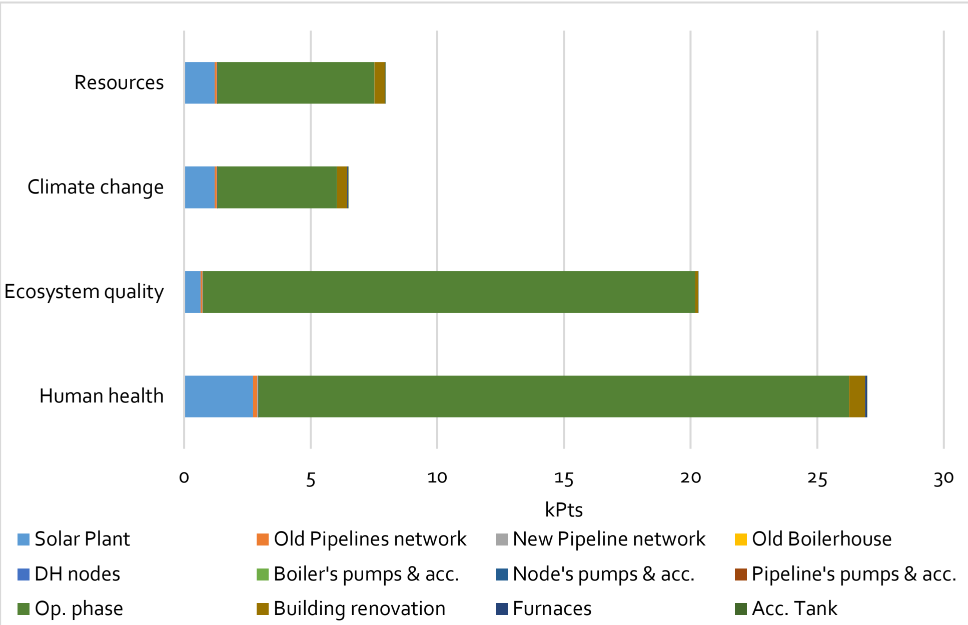


Figure 19. Damage assessment for Gulbene LowTemp scenario.

The single score graph is presented in Figure 20, where the operational phase (use stage) delivers 53.7 kPts while the whole DH system construction stage 6.5 kPts and the refurbishment activities in the buildings delivers 1.5 kPts.

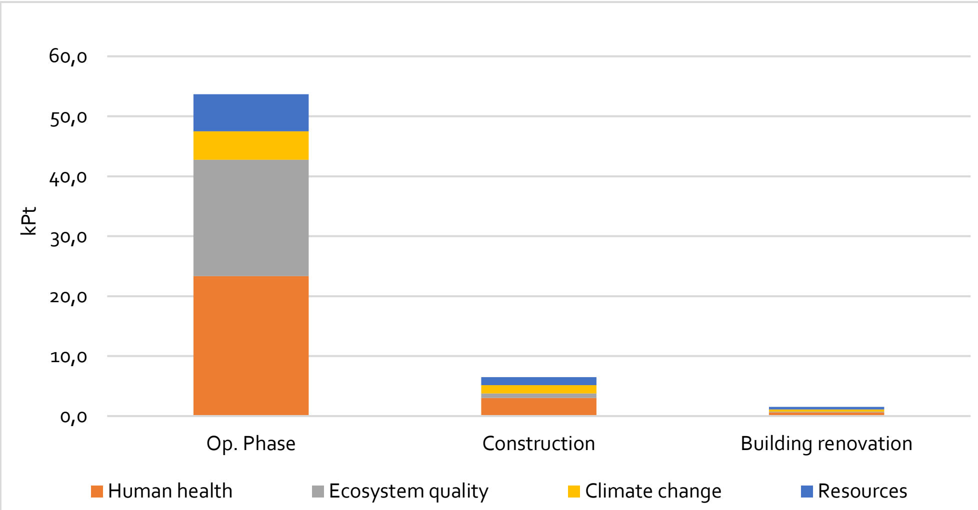



Figure 20. Single score per stage for Gulbene LowTemp scenario.

## 6.2 Life Cycle Assessment results for Stari village

Stari village is evaluated for its environmental impact under the introduced LCIA methodology.

### 6.2.1 Stari village: baseline scenario

In Table 9, the midpoint category results are presented for the current state scenario with reference to the functional unit.

TABLE 9. CHARACTERIZATION RESULTS FOR STARI VILLAGE (BASELINE SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 71,861.03 | 65,604.9 | 6,256.1 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 249,517.93 | 244,375.8 | 5,142.1 |
| Respiratory inorganics | kg PM2.5 eq | 114,772.52 | 114,614.3 | 158.2 |
| Ionizing radiation | Bq C-14 eq | 4.03E+07 | 3.93E+07 | 9.88E+05 |
| Ozone layer depletion | kg CFC-11 eq | 0.95 | 0.939 | 0.007 |

| | | | | |
|---|---|---|---|---|
| Respiratory organics | kg $C_2H_4$ eq | 8,842.69 | 8,785.4 | 57.3 |
| Aquatic ecotoxicity | kg TEG water | 1.96E+09 | 1.93E+09 | 3.35E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 6.92E+08 | 6.80E+08 | 1.22E+07 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 405,416.66 | 403,622.1 | 1,794.5 |
| Land occupation | m2org.arable | 1.85E+07 | 1.85E+07 | 4.25E+03 |
| Aquatic acidification | kg $SO_2$ eq | 59,935.59 | 59,442.1 | 493.4 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 1,309.27 | 1,246.5 | 62.8 |
| Global warming | kg $CO_2$ eq | 5.56E+06 | 5.46E+06 | 9.84E+04 |
| Non-renewable energy | MJ primary | 8.35E+07 | 8.22E+07 | 1.31E+06 |
| Mineral extraction | MJ surplus | 90,697.36 | 56,630.7 | 34,066.7 |

In Figure 21 the share of each life cycle stage per impact category is shown. The operational phase is the major environmental bearer in this scenario for all the categories. For the mineral extraction category, the construction stage carries 40% of the total impact for this category.

The weighted damage assessment per area of concern is presented in Figure 22, displaying all the assemblies considered in the model for this parish.

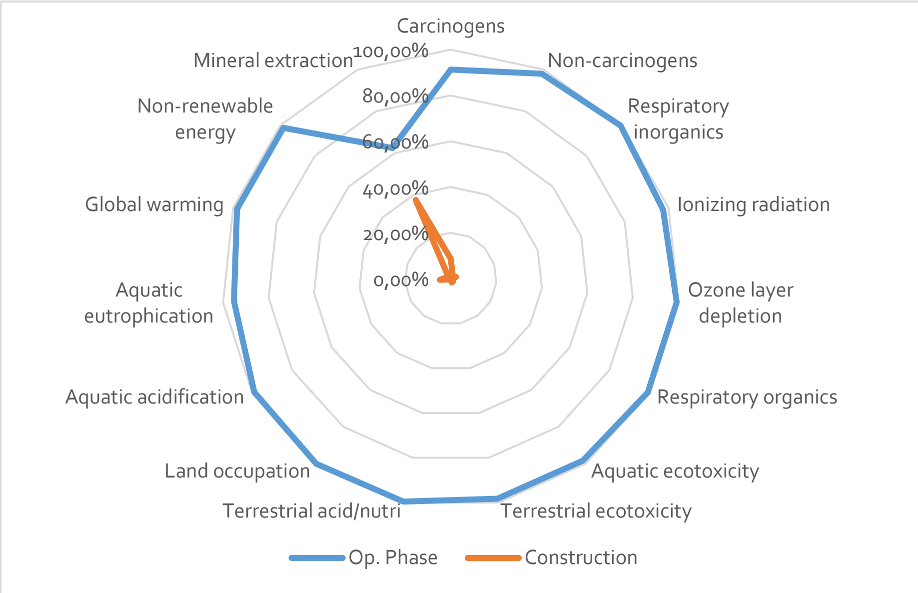



Figure 21. Characterization comparison between stages for Stari baseline scenario.

The operation phase is the main stage of concern in terms of weighted environmental toll. The highest impact is on human health with a total score of 11.46 kPts, followed by the impact on ecosystem quality with 1.91 kPts.

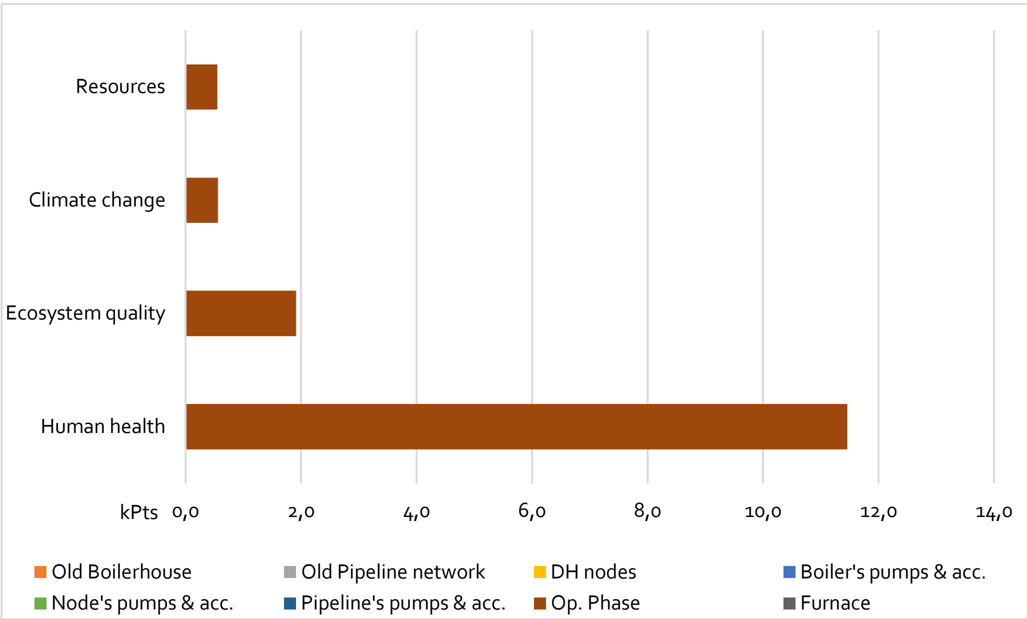



Figure 22. Damage assessment for Stari baseline scenario.

### 6.2.2 Stari village: LowTemp scenario

In Table 10 midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

TABLE 10. CHARACTERIZATION RESULTS FOR STARI VILLAGE (LOWTEMP SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 40,256.49 | 23,178.88 | 5,793.38 | 11,284.23 |
| Non-carcinogens | kg C2H3Cl eq | 188,374.30 | 177,087.54 | 5,156.33 | 6,130.43 |
| Respiratory inorganics | kg PM2.5 eq | 4,716.11 | 4,129.16 | 149.65 | 437.30 |
| Ionizing radiation | Bq C-14 eq | 2.30E+07 | 2.03E+07 | 7.12E+05 | 2.03E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.14 | 0.08 | 0.01 | 0.05 |
| Respiratory organics | kg C2H4 eq | 1,358.80 | 1,025.54 | 52.83 | 280.44 |
| Aquatic ecotoxicity | kg TEG water | 1.39E+09 | 1.30E+09 | 3.59E+07 | 5.13E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 5.11E+08 | 4.87E+08 | 1.35E+07 | 1.06E+07 |
| Terrestrial acid/nutri | kg SO2 eq | 72,801.64 | 64,592.78 | 1,619.16 | 6,589.70 |
| Land occupation | m2org.arable | 1.02E+06 | 1.00E+06 | 2.76E+03 | 1.43E+04 |
| Aquatic acidification | kg SO2 eq | 12,407.21 | 10,026.48 | 451.07 | 1,929.66 |
| Aquatic eutrophication | kg PO4 P-lim | 855.46 | 725.05 | 51.96 | 78.45 |
| Global warming | kg CO2 eq | 1.07E+06 | 6.61E+05 | 8.89E+04 | 3.19E+05 |
| Non-renewable energy | MJ primary | 1.86E+07 | 1.24E+07 | 1.22E+06 | 4.95E+06 |
| Mineral extraction | MJ surplus | 78,893.26 | 30,546.62 | 29,544.26 | 18,802.38 |

Figure 23 shows the share of each life cycle stage in the different impact categories including the building refurbishment at the end user side. The operational phase is the major environmental bearer, but thanks to reduction in fuel consumption across the project lifetime, its share has diminished for several impact categories. The building renovation is accountable for almost 40% of the substances released affecting the ozone layer. The construction stage has the same share for the mineral extraction impact category as the operation phase.

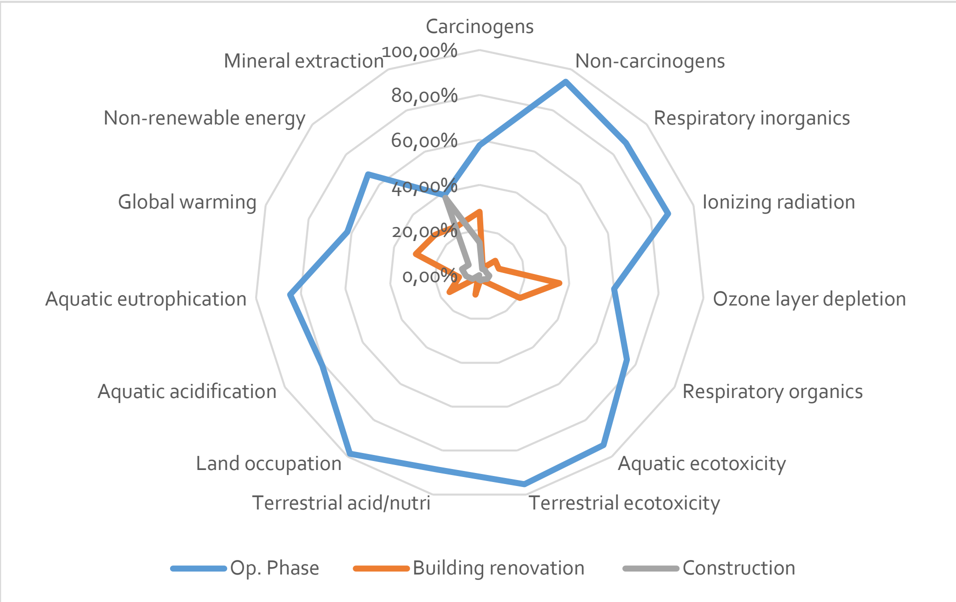



Figure 23. Characterization comparison between stages for Stari LowTemp scenario.

