Life Cycle Assessment (LCA) of the pilot measure in Beļava Parish in Gulbene Municipality (Latvia)

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Nomenclature

π	The ratio of the circumference of a circle to its diameter	
ρ	Density of pipeline material	kg/m^3
η	Boiler efficiency for fuel frequency factor	%
B	Fuel consumption for fuel i	tons per year
l	Length of pipeline	m
Q_i	Produced heat	MWh per year
Q_{zd}	Lowest calorific value for fuel i	MWh/tons per year
R	Outer radius of pipeline material n	m
r	Inner radius of pipeline material n	m
V	Volume of pipeline material n	m^3

Abstract

Sustainable heating solutions involving renewable energy sources and low supply/return temperatures for district heating are evolving. Low temperature use in district heating allows to reduce the heating operation costs significantly and at the same time contributes to sustainability criteria. However, in-depth studies on environmental impacts of the life cycle of low temperature district heating are still lacking both from data inventory and methodological approach perspective. This study aims to implement Life Cycle Assessment (LCA) methodology to evaluate the overall environmental feasibility of different scenarios of implementing local low temperature district heating solutions. For this purpose, a LCA-based methodology adopts life cycle analysis approach for assessing the environmental impacts according to a set of selected environmental performance criteria. The results of the study specifically addressed to the Pilot measures implemented in Beļava Parish in Gulbene Municipality showed an improvement in the overall environmental performance towards the transition of a conventional 3rd generation district heating to low temperature concept, including the effects of reconstruction and modernisation of the boiler house. Specifically, the scenario implementing low temperature district heating with solar PV showed the best score as environmental performance. The scenario with the implementation of low temperature district heating without solar PV did not show significant improvement in environmental performance under operation conditions of a pilot case study.

1. DH in the Context of Sustainability

Sustainable heating solutions have evolved over the last decades at European level [1]. Such solutions require an increase of the utilisation of renewable energy sources (RES) for district heating (DH) purposes [2]–[5], that will contribute to reductions in fossil energy use [4] and to decrease environmental impacts of DH by cutting CO2 emissions [5]. According to Connolly et al. [6], estimates on DH and renewable heat potentials in European Union member states for 2030 and 2050, heating and cooling costs can be reduced by 15 %, which equals to approximately EUR 100 billion per year. Besides increasing utilisation of Renewable Energy Sources (RES), another essential challenge for sustainable heating is making use of low temperatures in DH.

Low temperature district heating (LTDH) systems in future smart energy systems can lower energy losses, utilise excess industrial heat, balance the renewable energy in the electricity grid and have strong economic potential if adequately implemented [2].

A best-case practice of LTDH implementation is the DH of Helsinki. This DH distribution network includes a combined heat and power (CHP) unit, solar collectors, boilers and heat pumps. The results of such study show that the change of supply temperature from a range of 80 °C to 110 °C to a constant supply temperature of 65 °C improves system performance in terms of cost and emission reductions [7]. Aforetime estimations on low temperature district heating (LTDH) showed a possible reduction of heat loss by 75 % comparing with medium temperature DH system [8]. Imran et al. [9] in addition to heat losses mentioned other possible benefits like reduction of boiling risk, reduced thermal stress on materials along the pipeline, utilisation of thermal storage to handle peak loads without oversizing equipment, improving heat to steam ratio in steam CHP system to extract more power of the turbine.

According to Imran et al. [9], for the implementation of low supply and return temperatures, customer substations and secondary heating systems must perform without temperature faults and continuous commissioning is necessary to detect temperature faults without delays. With the help of the latest automatic metering systems fault detection has changed from being slow and expensive to become fast and inexpensive and thus more efficient DH systems with low supply and return temperatures can be put into practice [10]. Such systems match general sustainability criteria as they bring positive environmental and economic net gains. However, the interpretation of such criteria can differ depending on the needs of policy planning and decision making. Therefore, in this study, the existing methods for sustainability and environmental impact assessment of DH are reviewed to substantiate the need for Life Cycle Assessment (LCA) on a pilot case study of DH to find the best solutions for the development of LTDH from the environmental performance perspective.