The weighted damage assessment per area of concern is presented in Figure 24, displaying every single assembly considered for Stari lowtemp model. The operation phase has the highest impacts in all areas followed by the building renovation and the pipeline network assembly within the DH construction stage. The most impacted area of concern is the human health with a total score of 0.56 kPts, followed by the ecosystem quality with 0.39 kPts.

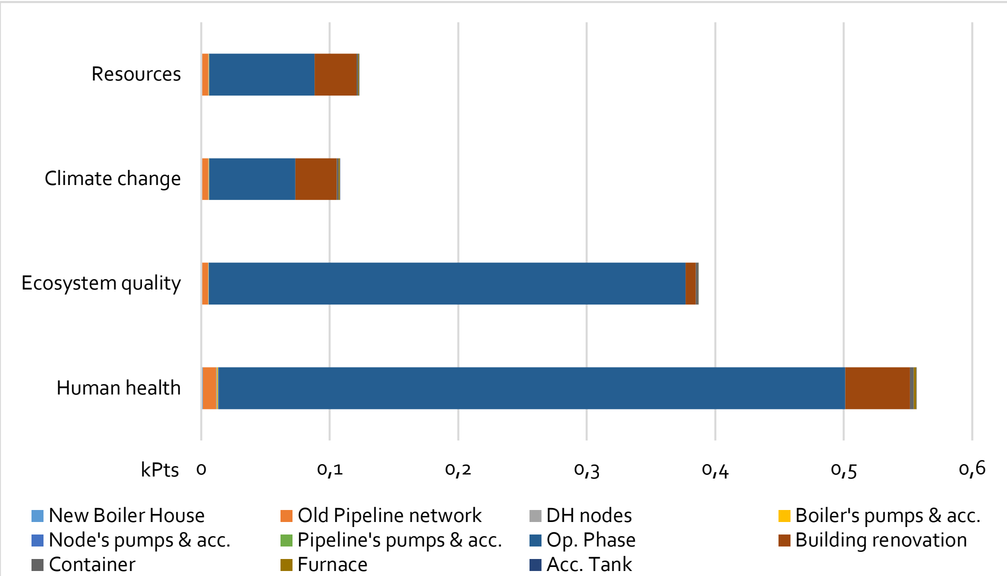
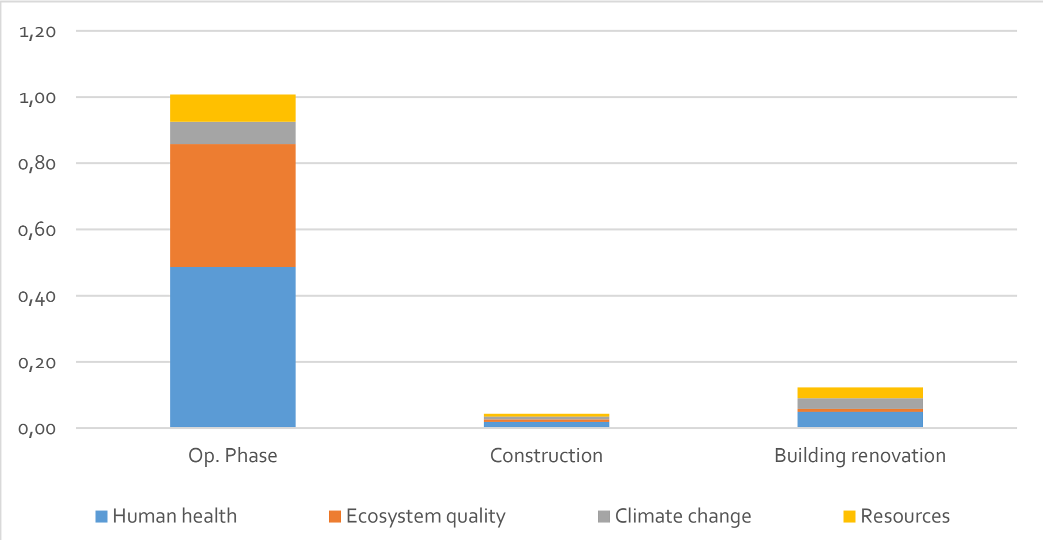



Figure 24. Damage assessment for Stari LowTemp scenario.

The single score graph is presented in Figure 25, where the operational phase (use stage) delivers 1.01 kPts while the refurbishment activities in the buildings delivers 0.12 kPts and the DH system construction stage 0.04 kPts. These low values compared with other parishes and with the current DH scenario in Stari, are explained by the consideration in 4GDH scenario in form of reduction in DH network length besides the decrease in heat load and energy generation (see section **Fehler! Verweisquelle konnte nicht gefunden werden.**). Furthermore, Stari is one of the smallest parishes as-




sessed in this study.

Figure 25. Single score per stage for Stari LowTemp scenario.

## 6.3 Life Cycle Assessment Results for Litene parish

### 6.3.1 Litene parish Baseline scenario

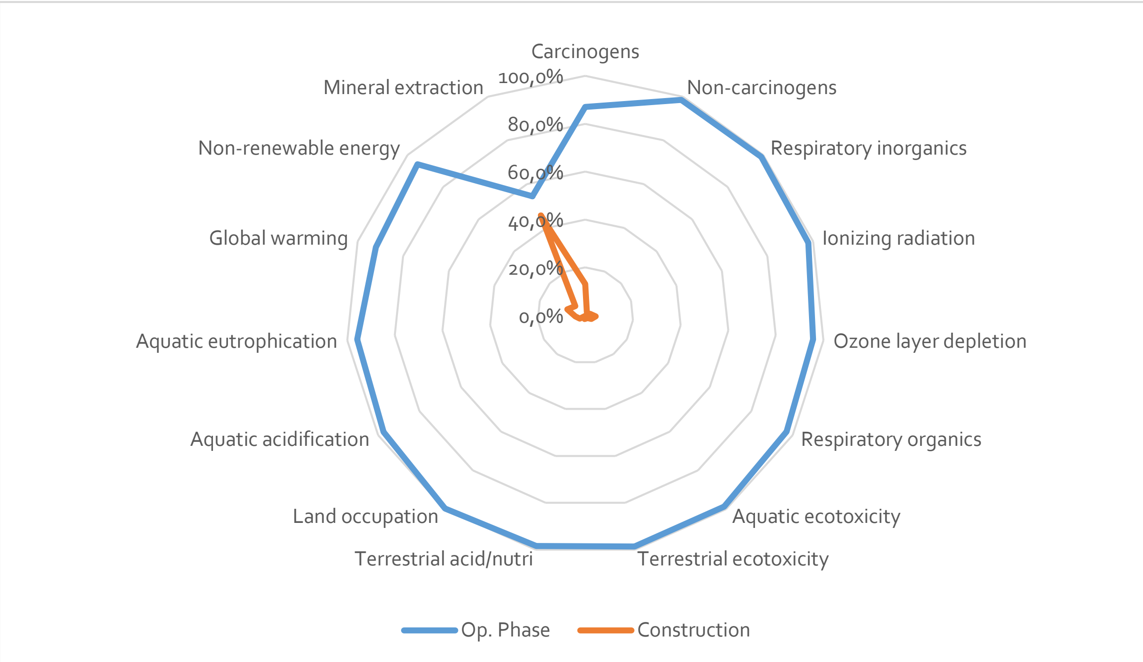
In Table 11, the midpoint category results are presented for the current state scenario with reference to the functional unit.

TABLE 11. CHARACTERIZATION RESULTS FOR LITENE PARISH (BASELINE SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 26,052.09 | 22,656.74 | 3,395.36 |
| Non-carcinogens | kg C2H3Cl eq | 180,820.28 | 178,075.55 | 2,744.73 |
| Respiratory inorganics | kg PM2.5 eq | 8,970.63 | 8,877.02 | 93.61 |
| Ionizing radiation | Bq C-14 eq | 2.02E+07 | 1.97E+07 | 4.16E+05 |
| Ozone layer depletion | kg CFC-11 eq | 0.09 | 0.08 | 0.00 |

| | | | | |
|---|---|---|---|---|
| Respiratory organics | kg $C_2H_4$ eq | 1,107.07 | 1,074.62 | 32.45 |
| Aquatic ecotoxicity | kg TEG water | 1.33E+09 | 1.32E+09 | 1.83E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 4.98E+08 | 4.91E+08 | 6.70E+06 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 65,849.37 | 64,820.71 | 1,028.66 |
| Land occupation | m2org.arable | 967,419.75 | 964,484.42 | 2,935.33 |
| Aquatic acidification | kg $SO_2$ eq | 10,312.07 | 10,031.99 | 280.08 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 751.25 | 719.88 | 31.37 |
| Global warming | kg $CO_2$ eq | 707,069.07 | 650,965.49 | 56,103.58 |
| Non-renewable energy | MJ primary | 1.30E+07 | 1.22E+07 | 7.39E+05 |
| Mineral extraction | MJ surplus | 39,993.04 | 21,740.51 | 18,252.54 |

Figure 26 shows the share of each life cycle stage in the different impact categories. As in the two previous parishes and current state, the operational phase is the major environmental bearer in this



scenario for all categories. In the mineral extraction, the construction stage has nearly 50% of the total impact for this category.

Figure 26. Characterization comparison between stages for Litene baseline scenario.

The weighted damage assessment per area of concern is presented in



Figure 27 displaying all the assemblies considered in the model for this parish. The operation phase is the main responsible stage in each area of concern. The most impacted area of concern is human health with a total score of 0.97 kPts, followed by the ecosystem quality with 0.37 kPts.

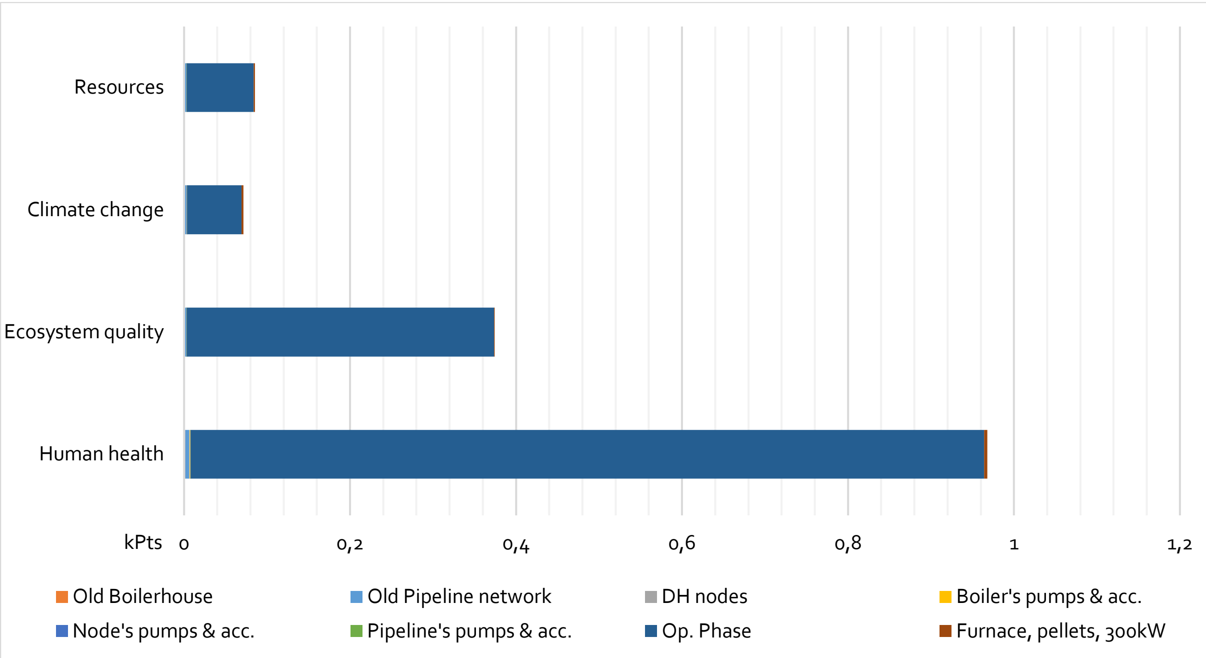



Figure 27. Damage assessment for Litene baseline scenario.

### 6.3.2 Litene parish: LowTemp scenario

In Table 12 midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

TABLE 12. CHARACTERIZATION RESULTS FOR LITENE PARISH (LOWTEMP SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 30,806.2 | 17,679.0 | 3,395.4 | 9,731.8 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 146,859.2 | 138,827.4 | 2,744.7 | 5,287.1 |
| Respiratory inorganics | kg $PM_{2.5}$ eq | 7,396.9 | 6,926.1 | 93.6 | 377.1 |
| Ionizing radiation | Bq C-14 eq | 1.76E+07 | 1.54E+07 | 4.16E+05 | 1.75E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.1 | 0.1 | 0.0 | 0.0 |
| Respiratory organics | kg $C_2H_4$ eq | 1,112.1 | 837.8 | 32.5 | 241.9 |
| Aquatic ecotoxicity | kg TEG water | 1.09E+09 | 1.03E+09 | 1.83E+07 | 4.42E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 3.99E+08 | 3.83E+08 | 6.70E+06 | 9.17E+06 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 57,313.9 | 50,602.1 | 1,028.7 | 5,683.1 |
| Land occupation | m2org.arable | 764,173.9 | 748,906.7 | 2,935.3 | 12,331.9 |
| Aquatic acidification | kg $SO_2$ eq | 9,787.9 | 7,843.6 | 280.1 | 1,664.2 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 660.3 | 561.3 | 31.4 | 67.7 |
| Global warming | kg $CO_2$ eq | 842,942.3 | 511,408.2 | 56,103.6 | 275,430.6 |
| Non-renewable energy | MJ primary | 1.46E+07 | 9.60E+06 | 7.39E+05 | 4.27E+06 |
| Mineral extraction | MJ surplus | 51,394.1 | 16,925.9 | 18,252.5 | 16,215.7 |

Figure 28 shows the comparison between life cycle stages for the different impact categories including the building refurbishment in the end user side. The operational phase provides the major environmental impact in terms of percentage of substances emitted across almost all impact categories, followed by the building renovation stage. The construction stage surpasses the other two stages only in the mineral extraction category with 35,5% of the total burden.

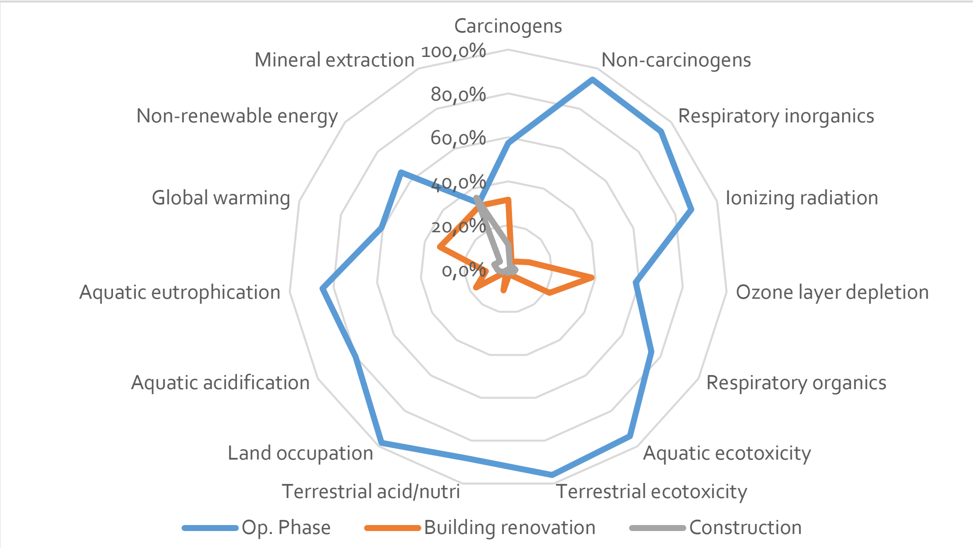


Figure 28. Characterization comparison between stages for Litene LowTemp scenario.

The weighted damage assessment per area of concern is presented Figure 29, displaying every single assembly considered for Litene lowtemp scenario. As seen before, operation phase brings most of the impacts to all areas of concern followed by the building renovation. All other assemblies represent a low share in the environmental impact. The most impacted area of concern is the human health with a total score of 0.8 kPts, followed by the ecosystem quality with 0.3 kPts and resources with 0.1 kPts.

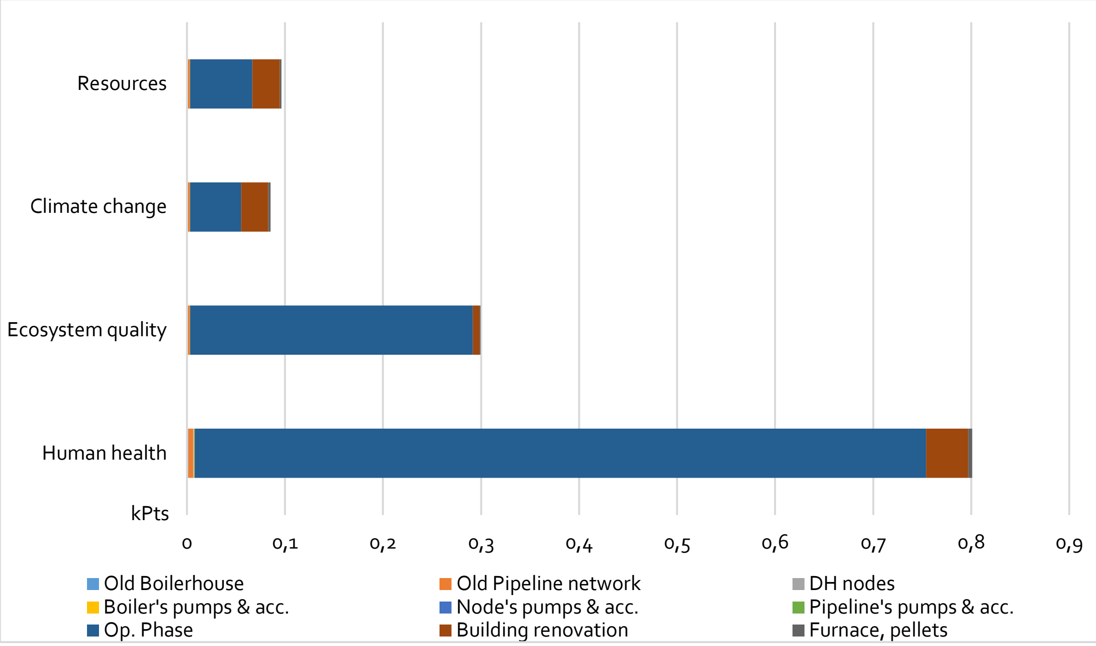



Figure 29. Damage assessment for Litene LowTemp scenario.

## 6.4 Life Cycle Assessment Results for Lejasciems parish

### 6.4.1 Lejasciems parish: Baseline scenario

In Table 13 the midpoint category results are presented for the baseline scenario with reference to the functional unit.

TABLE 13. CHARACTERIZATION RESULTS FOR LEJASCIEMS PARISH (BASELINE SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 107,354.6 | 96,930.3 | 10,424.3 |
| Non-carcinogens | kg C2H3Cl eq | 445,185.1 | 436,687.3 | 8,497.8 |
| Respiratory inorganics | kg PM2.5 eq | 150,171.9 | 149,913.6 | 258.3 |
| Ionizing radiation | Bq C-14 eq | 5.56E+07 | 5.39E+07 | 1.64E+06 |
| Ozone layer depletion | kg CFC-11 eq | 1.3 | 1.3 | 0.0 |

| | | | | |
|---|---|---|---|---|
| Respiratory organics | kg C2H4 eq | 11,728.2 | 11,632.8 | 95.3 |
| Aquatic ecotoxicity | kg TEG water | 3.48E+09 | 3.42E+09 | 5.56E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 1.24E+09 | 1.22E+09 | 2.01E+07 |
| Terrestrial acid/nutri | kg SO2 eq | 634,927.3 | 631,976.1 | 2,951.2 |
| Land occupation | m2org.arable | 2.45E+07 | 2.45E+07 | 7.04E+03 |
| Aquatic acidification | kg SO2 eq | 92,463.9 | 91,653.8 | 810.0 |
| Aquatic eutrophication | kg PO4 P-lim | 2,144.1 | 2,040.2 | 103.9 |
| Global warming | kg CO2 eq | 7.52E+06 | 7.35E+06 | 1.63E+05 |
| Non-renewable energy | MJ primary | 1.13E+08 | 1.11E+08 | 2.18E+06 |
| Mineral extraction | MJ surplus | 130,316.8 | 75,847.6 | 54,469.2 |

Figure 30 shows the share of each life cycle stage in the different impact categories. As in previous parishes, the operational phase presents the larger environmental toll for the nowadays DH system scenario in all categories. For the mineral extraction, the construction stage carries 42% of the total impact.

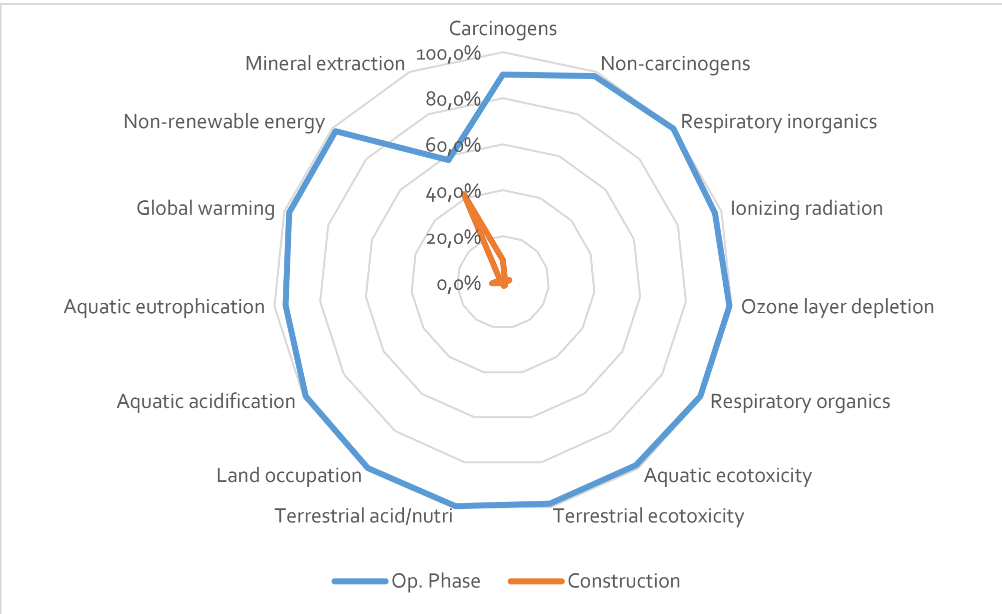


Figure 30. Characterization comparison between stages for Lejasciems baseline scenario.

The weighted damage assessment per area of concern is presented in

Figure 31, displaying all the assemblies considered in the model for this parish. Again, the operational phase is the main responsible stage in each area of concern. The most impacted area of concern is the human health with a total score of 15.05 kPts, followed by the ecosystem quality with 2.72 kPts.

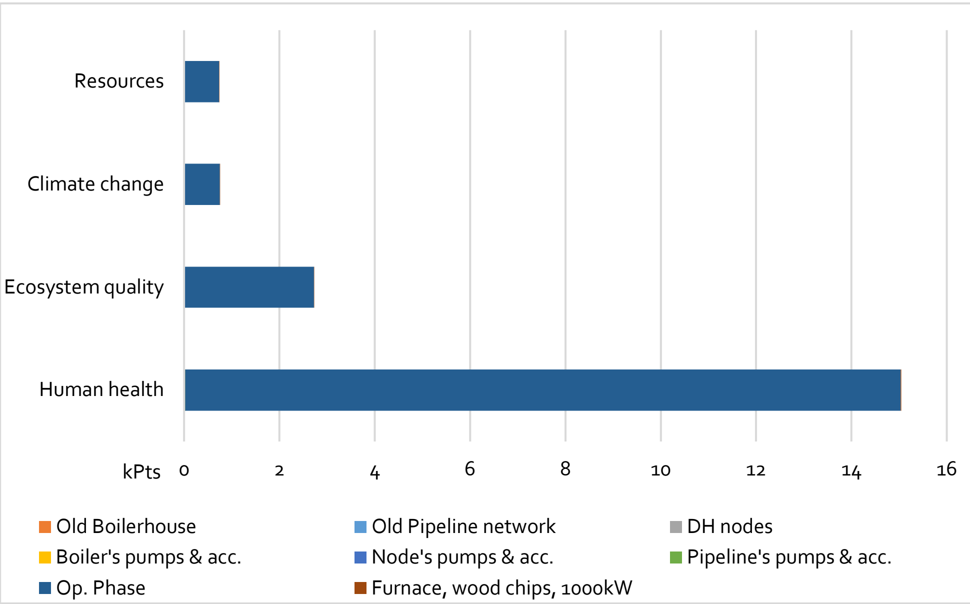


Figure 31. Damage assessment for Lejasciems baseline scenario.

### 6.4.2 Lejasciems parish: LowTemp scenario

In Table 14 midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

**TABLE 14. CHARACTERIZATION RESULTS FOR LEJASCIEMS PARISH (LOWTEMP SCENARIO)**

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 79,478.7 | 40,747.9 | 9,861.1 | 28,869.7 |
| Non-carcinogens | kg C2H3Cl eq | 346,285.5 | 322,109.4 | 8,492.0 | 15,684.2 |
| Respiratory inorganics | kg PM2.5 eq | 17,403.7 | 16,036.2 | 248.7 | 1,118.8 |
| Ionizing radiation | Bq C-14 eq | 4.16E+07 | 3.52E+07 | 1.20E+06 | 5.20E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.3 | 0.1 | 0.0 | 0.1 |
| Respiratory organics | kg C2H4 eq | 2,745.7 | 1,936.1 | 92.0 | 717.5 |
| Aquatic ecotoxicity | kg TEG water | 2.57E+09 | 2.38E+09 | 6.08E+07 | 1.31E+08 |
| Terrestrial ecotoxicity | kg TEG soil | 9.38E+08 | 8.89E+08 | 2.24E+07 | 2.72E+07 |
| Terrestrial acid/nutri | kg SO2 eq | 136,204.2 | 116,635.7 | 2,709.3 | 16,859.2 |
| Land occupation | m2org.arable | 1.79E+06 | 1.74E+06 | 4.42E+03 | 3.66E+04 |
| Aquatic acidification | kg SO2 eq | 23,653.5 | 17,957.0 | 759.7 | 4,936.9 |
| Aquatic eutrophication | kg PO4 P-lim | 1,589.4 | 1,299.5 | 89.2 | 200.7 |
| Global warming | kg CO2 eq | 2.11E+06 | 1.14E+06 | 1.49E+05 | 8.17E+05 |
| Non-renewable energy | MJ primary | 3.63E+07 | 2.15E+07 | 2.11E+06 | 1.27E+07 |
| Mineral extraction | MJ surplus | 134,859.1 | 39,051.4 | 47,703.4 | 48,104.2 |

Figure 32 shows the comparison between life cycle stages for the different impact categories including the building refurbishment in the end user side. The operational phase delivers most of the environmental impact in terms of percentage of substances emitted across almost all impact categories, followed by the building renovation stage.

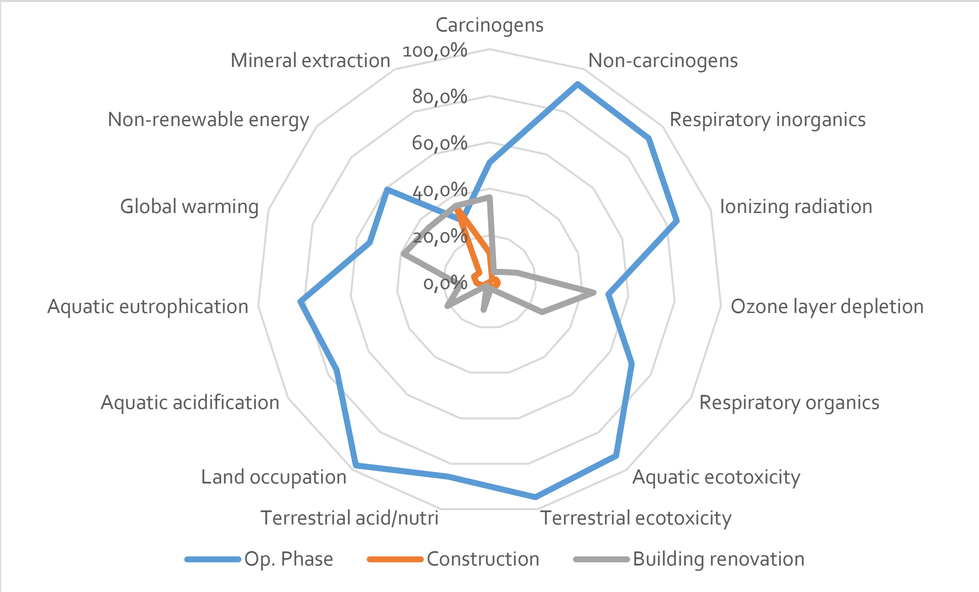



Figure 32. Characterization comparison between stages for Lejasciems LowTemp scenario.