2. District heating environmental impact metrics

2.1. Sustainability and environmental impact assessment of DH

Among all the available methods to determine the environmental impacts in the energy sector most used is Global Warming Potential (GWP) enhancing Climate Change in terms of CO_2 equivalent of all Green House Gases (GHG) [11], [12]. However, referring only to GWP reduction, as the only sustainability criteria, it could be misleading. Other environmental impacts can play a relevant role in the assessment of the environmental profile of the DH operational system and because carbon dioxide emissions only partly are addressed to climate change. For cases when biomass is handled as carbon-neutral fuel without considering a variation of carbon stock over time [13], other pollutants like SOx, NOx and particulate matters would give more in-depth insight about the overall environmental performance of the system [14], [15], not directly linked to the GWP.

Caputo et al. [16] in his study in addition to the emissions from DH used primary fossil fuel energy savings as an indicator to determine the environmental performance of DH in different scenarios and in this way included in his assessment the impact of DH system on resource depletion. Similar savings of primary fossil fuel energy, the exergy method is used to determine more efficient ways of energy resource use [17]. The exergy concept meets environmental constraints in terms of irreversibility or lost work due to system performance [18]. The work of Baldvinsson et al. [19] presents a case study on DH with biomass CHP in North Japan. This study highlights a high exergy efficiency of low temperature operation in DH due to the high quality of electricity because lower network temperature helps to achieve lower primary energy consumption and higher electricity generation in a CHP plant. Similarly, this concept was also underlined by [9].

Yazici [20] found that a lower network temperature provides the least primary energy consumption reducing electricity generation of CHP plant and overall energy losses. Indeed energy losses occur mainly because of the heat carrier, the heat exchanger losses, losses due to pumps and pipeline that could account of 15.94 %, 12.44 %, 5.52 % and 5.52 % respectively. However, these are only the internal indicators of a system, which do not show the external effects linked to specific pilot case conditions, for example of marginal electricity mix that can affect environmental and sustainability performance of the studied system.

Laukkanen et al. [21] in this study used Primary Exergy Analysis (PeXa) method, which combines Primary Energy Efficiency and Exergy Analysis. The main difference from exergy analysis is that PeXa considers the system exergetic values of the products, while exergy considers only the products produced in the studied process. Thus PeXa addresses also the external effects. Laukkanen et al. also suggested that PeXa method should be developed further to assess multi-product processes and with other factor calculation like CO_2 emissions can also be used to analyse the life cycle of a processor product by including the total production system into the model. Kouhia et al. [13] proceeded in that direction by studying PeXa factor with a variance of parameters that influence DH design, minimum CO_2 emissions, including maximum profit and minimum exergy losses. The study suggested considering metrics for sustainability that can include more externalities.

Andric et al. [22] introduced the concept of externalities using an energy approach to assess three different DH network types with three types of heat production options:

1. DH with central boiler running on different fuels (biofuels, petroleum, light fuel oil, landfill gas);

2. Central solar plant with thermal storage;

3. Natural gas boilers.

For all the systems tested, the operation phase is the main contributor to total environmental impact and therefore including the RES into DH would help to decrease these impacts. Even though the energy approach addresses the construction of a system and usage phase of products, which are the same steps as in LCA approach, the background of energy can be dubious. The basic idea behind energy approach is that product or service is more sustainable when more energy is available for further transformations of this product or service. Hence, the energy is defined as the available energy of one form that is used up in transformations directly and indirectly to make a product or a service. Energy gives a measure to the work of the environment that would be needed to replace what is consumed in different phases of a system's life cycle [23].

Coss et al. [24] stated that policy strategies that focus only on one criterion, like environmental or economic targets only, do not seem useful for a sustainable energy system design. Ther reason is lying on the multi-dimensional nature of sustainability is not taken into account. A holistic design approach should include an energy approach for environmental performance assessment in a multi-objective performance assessment together with levelized costs of providing energy by heating plant for economic and total system efficiency for technological assessment. After applying this methodology to a case study, he concluded that the link between minimising energy and maximising equipment efficiency is always depend by the type of different of fuels and the working loads of equipments. This evidence showed that the energy approach does not always provide the best solution from the energy efficiency point of view and thus should be used together with other relevant criteria for energy efficiency. At the same time, the drawback of using an energy approach as standalone criteria is that it is too much holistic from the environmental point of view. The effects of human activities on natural systems are defined in common "energy units" [25], and there is no insight on specific impacts on ecosystem quality and human's health.

In this context, LCA can give more insight into the decision making of DH modernisation for more sustainable pathways by assessing many environmental impacts. None of the methods reviewed above can provide such extensive information on environmental impacts as LCA. Thus, for this study LCA approach is suggested and described in the methodology part of this study.