The weighted damage assessment per area of concern is presented in

Figure 33, displaying every single assembly considered for Lejasciems lowtemp scenario. As before, the operation phase delivers the higher environmental toll in all areas of concern followed by the building renovation. All other assemblies represent a low share in the environmental impact. The most impact is for human health with a total score of 1.89 kPts.

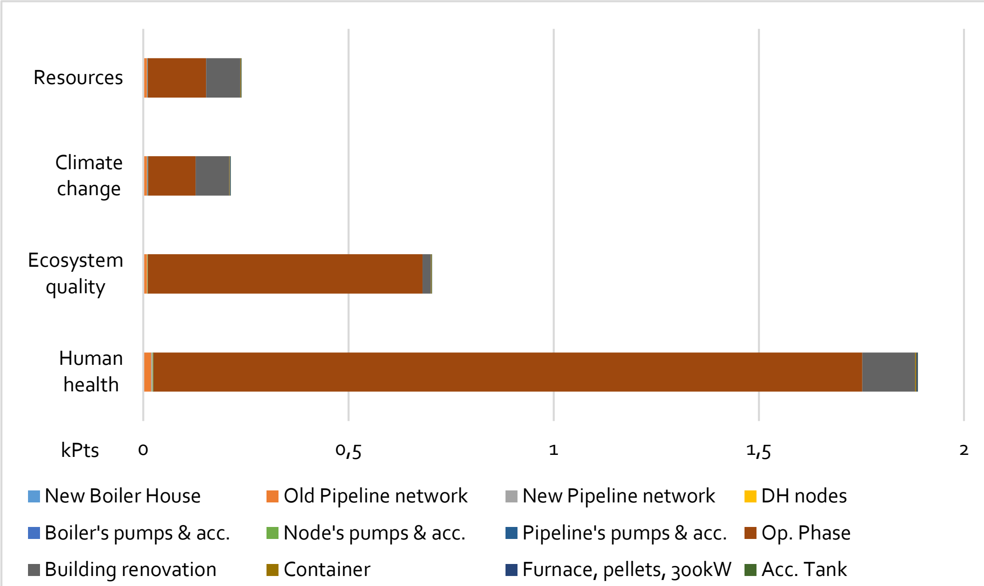



Figure 33. Damage assessment for Lejasciems LowTemp scenario.

## 6.5 Life Cycle Assessment results for Lizums parish

### 6.5.1 Lizums parish: baseline scenario

In Table 15 the midpoint category results are presented for the current state scenario with reference to the functional unit.

TABLE 15. CHARACTERIZATION RESULTS FOR LIZUMS PARISH (BASELINE SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 53,286.5 | 42,808.6 | 10,477.8 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 25,189.6 | 16,840.2 | 8,349.4 |
| Respiratory inorganics | kg PM2.5 eq | 3,150.9 | 2,905.1 | 245.9 |
| Ionizing radiation | Bq C-14 eq | 2.82E+07 | 2.70E+07 | 1.25E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.8 | 0.8 | 0.0 |
| Respiratory organics | kg $C_2H_4$ eq | 1,507.2 | 1,412.0 | 95.1 |

| | | | | |
|---|---|---|---|---|
| Aquatic ecotoxicity | kg TEG water | 2.00E+08 | 1.32E+08 | 6.78E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 6.31E+07 | 3.86E+07 | 2.45E+07 |
| Terrestrial acid/nutri | kg SO2 eq | 82,934.2 | 80,273.6 | 2,660.6 |
| Land occupation | m2org.arable | 44,916.6 | 42,262.3 | 2,654.3 |
| Aquatic acidification | kg SO2 eq | 17,131.9 | 16,369.2 | 762.7 |
| Aquatic eutrophication | kg PO4 P-lim | 292.3 | 198.4 | 94.0 |
| Global warming | kg CO2 eq | 6.32E+06 | 6.17E+06 | 1.50E+05 |
| Non-renewable energy | MJ primary | 1.12E+08 | 1.10E+08 | 2.23E+06 |
| Mineral extraction | MJ surplus | 70,264.9 | 24,878.5 | 45,386.4 |

Figure 34 shows the share of each life cycle stage in the different impact categories. As seen, the operational phase is the major environmental bearer in this scenario for almost all categories, except for mineral et is worth to notice that construction stage carries 64% of the total impact for this category.

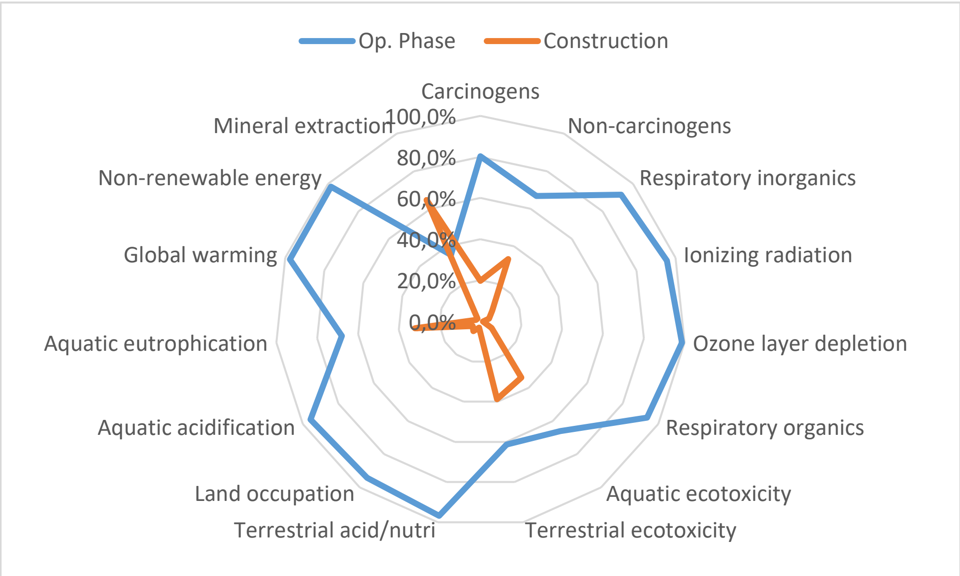



Figure 34. Characterization comparison between stages for Lizums baseline scenario.

The weighted damage assessment per area of concern is presented in

Figure 35, displaying all the assemblies considered in the model for this parish. The operation phase has the highest environmental impact in each area of concern. Within the construction stage, the pipeline network deployment is the main bearer with most impact on resources with a total score of 0.74 kPts, followed by climate change with 0.64 kPts.

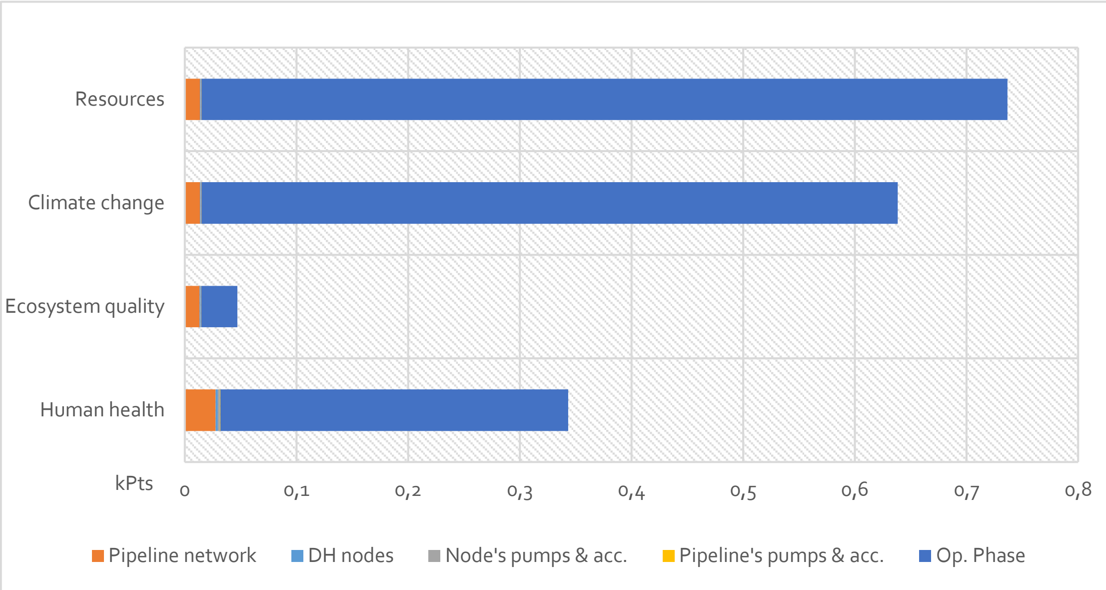



Figure 35. Damage assessment for Lizums baseline scenario.

Resources and climate changes are the most impacted areas in this scenario, as no boilerhouse is required for this scenario due to the thermal energy purchase from a CHP plant (see section 4.6) that uses woodchips as a combustion fuel. Other parishes are employing old boiler technologies using renewable fuels such as woodchips or pellets.

### 6.5.2 Lizums parish: LowTemp scenario

In Table 16, midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

**TABLE 16. CHARACTERIZATION RESULTS FOR STARI VILLAGE (LOWTEMP SCENARIO)**

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 68,130.0 | 20,465.3 | 10,477.8 | 37,186.9 |
| Non-carcinogens | kg C2H3Cl eq | 33,819.1 | 5,267.0 | 8,349.4 | 20,202.7 |
| Respiratory inorganics | kg PM2.5 eq | 2,807.5 | 1,120.5 | 245.9 | 1,441.1 |
| Ionizing radiation | Bq C-14 eq | 1.53E+07 | 7.37E+06 | 1.25E+06 | 6.70E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.6 | 0.4 | 0.0 | 0.2 |
| Respiratory organics | kg C2H4 eq | 1,690.2 | 670.9 | 95.1 | 924.2 |
| Aquatic ecotoxicity | kg TEG water | 2.78E+08 | 4.17E+07 | 6.78E+07 | 1.69E+08 |
| Terrestrial ecotoxicity | kg TEG soil | 7.13E+07 | 1.18E+07 | 2.45E+07 | 3.50E+07 |
| Terrestrial acid/nutri | kg SO2 eq | 59,659.1 | 35,282.3 | 2,660.6 | 21,716.2 |
| Land occupation | m2org.arable | 60,130.4 | 10,353.9 | 2,654.3 | 47,122.3 |
| Aquatic acidification | kg SO2 eq | 13,486.5 | 6,364.7 | 762.7 | 6,359.1 |
| Aquatic eutrophication | kg PO4 P-lim | 411.7 | 59.2 | 94.0 | 258.5 |
| Global warming | kg CO2 eq | 4.20E+06 | 3.00E+06 | 1.50E+05 | 1.05E+06 |
| Non-renewable energy | MJ primary | 7.18E+07 | 5.32E+07 | 2.23E+06 | 1.63E+07 |
| Mineral extraction | MJ surplus | 117,386.2 | 10,037.0 | 45,386.4 | 61,962.8 |

As reportedin Figure 36 the building refurbishment in the end-user side reapresents the major environmental bearer in terms of percentage in most impact categories, followed by the operational stage. The construction stage presents large contribution in the mineral extraction and terrestrial ecotoxicity impact categories. In this LowTemp scenario, heat from the CHP plant is still considered, and this is presented in the results as a large share of production stage in non-renewable energy and global warming categories.

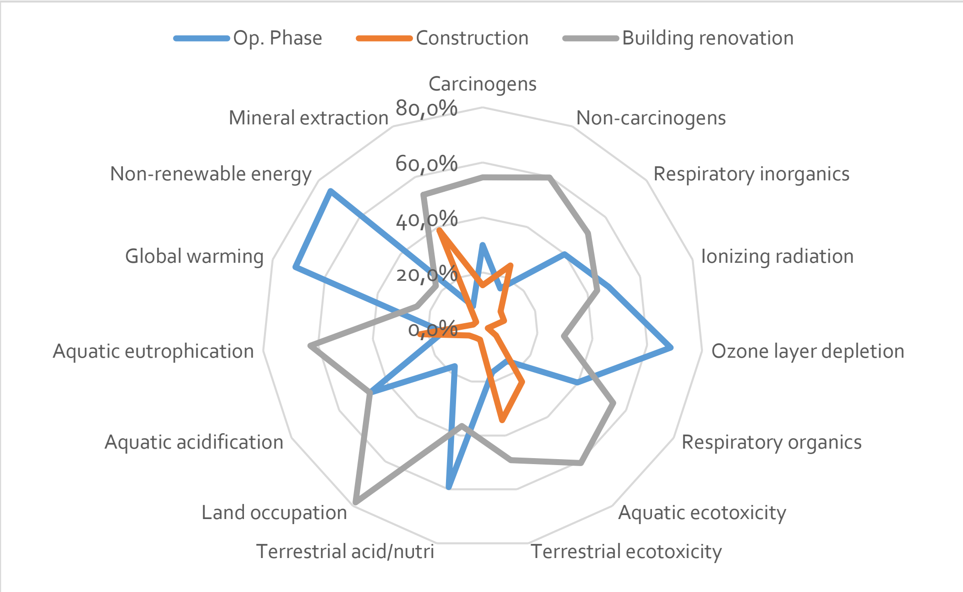
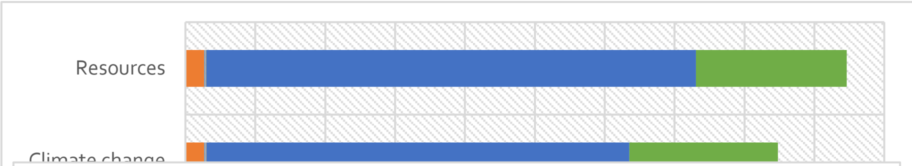
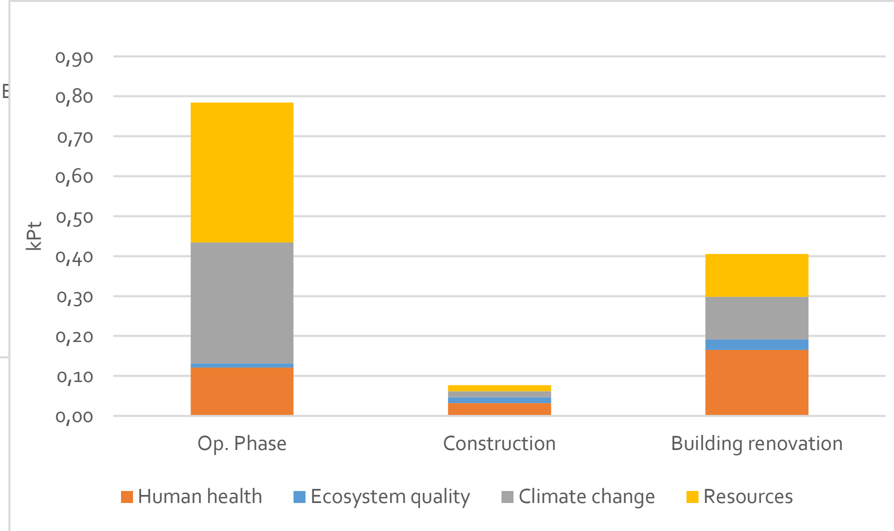



Figure 36. Characterization comparison between stages for Lizums LowTemp scenario.

The weighted damage assessment per area of concern is presented in Figure 37, displaying every single assembly considered for this parish. Here, it is observed how, although the refurbishment at the end user side had most of the share contribution in many categories, is the operational phase the one which delivers most of the impacts in all areas of concern. This is due to the weighted factor each category is given within the IMPACT 2002+ methodology. The building renovation is the second stage with the larger environmental burden followed by the pipeline network assembly within the DH construction stage. The most impacted area of concern is resources and then climate change, and human health.

Figure 37. Damage assessment for Lizums LowTemp scenario.




The single score graph is presented in Figure 38, As explained before, when environmental impact results are weighted under the IMPACT 2002+ methodology, the operational phase turns to be the main hotspot for this 4GDH parish scenario.

Figure 38. Single score per stage for Lizums scenario.

## 6.6 Life Cycle Assessment results for Galgauska parish

### 6.6.1 Galgauska parish: 3GDH scenario

As mentioned in section 4.7, nowadays there is no DH system in this parish and heat is produced locally for each building. Therefore, the scenario analyzed in this subsection, is the construction of the new DH but operating under a temperature profile consistent with the Third Generation District Heating (3GDH) system technology.

In Table 17, the midpoint category results are presented for the current state scenario with reference to the functional unit.

**TABLE 17. CHARACTERIZATION RESULTS FOR GALGAUSKA PARISH (BASELINE SCENARIO)**

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 60,971.4 | 55,896.5 | 5,075.0 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 249,238.6 | 244,580.4 | 4,658.2 |
| Respiratory inorganics | kg $PM_{2.5}$ eq | 93,958.9 | 93,818.6 | 140.3 |
| Ionizing radiation | Bq C-14 eq | 3.11E+07 | 3.03E+07 | 7.72E+05 |
| Ozone layer depletion | kg CFC-11 eq | 0.7 | 0.7 | 0.0 |
| Respiratory organics | kg $C_2H_4$ eq | 7,214.4 | 7,157.2 | 57.2 |
| Aquatic ecotoxicity | kg TEG water | 1.95E+09 | 1.92E+09 | 3.00E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 6.95E+08 | 6.84E+08 | 1.10E+07 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 340,139.0 | 338,510.6 | 1,628.4 |
| Land occupation | $m^2$org.arable | 1.47E+07 | 1.47E+07 | 3.37E+03 |
| Aquatic acidification | kg $SO_2$ eq | 49,816.4 | 49,361.9 | 454.5 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 1,208.3 | 1,155.8 | 52.5 |
| Global warming | kg $CO_2$ eq | 4.38E+06 | 4.29E+06 | 8.67E+04 |
| Non-renewable energy | MJ primary | 6.55E+07 | 6.42E+07 | 1.21E+06 |
| Mineral extraction | MJ surplus | 73,102.6 | 44,540.1 | 28,562.5 |

Figure 39 shows that the operational phase is the major environmental bearer in this scenario for all categories. Construction stage is only relevant at the mineral extraction impact category with 39.1 % of the total impact for this category.

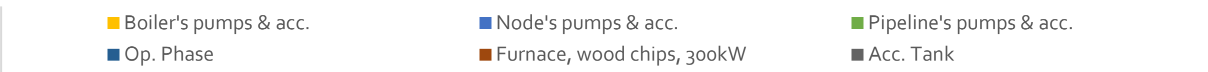



Figure 40 displaying all the assemblies considered in the model for this parish. The operational phase is the stage carrying most of the environmental impact for each area of concern. The area of concern with the larger impact is human health with a score of 9.4 kPts, followed by ecosystem quality with 1.6 kPts.

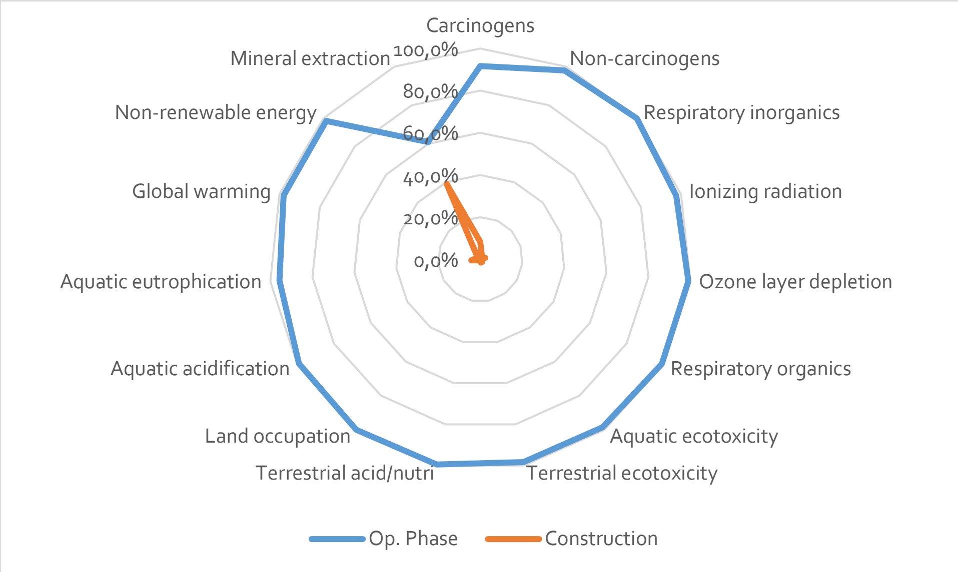



Figure 39. Characterization comparison between stages for Galgauska baseline scenario.

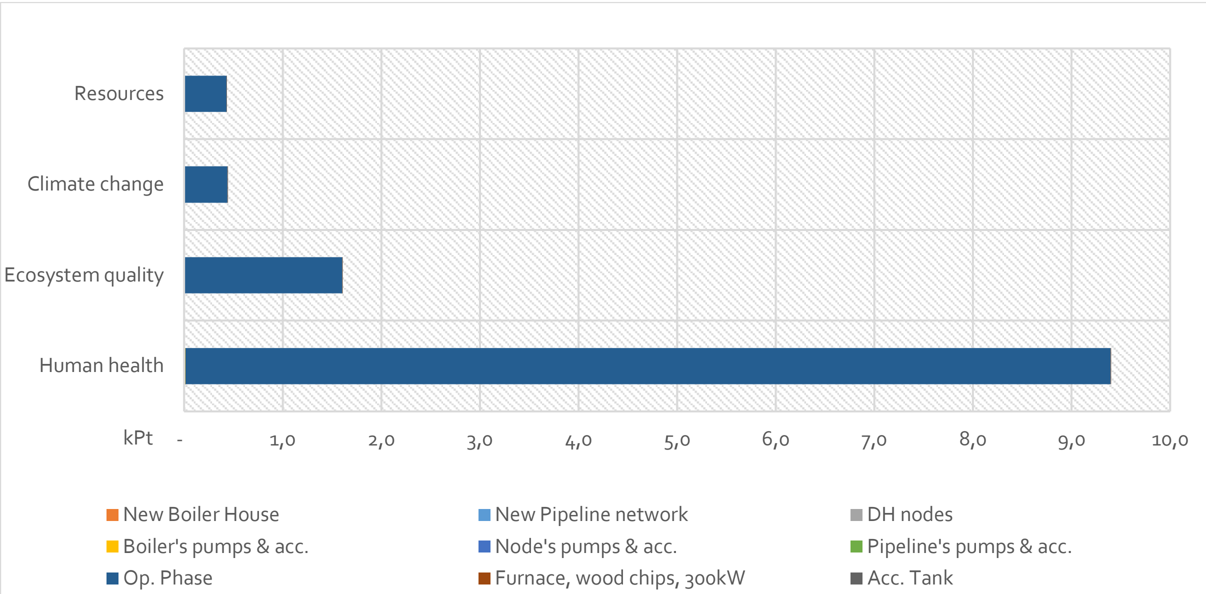



Figure 40. Damage assessment for Galgauska baseline scenario.

### 6.6.2 Galgauska parish: LowTemp scenario

For this scenario, the same DH system is built for the parish, but operating under the 4GDH approach. Hence, building refurbishment stage is considered. In Table 18, midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

As seen before in many parishes, the midpoint categories with a larger amount of substances emitted are ionizing radiation, aquatic and terrestrial ecotoxicity, land occupation, global warming and non-renewable energy.

TABLE 18. CHARACTERIZATION RESULTS FOR GALGAUSKA PARISH (LOWTEMP SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 39,958.6 | 28,280.0 | 5,749.9 | 5,928.7 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 229,582.4 | 220,956.0 | 5,405.5 | 3,220.9 |
| Respiratory inorganics | kg PM2.5 eq | 11,420.4 | 11,034.3 | 156.3 | 229.8 |
| Ionizing radiation | Bq C-14 eq | 2.67E+07 | 2.49E+07 | 7.40E+05 | 1.07E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.1 | 0.1 | 0.0 | 0.0 |
| Respiratory organics | kg $C_2H_4$ eq | 1,547.9 | 1,338.3 | 62.3 | 147.3 |
| Aquatic ecotoxicity | kg TEG water | 1.70E+09 | 1.63E+09 | 3.59E+07 | 2.69E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 6.28E+08 | 6.09E+08 | 1.34E+07 | 5.59E+06 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 86,101.4 | 80,898.6 | 1,740.5 | 3,462.2 |
| Land occupation | m2org.arable | 1.20E+06 | 1.19E+06 | 2.80E+03 | 7.51E+03 |
| Aquatic acidification | kg $SO_2$ eq | 14,100.9 | 12,594.2 | 492.8 | 1,013.8 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 993.0 | 895.0 | 56.8 | 41.2 |
| Global warming | kg $CO_2$ eq | 1.09E+06 | 8.34E+05 | 9.24E+04 | 1.68E+05 |

| | | | | | |
|---|---|---|---|---|---|
| Non-renewable energy | MJ primary | 1.95E+07 | 1.56E+07 | 1.31E+06 | 2.60E+06 |
| Mineral extraction | MJ surplus | 68,168.6 | 27,124.2 | 31,165.6 | 9,878.8 |

Figure 41 shows the participation of each life cycle stage in the different impact categories including the building refurbishment in the end user side. The operational stage is the major environmental bearer in terms of percentage in most impact categories. The construction stage presents the large share for mineral extraction impact category. The building refurbishment stage share is low, since the heated area (area susceptible to refurbishment) is small, due to the parish size.

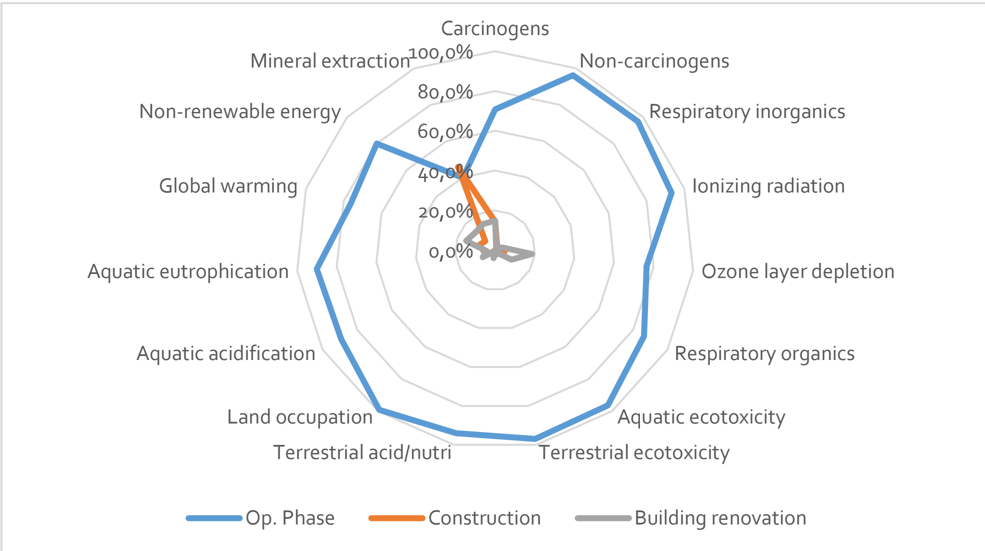



Figure 41. Characterization comparison between stages for Galgauska LowTemp scenario.


Figure 42, displaying every single assembly considered for this parish. Human health is the most impacted area with 1.23 kPts, followed by ecosystem quality with 0.47 kPts. Operational phase is once again the activity with the largest impact in the model.

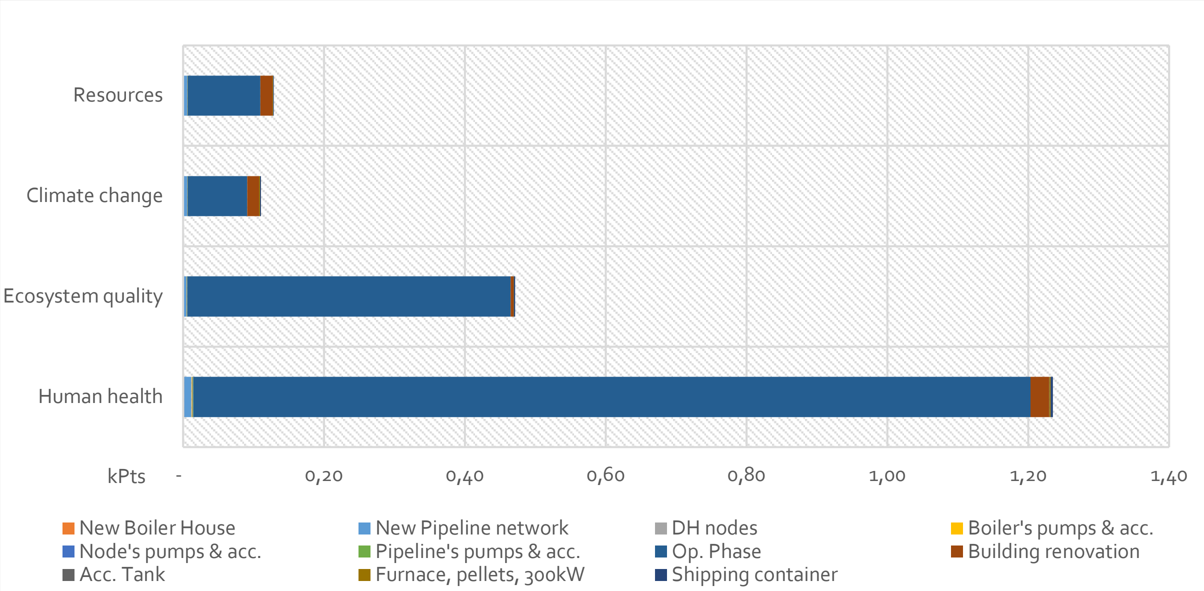



Figure 42. Damage assessment for Galgauska LowTemp scenario.