2.2. LCA of District Heating

For this study, existing LCA studies on DH infrastructure were reviewed to obtain the understanding of the current state-of-art of LCA on DH. A summary of reaserch studies found in literature over the last ten years is presented in Table 1 for comparison.

TABLE 1. SELECTION OF STUDIES PERFORMING LCA OF LCA

Author, year of study	Methodology	Subject of study	Software
Oliver-Sola, 2009 [26]	LCA ISO 14041 and 14042	DH infrastructure with a street section of 100 m, 10 blocks of 24 dwellings each	*Gabi 4*
Nitkiewicz, 2014 [27]	LCA ISO 14040	Low-temperature heating plant with electric heat pump, absorption heat pump and gas-fired boiler	*SimaPro* 7.3.2
Parajuli, 2014 [28]	LCA	District heat production in a straw fired CHP plant	*SimaPro* 7.3.3
Ivner, 2015 [29]	LCA ISO 14040	Industrial excess heat in DH system	*SimaPro* software and ENPAC tool
Sandvall, 2017 [30]	TIMES	Small-town, medium-sized and a large DH system with specific characteristics in terms of DH supply technologies and fuel use	TIMES_UH model
Bartolozzi, 2017 [31]	LCA ISO 14040 and 14044	Heating and cooling in a residential neighbourhood of 1000 inhabitants (equivalent to 250 apartments), located in Tuscany, Italy	*SimaPro* 8.02
Havukainen, 2018 [32]	LCA ISO 14040 and 14044	Small-scale CHP plant fired by forest biomass, located in the Saimaanharju, Taipalsaari, Finland	*GaBi* 6.0
Pericault, 2018 [33]	LCA and cost	System processes of five alternatives for water supply, sanitation and heating in a residential area in Gallivare, Sweden	*Open LCA*

The studies presented in Table 1 are made as case studies of a specific DH case or as a comparative study about the application of different technologies. The methodologies for LCA differ across the presented studies, but the most common methods remain LCA ISO standard. Latest studies employ LCA ISO standards 14040 and 14044. Two of the studies found have different methodologies: one applies TIMES method for CO_2 emission calculation with TIMES_UH model, another implements LCA and cost assessment with Open LCA software. The most popular software among reviewed studies is SimaPro.

One of the earliest studies found is by Oliver-Sola et al. [26], in which LCA was performed on DH systems. The study determined the environmental impacts of a DH infrastructure in an urban neighbourhood. The objective of the study was to identify which subsystems and components of a DH grid are the main contributors to the overall environment impact. The analysis of the study covered seven subsystems: power plant; main grid; auxiliary components of the main grid; trench works, service pipes, buildings and components of dwellings. Data was gathered from Ecoinvent 1.2 and PE Europe database. The data for components was averaged from based on a real DH network. The study applied CML 2 Baseline 2000 for the following impact categories: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity (HTP), ozone layer depletion (ODP), abiotic depletion (ADP). The selected functional unit for this study was neighbourhood infrastructure that serves to provide heat for satisfying the domestic requirements for space heating and sanitary hot water of standard family in 240 dwellings within a local urban neighbourhood for 50 years. The study did not include the energy consumption or heat losses during the use phase, and for transportation only local resource transportation was included. Results of the study showed that neighbourhood system that is the main contributor in four impact categories (49.4 % in EP, 59.5 % in GWP, 65.1 % in ODP, 44.8 % in ADP), while building system was a less relevant contribution. Urban planners and DH designers need to adequately evaluate strategies for environmental impact reduction to avoiding problem-shifting between life-cycle phases and all parts of DH systems. For this purpose, the LCA method is an appropriate tool. More studies since the work of Oliver-Sola et al. performed LCA of DH different in scope and scale. .

Nitkiewicz et al. [27] in the study of low temperature heat plant using an electric heat pump, absorption heat pump and a gas-fired boiler considered the seasonality of heat production and electricity generation reduction in CHP. The study evaluated the CHP efficiency and substituted the marginal electricity mix. In the analysed scenario, the characteristic temperature of DH network was 50/40 °C. Study boundaries included facility construction, fuel extraction, processing and transport, electricity generation and distribution for facility operation and facility operation itself. However, the study did not include information about DH network grid. The functional unit was chosen as the heating plant system with a given amount of heat to be delivered to meet local heat demand in the assumed average season. The study evaluated the life cycle impact with eco-indicator '99 in three damage categories: damage to human health, damage to ecosystem quality, damage to resources. Within this study was concluded that electrical heat pump with low efficiency could have a higher environmental impact than gas boiler in DH system.