## 6.7 Life Cycle Assessment results for Ranka parish

### 6.7.1 Ranka parish: 3GDH scenario

As for Galgauska parish, the scenario modeled in this section is for a new DH, operating under a 3GDH system technology.

In Table 19, the midpoint category results are presented for the current state scenario with reference to the functional unit.

TABLE 19. CHARACTERIZATION RESULTS FOR RANKA PARISH (BASELINE SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction |
|---|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 82,837.9 | 77,164.2 | 5,673.8 |
| Non-carcinogens | kg C2H3Cl eq | 373,335.0 | 368,486.8 | 4,848.1 |
| Respiratory inorganics | kg PM2.5 eq | 19,801.4 | 19,635.7 | 165.7 |
| Ionizing radiation | Bq C-14 eq | 3.87E+07 | 3.80E+07 | 6.98E+05 |
| Ozone layer depletion | kg CFC-11 eq | 0.3 | 0.3 | 0.0 |

| | | | | |
|---|---|---|---|---|
| Respiratory organics | kg $C_2H_4$ eq | 3,888.1 | 3,826.4 | 61.7 |
| Aquatic ecotoxicity | kg TEG water | 2.80E+09 | 2.77E+09 | 3.11E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 1.02E+09 | 1.01E+09 | 1.12E+07 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 165,144.2 | 163,272.3 | 1,871.8 |
| Land occupation | m2org.arable | 1.69E+06 | 1.69E+06 | 3.87E+03 |
| Aquatic acidification | kg $SO_2$ eq | 26,344.0 | 25,729.8 | 614.2 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 1,650.7 | 1,593.6 | 57.1 |
| Global warming | kg $CO_2$ eq | 2.00E+06 | 1.90E+06 | 9.20E+04 |
| Non-renewable energy | MJ primary | 4.07E+07 | 3.95E+07 | 1.27E+06 |
| Mineral extraction | MJ surplus | 111,168.9 | 78,479.6 | 32,689.3 |

Figure 43 shows how the operational phase as it is usual, bears the highest share for all impact categories in this scenario. Construction stage is only relevant at the mineral extraction impact category with 29.4 % of the total impact for this category.

Boiler's pumps & acc. | Node's pumps & acc. | Pipeline's pumps & acc.
Op. Phase | Furnace, wood chips, 300kW | Acc. Tank

Figure 44, displaying all the assemblies considered in the model for this parish. The operational phase is the stage carrying almost all the environmental impact for each area of concern. The area of concern with the larger impact is human health with a score of 2.1 kPts, followed by ecosystem quality with 0.7 kPts.

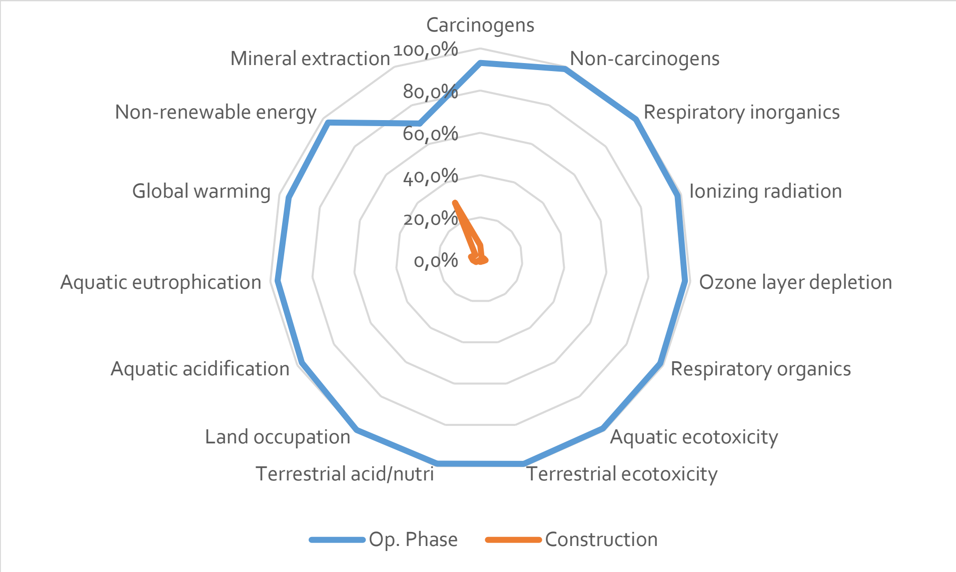



Figure 43. Characterization comparison between stages for Ranka baseline scenario.

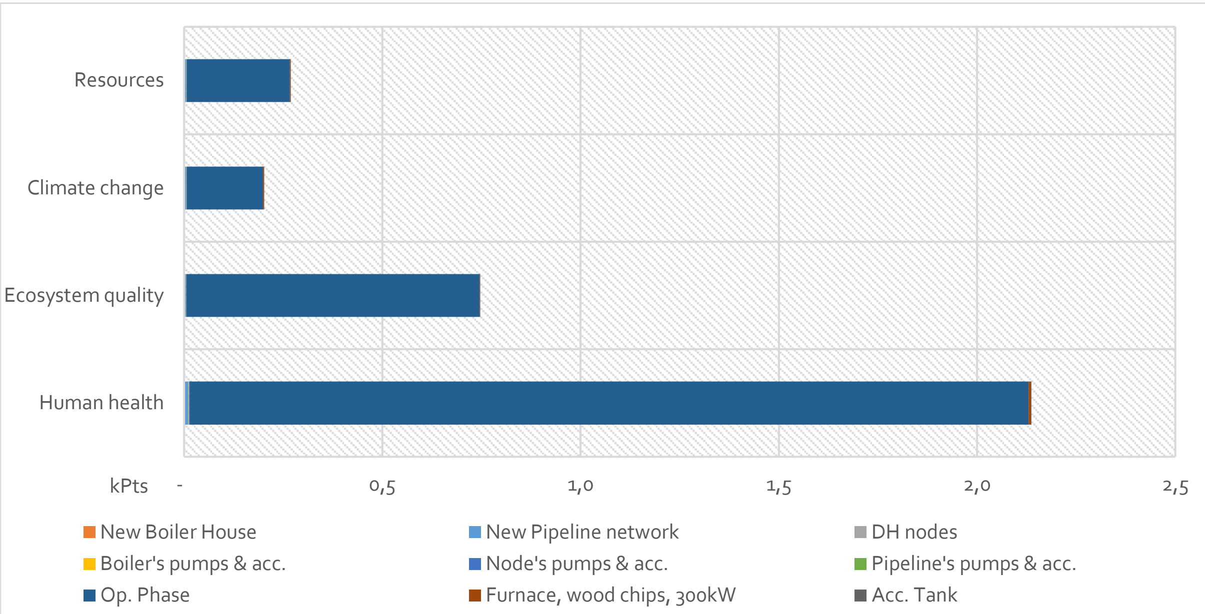



Figure 44. Damage assessment for Ranka baseline scenario.

### 6.7.2 Ranka parish: LowTemp scenario

In Table 20, midpoint category characterization is presented for the LowTemp scenario with reference to the functional unit.

As seen before in many parishes, the midpoint categories with larger amount of substances emitted are ionizing radiation, aquatic and terrestrial ecotoxicity, land occupation, global warming and non-renewable energy.

TABLE 20. CHARACTERIZATION RESULTS FOR RANKA PARISH (LOWTEMP SCENARIO)

| Impact category | Unit | Total | Op. Phase | Construction | Building renovation |
|---|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | 45,672.5 | 31,204.8 | 3,861.3 | 10,606.4 |
| Non-carcinogens | kg $C_2H_3Cl$ eq | 261,978.2 | 252,479.6 | 3,736.4 | 5,762.2 |
| Respiratory inorganics | kg $PM_{2.5}$ eq | 13,066.4 | 12,546.8 | 108.6 | 411.0 |
| Ionizing radiation | Bq C-14 eq | 2.92E+07 | 2.67E+07 | 4.99E+05 | 1.91E+06 |
| Ozone layer depletion | kg CFC-11 eq | 0.16 | 0.11 | 0.00 | 0.05 |
| Respiratory organics | kg $C_2H_4$ eq | 1,774.6 | 1,470.8 | 40.2 | 263.6 |
| Aquatic ecotoxicity | kg TEG water | 1.95E+09 | 1.88E+09 | 2.32E+07 | 4.82E+07 |
| Terrestrial ecotoxicity | kg TEG soil | 7.19E+08 | 7.00E+08 | 8.89E+06 | 1.00E+07 |
| Terrestrial acid/nutri | kg $SO_2$ eq | 111,930.8 | 104,533.3 | 1,203.6 | 6,193.9 |
| Land occupation | m2org.arable | 1,341,402.4 | 1,325,461.8 | 2,500.4 | 13,440.2 |
| Aquatic acidification | kg $SO_2$ eq | 17,823.6 | 15,676.1 | 333.7 | 1,813.7 |
| Aquatic eutrophication | kg $PO_4$ P-lim | 1,125.2 | 1,014.2 | 37.2 | 73.7 |
| Global warming | kg $CO_2$ eq | 1.23E+06 | 8.69E+05 | 6.40E+04 | 3.00E+05 |
| Non-renewable energy | MJ primary | 2.19E+07 | 1.63E+07 | 8.59E+05 | 4.66E+06 |
| Mineral extraction | MJ surplus | 69,386.3 | 29,683.2 | 22,030.2 | 17,672.9 |

Figure 45 shows the share of each life cycle stage in the emission of equivalent substances in the different impact categories. The operational stage is the major environmental bearer in terms of percentage in all categories. The construction stage is relevant in the mineral extraction category while the refurbishment that would take place in the buildings is relevant for the ozone layer depletion category.

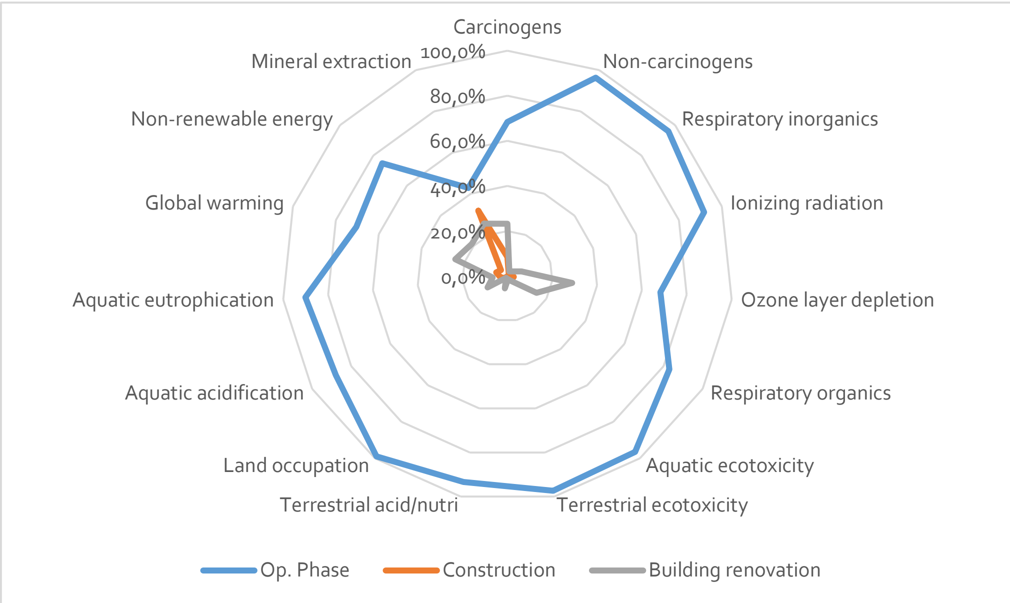



Figure 45. Characterization comparison between stages for Ranka LowTemp scenario.

The weighted damage assessment per area of concern is presented in Figure 46, displaying every single assembly considered for this parish. Human health is the most impacted area with 1.41 kPts, followed by ecosystem quality with 0.54 kPts. Operational phase is once again the activity with the largest impact.

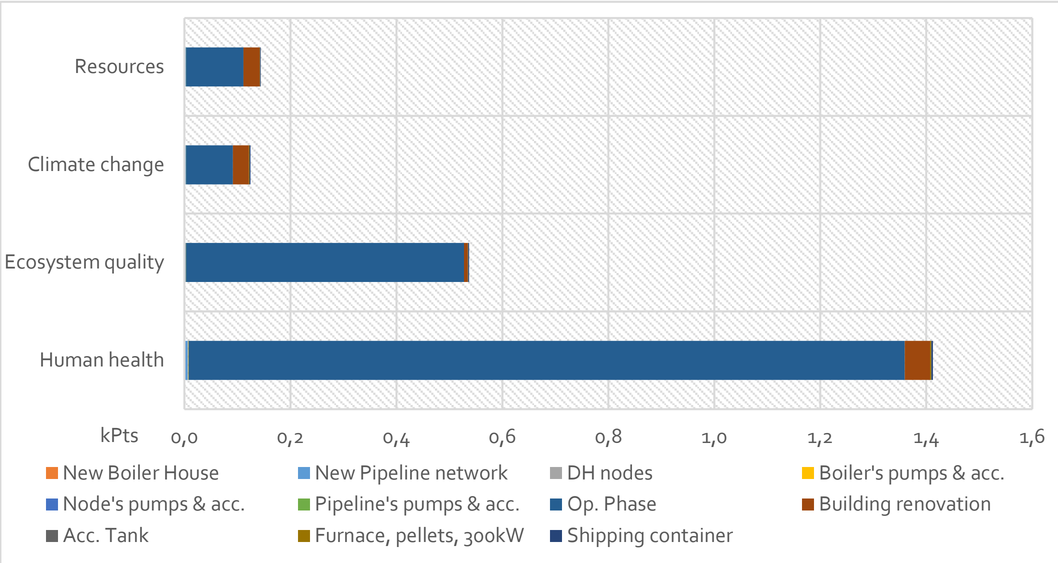



Figure 46. Damage assessment for Ranka LowTemp scenario.

# 7. LCIA DH comparison and conclusions

After performing LCIA for every single parish, scenarios were aggregated in two parts, 3GDH systems and the ones running under LowTemp profiles known as 4GDH systems. Table 21 shows the characterized results in terms of released equivalent substances or midpoint level.

TABLE 21. CHARACTERIZATION RESULTS COMPARISON BETWEEN DH TECHNOLOGIES

| Impact category | Unit | 3GDH | 4GDH |
|---|---|---|---|
| Carcinogens | kg C2H3Cl eq | 2,595,945 | 2,596,420 |
| Non-carcinogens | kg C2H3Cl eq | 12,830,261 | 12,268,175 |
| Respiratory inorganics | kg PM2.5 eq | 608,624 | 276,023 |
| Ionizing radiation | Bq C-14 eq | 1.28E+09 | 1.25E+09 |
| Ozone layer depletion | kg CFC-11 eq | 12.3 | 10.3 |

| | | | |
|---|---|---|---|
| Respiratory organics | kg C2H4 eq | 116,518 | 94,036 |
| Aquatic ecotoxicity | kg TEG water | 9.71E+10 | 9.25E+10 |
| Terrestrial ecotoxicity | kg TEG soil | 3.43E+10 | 3.26E+10 |
| Terrestrial acid/nutri | kg SO2 eq | 5,794,645 | 4,625,667 |
| Land occupation | m2org.arable | 95,823,050 | 40,678,584 |
| Aquatic acidification | kg SO2 eq | 950,161 | 802,406 |
| Aquatic eutrophication | kg PO4 P-lim | 91,312 | 89,408 |
| Global warming | kg CO2 eq | 85,935,081 | 74,669,357 |
| Non-renewable energy | MJ primary | 1.56E+09 | 1.38E+09 |
| Mineral extraction | MJ surplus | 6,846,417 | 7,056,832 |

Implementation of Low Temperature District Heating system has proven to have an overall environmental benefit in almost all categories. Exception are the *carcinogens and mineral extraction*, where the increase related to the development of a 4GDH system is in the order of 0.02% and 2.98% respectively. On the other hand, the *respiratory inorganics* category shows a 54.65% reduction, *Respiratory organics* and *Terrestrial acidity* have a 20% reduction and *land occupation* category has the largest decrease with a reduction in the required area for extracting raw materials of 55,144,466 square meters, and a 57.55% drop. The changes per impact category can be seen in Figure 47.

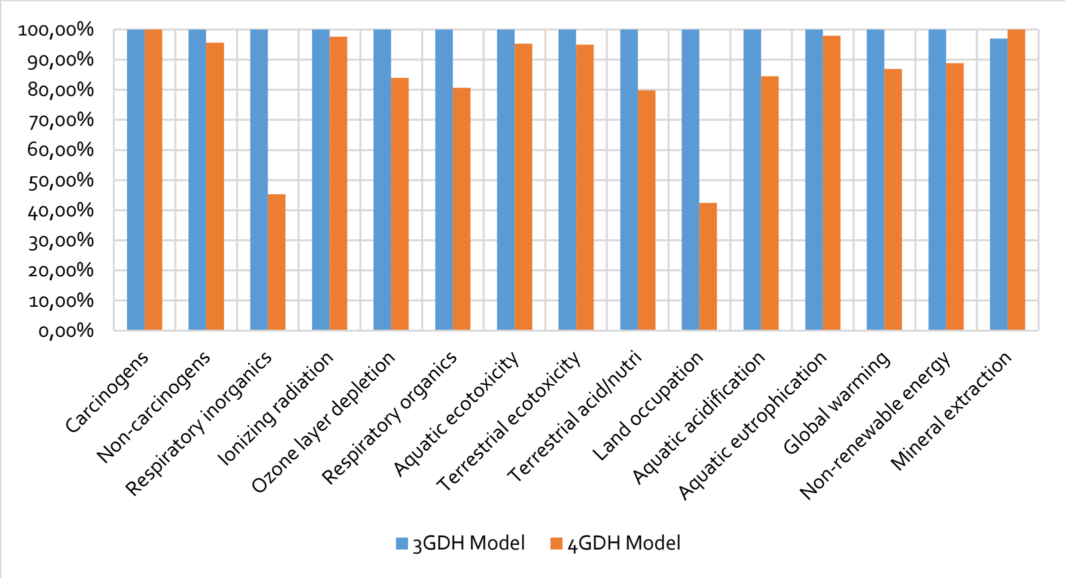



Figure 47. Characterization comparison between impact categories.

The difference at endpoint categories, or areas of concern, is shown in Figure 48. For human health area, which is has the highest environmental impact in the LCIA results per parish in the previous section, the reduction of moving from a 3GDH to a 4GDH system, is 50%. The total environmental score for human health area under the current conditions in Gulbene region, is 66.24 kPts for the analyzed FU, while under a 4GDH system the resulting score is 33.18 kPts.

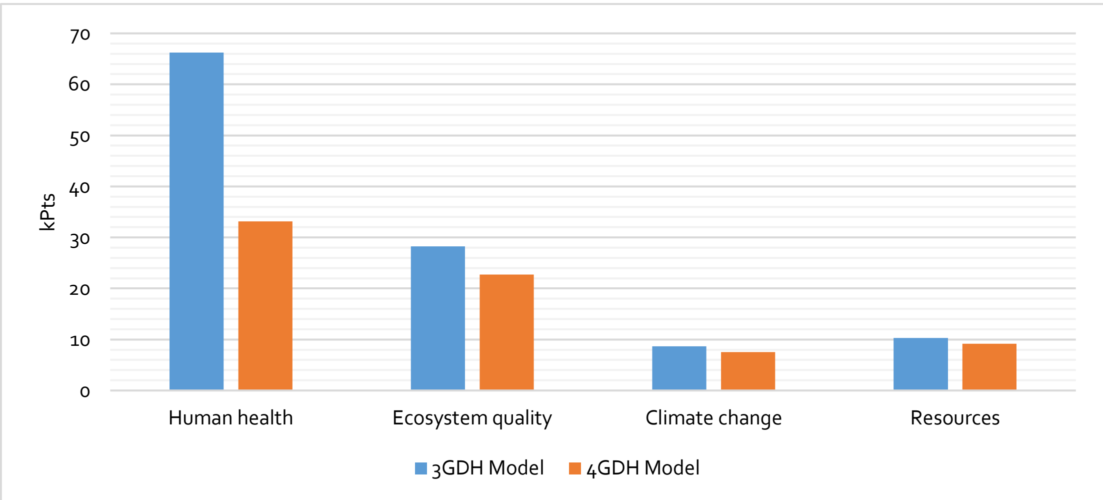
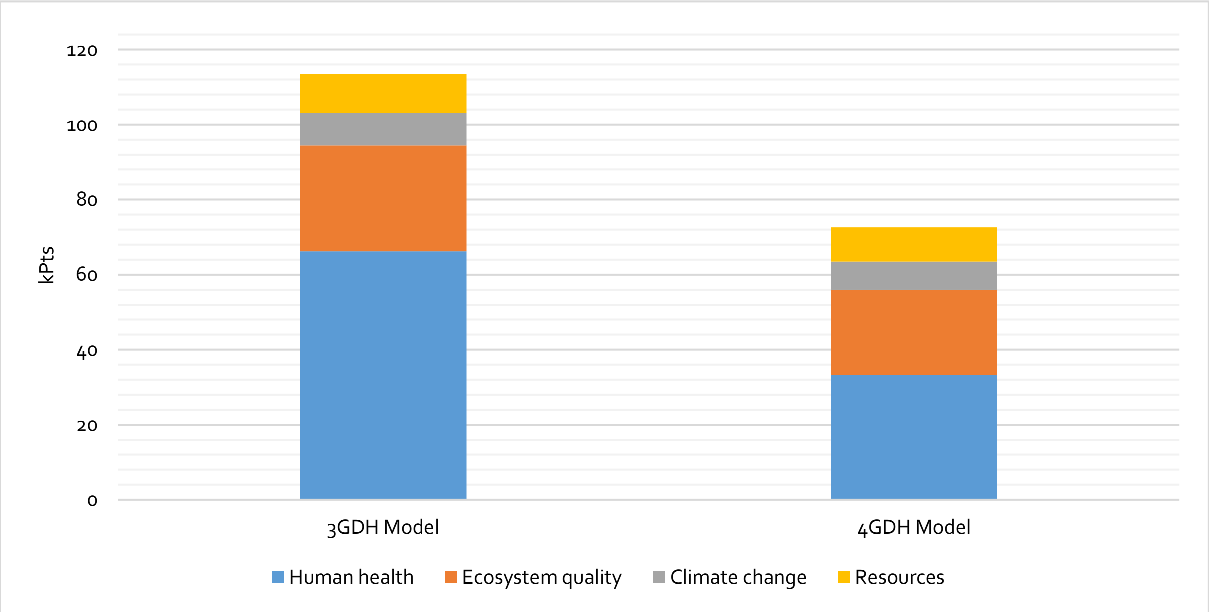



Figure 48. Weighted damage assessment comparison at end point categories.

Finally, the total single score for each model is plotted in Figure 49, where the aggregated results at each area of concern are presented. The 3GDH system gives a total score of 113.45 kPts, and the 4GDH system 72.62 kPts, showing a total reduction of 4.83 kPts, representing an environmental impact reduction of 36%.

The environmental benefit of implementing low temperature district heating systems comes mainly from the reduction in the amount of fuel required for operation and from moving from fossil non-renewable energy resources towards renewable, such as biomass for this case. The use of renewable energy is the key aspect in 4GDH systems, since the use of fossil fuels even for a low temperature




scenario might result in higher damage values to the resources and climate change areas than in systems where thermal energy is 100% provided from biomass.

Figure 49. Single score comparison between models.

The building refurbishment activity is another aspect to pay special attention. The amount of materials required to lower the specific heat consumption per area, depends on the current building insulation condition. If the area to refurbish is to large, and the initial specific heat consumption value is also high, the environmental impact from this activity could be quite large, even larger than the DH system construction itself, as seen in the LowTemp scenarios for some parishes..

# 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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Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

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Annex 1

## ITEM INVENTORY FOR OLD BOILER HOUSE CONSTRUCTION

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *313.3* | *kg* |
| *Steel, chromium steel 18/8 {GLO}\| market for \| APOS, U* | *390.1* | *kg* |
| *Sand {GLO}\| market for \| APOS, U* | *14* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *23* | *kg* |
| *Brass {CH}\| market for brass \| APOS, U* | *0.4* | *kg* |
| *Stone wool {GLO}\| market for stone wool \| APOS, U* | *1059.7* | *kg* |
| *Polyethylene, low density, granulate {GLO}\| market for \| APOS, U* | *5* | *kg* |
| *Exhaust air outlet, steel/aluminium, 85x365 mm {GLO}\| market for \| APOS, U* | *4* | *p* |
| *Ventilation duct, elbow 90 degrees, steel, 100x50 mm {GLO}\| market for \| APOS, U* | *5* | *p* |
| *Room-connecting overflow element, steel, approx. 40 m3/h {GLO}\| market for \| APOS, U* | *1* | *p* |
| *Ventilation duct, steel, 100x50 mm {GLO}\| market for \| APOS, U* | *5* | *p* |
| *Ventilation duct, connection piece, steel, 100x50 mm {GLO}\| market for \| APOS, U* | *1* | *p* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \| APOS, U* | *313.3* | *kg* |
| *Metal working, average for chromium steel product manufacturing {GLO}\| market for \| APOS, U* | *390.1* | *kg* |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *23.4* | *kg* |

## ITEM INVENTORY FOR NEW BOILER HOUSE CONSTRUCTION

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|

| | | |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *113.3* | *kg* |
| *Steel, chromium steel 18/8 {GLO}\| market for \| APOS, U* | *390.1* | *kg* |
| *Concrete, sole plate and foundation {CH}\| market for \| APOS, U* | *4.2* | *m3* |
| *Sand {GLO}\| market for \| APOS, U* | *14* | *kg* |
| *Polyurethane, rigid foam {GLO}\| market for \| APOS, U* | *21.5* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *23* | *kg* |
| *Brass {CH}\| market for brass \| APOS, U* | *0.4* | *kg* |
| *Stone wool {GLO}\| market for stone wool \| APOS, U* | *1040* | *kg* |
| *Flat glass, coated {GLO}\| market for \| APOS, U* | *4* | *kg* |
| *Alkyd paint, white, without solvent, in 60% solution state {RER}\| market for alkyd paint, white, without solvent, in 60% solution state \| APOS, U* | *3.6* | *kg* |
| *Polyethylene, low density, granulate {GLO}\| market for \| APOS, U* | *5* | *kg* |
| *Exhaust air outlet, steel/aluminium, 85x365 mm {GLO}\| market for \| APOS, U* | *4* | *p* |
| *Ventilation duct, elbow 90 degrees, steel, 100x50 mm {GLO}\| market for \| APOS, U* | *5* | *p* |
| *Room-connecting overflow element, steel, approx. 40 m3/h {GLO}\| market for \| APOS, U* | *1* | *p* |
| *Ventilation duct, steel, 100x50 mm {GLO}\| market for \| APOS, U* | *5* | *p* |
| *Ventilation duct, connection piece, steel, 100x50 mm {GLO}\| market for \| APOS, U* | *1* | *p* |
| *Insulation spiral-seam duct, rockwool, DN 400, 30 mm {GLO}\| market for \| APOS, U* | *4.95* | *m* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \| APOS, U* | *113.3* | *kg* |
| *Metal working, average for chromium steel product manufacturing {GLO}\| market for \| APOS, U* | *390.1* | *kg* |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *23.4* | *kg* |

| | | |
|---|---|---|
| *Polymer foaming {GLO}\| market for \| APOS, U* | *21.5* | *kg* |
| *Extrusion, plastic pipes {GLO}\| market for \| APOS, U* | *3.6* | *kg* |

### ITEM INVENTORY FOR SOLAR PLANT CONSTRUCTION

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Photovoltaic panel, multi-Si wafer {GLO}\| market for \| APOS, U* | *1000* | *m2* |
| *Electronic component, active, unspecified {GLO}\| market for \| APOS, U* | *462* | *kg* |
| *Inverter, 2.5kW {GLO}\| market for \| APOS, U* | *36.4* | *p* |
| *Steel, unalloyed {RoW}\| steel production, converter, unalloyed \| APOS, U* | *2045.8* | *kg* |
| *Cable, three-conductor cable {GLO}\| market for \| APOS, U* | *2818.7* | *m* |
| *Electric connector, wire clamp {GLO}\| market for \| APOS, U* | *72.7* | *kg* |
| **Processes** | **Amount** | **Unit** |
| *Photovoltaic plant, electric installation for 3kWp module {GLO}\| market for photovoltaics, electric installation for 3kWp module, at building \| APOS, U* | *55* | *p* |