A study of Ivner et al. [29] applied GWP100 method to evaluate the effect of the use of excess industrial heat in DH on GHG in future energy markets. The functional unit of 1 GJ heat delivered was used for this purpose. Study boundaries included resource extraction, fuel refining, fuel inputs and facility operation, electricity and heat distribution. Data were obtained from the Ecoinvent database, and the Swedish Environmental Research Institute for average estimations for heat production in Sweden, while ignoring the production losses. The study found that industrial excess heat utilisation through DH can be beneficial in some conditions and suggested that EU-policy should recommend the use of biomass for emission reduction.

Parajuli et al. [28] performed LCA of DH production in a straw fired CHP by using "Stepwise2006" lice cycle assessment method with a functional unit of 1 MJ of heat production to determine if straw for production of a CHP plant is better than in DH from a boiler. Study boundaries included the straw removal process, collection and preprocessing, conversion to heat and power, the substitution of marginal electricity. The study found that use of straw for substitution of marginal electricity has lower environmental impact compared to natural gas in GWP and NRE-use, but leads to higher AP, EPs.

For cradle-to-grave type LCA Bartolozzi et al. [31] applied the ILCD 2011 Midpoint method to evaluate the thermal energy supply for heating, sanitary hot water and cooling of residential buildings in DH with biomass energy and shallow geothermal energy scenarios in lifetime of 50 years. For smaller parts of DH, such as flow limiting devices and heat meters, lifetime of 15 years was considered. These scenarios were benchmarked according to centralised and decentralized natural gas use for heating and cooling scenarios. The functional unit refers to systems' performance (i.e. energy units per year). The study found that transportation of resources does not make a significant contribution because of short transport distances. Results confirmed that DH with combined with RES can improve carbon footprint and resource depletion of energy production system. Thus, the study suggested using RES in the form of biomass and shallow geothermal energy to decrease the impacts.

Havukainen et al. [32] in the study about different forest biofuel use and replacement of natural gas in small-scale combined heat and power plant used CML2001 assessment method with impact categories of GWP, AP and EP. The functional unit of 1MJ of produced energy was used. The study concluded that when using forest biomass instead of natural gas in energy production, the global climate impacts are reduced (excluding biogenic carbon), but still the local effects like AD and EP are higher. When biogenic carbon is considered in assessing the calculated climate benefit in terms of total emissions, ends up to reach 4–7 % over that of natural gas use because of the environmental impacts during their production, especially for pellets due to amount of electricity and heat required for their production. However, the study did not consider the transportation of gas from the extraction field.

The study of Pericault et al. [33] addressed LTDH as one alternative of different scenarios. The study included sewerage, freeze protection and heating solution for specific LCA related to heat production, drinking water production, sewage water treatment, transport to and from the residential area and transport within the residential area. The scenarios were compared by sustainability criteria in five categories: environmental, economy, social, health and safety, and technical. For the environmental assessment the energy efficiency (as of climate preservation in terms of GWP), material efficiency (as abiotic depletion potential of elements) were mainly considered. Study boundaries included processes related to the production, transport, construction, maintenance and use phase of the elements. Also, a sensitivity analysis of criteria weights was performed. The analysis showed that economic factor of affordability is the most sensitive criterion that can influence the results of the assessment, followed by material efficiency criterion, which was chosen as one of the environmental criteria and had relatively low weight compared to other indicators. The study suggested making integration of LTDH with sewer and water pipes in one trench from the perspective of costs. Such an approach would also score the highest for sustainability if DH source changed from biomass to shallow geothermal energy. The data for this study was gathered from European Life Cycle Database and Oekobaudat databases, environmental product declarations, scientific publications and personal communications with companies.

From the reviewed studies, the central aspect of applying LCA is the comprehensive scope that this methodology can capture for system performance assessment. These studies help to determine which factors are crucial to consider in further work and gaps that are yet to be filled. Based on this information, the current study will aim to investigate optimal solutions applying the LCA method for the LTDH system developed in the Parish of Beļava (Gulbene, Latvia).

2.3. Case Study of LTDH

This study adopts the LCA methodology for a pilot case study of LTDH located in the eastern part of Latvia, namely in the Beļava parish situated in the municipality of Gulbene [34]. This investogated pilot measure aims to reconvert an existing heating network to a low temperature concept. In the former DH, heat was produced in a boiler house from firewood, which according to Sneum et al. [35] is one of the more competitive way of producing heat than electric boilers in context of the Baltic states.

For the particular pilot, the DH network has been optimised in order to increase the overall heat density and system efficiency. Before the reconstruction (existing heating network in Fig. 1) in total nine buildings were connected to DH with a total heating area of 4067 m2. After the reconstruction, only five buildings (3501 m^2 out of 4067 m^2) are connected to DH system from which thee buildings are renovated. Therefore, it is assumed that the installed heating surfaces in the building would be sufficient to provide necessary indoor climate conditions with lower heat supply temperature. For optimal design and modernisation of DH, the reconstruction of old DH includes reduction of DH pipeline length from 917 m to 491 m, change of DH node components such as valves and pumps, change of pipelines, boiler house, firewood boiler and its components to pellet boiler, and thus increase of heat production efficiency. The realised pilot is reported in Fig.1 and described in the section 3.2.

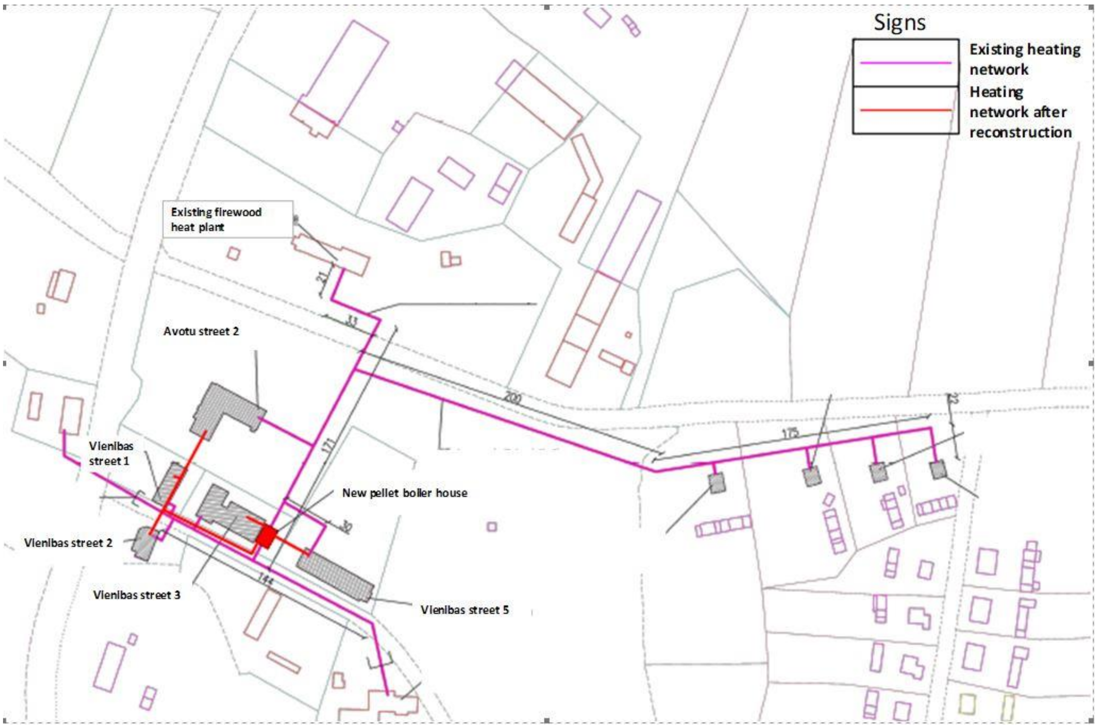

Figure 1. Analysed DH network before and after reconstruction [34].

For insulation of pipelines in old DH stone wool is used, while in new DH pipelines polyurethane foam insulation from industrial production is used. The new boiler house consists of a modular container where a wood pellet boiler produces the heat by an automatic silo and storage area. The old boiler house did not have a storage area or silo. A firewood boiler was producing the heat.