### ITEM INVENTORY FOR DH NODES CONSTRUCTION

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *256.8* | *kg* |
| *Stone wool {GLO}\| market for stone wool \| APOS, U* | *1806.3* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *132* | *kg* |
| *Copper {GLO}\| market for \| APOS, U* | *9* | *kg* |
| *Brass {RoW}\| market for brass \| APOS, U* | *61.6* | *kg* |
| *Alkyd paint, white, without water, in 60% solution state {RER}\| market for alkyd paint, white, without water, in 60% solution state \| APOS, U* | *4.8* | *kg* |
| *Cable, ribbon cable, 20-pin, with plugs {GLO}\| market for \| APOS, U* | *15* | *kg* |
| | | |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \|* | *256.8* | *kg* |

| | | |
|---|---|---|
| *APOS, U* | | |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *132* | *kg* |
| *Metal working, average for copper product manufacturing {GLO}\| market for \| APOS, U* | *9* | *kg* |
| *Welding, arc, steel {GLO}\| market for \| APOS, U* | *0.3* | *m* |

### ITEM INVENTORY FOR CURRENT DH PIPELINES CONSTRUCTION

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *18502.5* | *kg* |
| *Stone wool {CH}\| stone wool production \| APOS, U* | *468.2* | *kg* |
| *Polyethylene, low density, granulate {GLO}\| market for \| APOS, U* | *3561.3* | *kg* |
| *Concrete block {GLO}\| market for \| APOS, U* | *2901* | *kg* |
| *Sand {GLO}\| market for \| APOS, U* | *323.5* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *283* | *kg* |
| *Copper {GLO}\| market for \| APOS, U* | *15* | *kg* |
| *Bitumen adhesive compound, cold {GLO}\| market for \| APOS, U* | *10* | *kg* |
| *Acrylic varnish, without water, in 87.5% solution state {RER}\| market for acrylic varnish, without water, in 87.5% solution state \| APOS, U* | *9.6* | *kg* |
| *Gravel, crushed {RoW}\| market for gravel, crushed \| APOS, U* | *570.2* | *kg* |
| *Mastic asphalt {GLO}\| market for \| APOS, U* | *6733.8* | *kg* |
| *Cable, three-conductor cable {GLO}\| market for \| APOS, U* | *10* | *m* |
| *Concrete, sole plate and foundation {RoW}\| market for \| APOS, U* | *0.2* | *m3* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \| APOS, U* | *18502.5* | *kg* |
| *Extrusion, plastic pipes {GLO}\| market for \| APOS, U* | *3561.3* | *kg* |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *283* | *kg* |



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|---|---|---|
| *Metal working, average for copper product manufacturing {GLO}\| market for \| APOS, U* | *15* | *kg* |
| *Welding, arc, steel {GLO}\| market for \| APOS, U* | *6.4* | *m* |
| *Excavation, hydraulic digger {GLO}\| market for \| APOS, U* | *515* | *m3* |

**ITEM INVENTORY FOR NEW DH PIPELINES CONSTRUCTION**

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *10639.4* | *kg* |
| *Polyurethane, rigid foam {RoW}\| market for polyurethane, rigid foam \| APOS, U* | *816.8* | *kg* |
| *Polyethylene, low density, granulate {GLO}\| market for \| APOS, U* | *2038.7* | *kg* |
| *Concrete block {GLO}\| market for \| APOS, U* | *2901* | *kg* |
| *Sand {GLO}\| market for \| APOS, U* | *323.5* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *283* | *kg* |
| *Copper {GLO}\| market for \| APOS, U* | *15* | *kg* |
| *Bitumen adhesive compound, cold {GLO}\| market for \| APOS, U* | *10* | *kg* |
| *Acrylic varnish, without water, in 87.5% solution state {RER}\| market for acrylic varnish, without water, in 87.5% solution state \| APOS, U* | *7.2* | *kg* |
| *Gravel, crushed {RoW}\| market for gravel, crushed \| APOS, U* | *570.2* | *kg* |
| *Mastic asphalt {GLO}\| market for \| APOS, U* | *6733.8* | *kg* |
| *Cable, three-conductor cable {GLO}\| market for \| APOS, U* | *5* | *m* |
| *Concrete, sole plate and foundation {RoW}\| market for \| APOS, U* | *0.2* | *m3* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \| APOS, U* | *10639.4* | *kg* |
| *Polymer foaming {GLO}\| market for \| APOS, U* | *816.8* | *kg* |
| *Extrusion, plastic pipes {GLO}\| market for \| APOS, U* | *2038.7* | *kg* |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *283* | *kg* |

| | | |
|---|---|---|
| *Metal working, average for copper product manufacturing {GLO}\| market for \| APOS, U* | *15* | *kg* |
| *Welding, arc, steel {GLO}\| market for \| APOS, U* | *6.4* | *m* |
| *Excavation, hydraulic digger {GLO}\| market for \| APOS, U* | *515* | *m3* |

### ITEM INVENTORY FOR BOILE'S PUMPS, TAPS AND OTHER ACCESSORIES

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, chromium steel 18/8 {GLO}\| market for \| APOS, U* | *188.6* | *kg* |
| *Polyethylene, high density, granulate {GLO}\| market for \| APOS, U* | *17.4* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *13* | *kg* |
| *Brass {CH}\| market for brass \| APOS, U* | *23.3* | *kg* |
| *Flat glass, coated {GLO}\| market for \| APOS, U* | *4* | *kg* |
| *Battery cell, Li-ion {GLO}\| market for \| APOS, U* | *1.8* | *kg* |
| *Electronics, for control units {GLO}\| market for \| APOS, U* | *8.8* | *kg* |
| *Polyethylene, low density, granulate {GLO}\| market for \| APOS, U* | *5* | *kg* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for chromium steel product manufacturing {GLO}\| market for \| APOS, U* | *188.6* | *kg* |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *36.3* | *kg* |
| *Thermoforming, with calendering {GLO}\| market for \| APOS, U* | *17.4* | *kg* |
| *Injection moulding {GLO}\| market for \| APOS, U* | *5* | *kg* |

### ITEM INVENTORY FOR NODE'S PUMPS, TAPS AND OTHER ACCESSORIES

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *72* | *kg* |
| *Steel, chromium steel 18/8 {GLO}\| market for \| APOS, U* | *79.2* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *132* | *kg* |

| | | |
|---|---|---|
| *Brass {RoW}\| market for brass \| APOS, U* | *56.5* | *kg* |
| *Electronics, for control units {GLO}\| market for \| APOS, U* | *13.8* | *kg* |
| *Polyurethane, rigid foam {RoW}\| market for polyurethane, rigid foam \| APOS, U* | *1.2* | *kg* |
| *Copper {GLO}\| market for \| APOS, U* | *0.8* | *kg* |
| *Stone wool {GLO}\| market for stone wool \| APOS, U* | *1805.1* | *kg* |
| *Polyethylene, high density, granulate {GLO}\| market for \| APOS, U* | *0.4* | *kg* |
| *Cable, ribbon cable, 20-pin, with plugs {GLO}\| market for \| APOS, U* | *15* | *kg* |
| *Battery cell, Li-ion {GLO}\| market for \| APOS, U* | *0.1* | *kg* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \| APOS, U* | *84* | *kg* |
| *Metal working, average for chromium steel product manufacturing {GLO}\| market for \| APOS, U* | *79.2* | *kg* |
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *144.3* | *kg* |
| *Polymer foaming {GLO}\| market for \| APOS, U* | *1.2* | *kg* |
| *Metal working, average for copper product manufacturing {GLO}\| market for \| APOS, U* | *0.8* | *kg* |

## ITEM INVENTORY FOR PIPELINE'S PUMPS, TAPS AND OTHER ACCESSORIES

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Steel, low-alloyed {GLO}\| market for \| APOS, U* | *33* | *kg* |
| *Cast iron {GLO}\| market for \| APOS, U* | *12* | *kg* |
| *Cable, three-conductor cable {GLO}\| market for \| APOS, U* | *5* | *m* |
| *Electronics, for control units {GLO}\| market for \| APOS, U* | *0.5* | *kg* |
| **Processes** | **Amount** | **Unit** |
| *Metal working, average for steel product manufacturing {GLO}\| market for \| APOS, U* | *33* | *kg* |

| | | |
|---|---|---|
| *Metal working, average for metal product manufacturing {GLO}\| market for \| APOS, U* | *12* | *kg* |

### ITEM INVENTORY FOR GULBENE OPERATIONAL PHASE (3GDH SCENARIO)

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Wood chips, dry, measured as dry mass {RER}\| market for \| APOS, U* | *9938.7* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *783* | *MWh* |
| *Heat, district or industrial, other than natural gas {CH}\| heat production, softwood chips from forest, at furnace 1000kW, state-of-the-art 2014 \| APOS, U* | *31307* | *MWh* |
| *Electricity, low voltage {LV}\| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted \| APOS, U* | *162* | *MWh* |

### ITEM INVENTORY FOR GULBENE OPERATIONAL PHASE (4GDH SCENARIO)

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Wood chips, dry, measured as dry mass {RER}\| market for \| APOS, U* | *9608.6* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *908* | *MWh* |
| *Heat, district or industrial, other than natural gas {CH}\| heat production, softwood chips from forest, at furnace 1000kW, state-of-the-art 2014 \| APOS, U* | *30267* | *MWh* |
| *Electricity, low voltage {LV}\| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted \| APOS, U* | *162* | *MWh* |

### ITEM INVENTORY FOR STARI OPERATIONAL PHASE (3GDH SCENARIO)

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Roundwood, parana pine from sustainable forest management, under bark {GLO}\| market for \| APOS, U* | *1194* | *m3* |
| | | |

| Processes | Amount | Unit |
|---|---|---|
| *Heat, district or industrial, other than natural gas {CH}\| heat production, hardwood chips from forest, at furnace 300kW \| APOS, U* | *900* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *23.1* | *MWh* |

## ITEM INVENTORY FOR STARI OPERATIONAL PHASE (4GDH SCENARIO)

| Material/Assemblies in SimaPro | Amount | Unit |
|---|---|---|
| *Wood pellet, measured as dry mass {RER}\| market for wood pellet \| APOS, U* | *158* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, softwood chips from forest, at furnace 300kW, state-of-the-art 2014 \| APOS, U* | *612* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *6* | *MWh* |

## ITEM INVENTORY FOR LITENE OPERATIONAL PHASE (3GDH SCENARIO)

| Material/Assemblies in SimaPro | Amount | Unit |
|---|---|---|
| *Wood pellet, measured as dry mass {RER}\| market for wood pellet \| APOS, U* | *152* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, softwood chips from forest, at furnace 300kW \| APOS, U* | *587* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *7.2* | *MWh* |

## ITEM INVENTORY FOR LITENE OPERATIONAL PHASE (4GDH SCENARIO)

| Material/Assemblies in SimaPro | Amount | Unit |
|---|---|---|
| *Wood pellet, measured as dry mass {RER}\| market for wood pellet \| APOS, U* | *118* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, softwood chips from forest, at furnace 300kW \| APOS, U* | *458* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *6* | *MWh* |

### ITEM INVENTORY FOR LEJASCIEMS OPERATIONAL PHASE (3GDH SCENARIO)

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Roundwood, parana pine from sustainable forest management, under bark {GLO}\| market for \| APOS, U* | *1578* | *m3* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, hardwood chips from forest, at furnace 1000kW \| APOS, U* | *1656* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *38.9* | *MWh* |

### ITEM INVENTORY FOR LEJASCIEMS OPERATIONAL PHASE (4GDH SCENARIO)

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Wood pellet, measured as dry mass {RER}\| market for wood pellet \| APOS, U* | *275* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, softwood chips from forest, at furnace 300kW \| APOS, U* | *1063* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *10.63* | *MWh* |

### ITEM INVENTORY FOR LIZUMS OPERATIONAL PHASE (3GDH SCENARIO)

| **Processes** | **Amount** | **Unit** |
|---|---|---|
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, hardwood chips from forest, at furnace 1000kW \| APOS, U* | *2095* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *102.7* | *MWh* |

### ITEM INVENTORY FOR LIZUMS OPERATIONAL PHASE (4GDH SCENARIO)

| **Processes** | **Amount** | **Unit** |
|---|---|---|
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, hardwood chips from forest, at furnace 1000kW \| APOS, U* | *1186* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *23.72* | *MWh* |

### ITEM INVENTORY FOR GALGAUSKA OPERATIONAL PHASE (3GDH SCENARIO)

| Material/Assemblies in SimaPro | Amount | Unit |
|---|---|---|
| *Roundwood, parana pine from sustainable forest management, under bark {GLO}\| market for \| APOS, U* | *950* | *m3* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, hardwood chips from forest, at furnace 300kW \| APOS, U* | *926* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *13.9* | *MWh* |

### ITEM INVENTORY FOR GALGAUSKA OPERATIONAL PHASE (4GDH SCENARIO)

| Material/Assemblies in SimaPro | Amount | Unit |
|---|---|---|
| *Wood pellet, measured as dry mass {RER}\| market for wood pellet \| APOS, U* | *188* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, softwood chips from forest, at furnace 300kW \| APOS, U* | *728* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *10.9* | *MWh* |

### ITEM INVENTORY FOR RANKA OPERATIONAL PHASE (3GDH SCENARIO)

| Material/Assemblies in SimaPro | Amount | Unit |
|---|---|---|
| *Wood chips, dry, measured as dry mass {RER}\| market for \| APOS, U* | *480* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, hardwood chips from forest, at furnace 300kW \| APOS, U* | *1159* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *17.4* | *MWh* |

ITEM INVENTORY FOR RANKA OPERATIONAL PHASE (4GDH SCENARIO)

| **Material/Assemblies in SimaPro** | **Amount** | **Unit** |
|---|---|---|
| *Wood pellet, measured as dry mass {RER}\| market for wood pellet \| APOS, U* | *209* | *ton* |
| **Processes** | **Amount** | **Unit** |
| *Heat, district or industrial, other than natural gas {RoW}\| heat production, hardwood chips from forest, at furnace 300kW \| APOS, U* | *807* | *MWh* |
| *Electricity, medium voltage {LV}\| market for \| APOS, U* | *8.1* | *MWh* |