The design of the pilot project considers efficiency gains from the reconstruction of the heating network, change of boiler and the reduction of supply and return water temperature from 90/60 °C to

60/35 °C. Similar aspects are found in the study of Park et al. [36]. The authors highlight that a temperature of 60/35 °C avoids a significant increase in pumping power and domestic hot water heat exchanger costs. For supply and return temperature decrease, findings in the literature address beneficial in terms of reduction of heat loss, reduced pumping power, improved domestic hot water heat exchanger and lower operation costs. The change in power consumption for pumping due to temperature decrease in DH can differ depending on the system. Flores et al. [37] in a study on load impacts of LTDH connected to conventional DH network for case of Stockholm, Sweden, found that the impact of LTDH with operating conditions 55.2/30.1 °C in convention DH network with operating conditions 81.7/46.3 °C decrease relative pumping power. Another case study on DH in Sweden found that decrease of temperature from 80/40 °C to 65/30 °C and 50/20 °C increase the electricity consumption for pumps in DH in the case of reduced supply and return temperature. According to Kauko et al. [38], such an increase of electricity demand for recirculation flow due to the decrease in temperatures in DH will be meagre. Moreover, in the case study, the difference between supply and return temperatures did not change. Thus the LCA study considers that the electricity consumption for pumps will not change.

Findings in literature [39] suggest increasing the RES utilisation in the electric power mix, because DH supply and return temperature reduction can lead to higher CO_2 emissions, in cases when electricity demand is increased. Regarding this aspect, during the pilot case project development, additional application solar PV was considered. Solar PV application in DH ensures both the replacement of fossil fuel and a decrease in CO_2 emissions [40]. The study includes solar PV implementation scenario in life cycle assessment.

3. Methodology

This particular case study aims to implement LCA methodology to provide an assessment on environmental impacts of different renewing/modernising scenarios of an existing DH system to an LTDH system, which also includes the application of solar PV. The development of the LCA mainly follows the ISO 14044 standard, which identifies four phases of LCA studies:

1. Goal and scope definition phase;
2. Inventory analysis phase;
3. Impact assessment phase;
4. Interpretation phase.

The first three phases for this study are described further in 3.1., 3.2. and 3.3. parts of the methodology. The interpretation phase is included as the analysis of results, and discussion and conclusions part of this paper.

3.1. Goal and Scope

The goal of this study is to assess environmental impacts of different renewing/modernising scenarios of an existing DH system to an LTDH system, which also includes the option for application of solar PV. For the comparison of the new DH operation, the DH model before the renovation is also included as one of the studied scenarios defined as the business-as-usual scenario. Since the former DH system had more residential house connections than the new one, the Functional unit thus includes the relation to the heated area to compare the performance of renovation scenario. The selected Functional unit is the construction of DH and produced energy over the assumed lifetime of DH per heated area. The study in total includes four scenarios for one DH located in the municipality in the eastern part of Latvia, namely, in the parish of Belava of Gulbene Municipality:

- Scenario 1: New LTDH with supply and return temperatures 60/35 °C;
- Scenario 2: New LTDH with supply and return temperatures 60/35 °C and solar PV;
- Scenario 3: New DH with supply and return temperatures 90/60 °C;
- Scenario 4: Former DH with supply and return temperatures 90/60 °C (i.e. business-us-usual).

The Life cycle inventory (LCI) of the proposed LCA is defined considering the information found in literature about LCA on DH and the availability of data for this specific case study. The study boundaries include the assembly stage of DH and its components, the operation phase with heat production, electricity consumption and maintenance of DH in terms of replacement of taps, valves, pumps and surface boxes over the 20-year lifetime. The study considered new LTDH and DH scenario comparison in respect to the former DH (also including impact for construction, operation and maintenance). The disposal phase is not included in the study, except the waste treatment already considered in products from Ecoinvent 3 database. Moreover, additional transportation of products was not considered, except transportation that is already defined by default in Ecoinvent 3 database. All of the scenarios include the following parts of DH system: boiler house, pipelines, DH pipeline nodes. In addition to other parts, scenario two also consists of a solar PV plant for powering the boiler house and pumps. All scenarios consider the electricity connection to the grid.

3.2. Life Cycle Inventory

Gulbene municipality provides the primary information and for the LCA modelling. The authors of the study included specific details of the overall design – i.e. valves, pumps, pipelines, insulation, heat meters, wells, ventilation system and excavation works, etc. Whenever possible Ecoinvent 3 database was used as a reference database for the study.

The main inventory of the study is reported in the Annexe. In Table 2 are presented the processes directly selected by Ecoinvent 3 and those direcly created in the LCA software.

TABLE 2. ENERGY FLOWS IN DEFINED SCENARIOS

Part of DH	Process accounted	Processes from Ecoinvent 3 database	New processes created	Processes excluded from LCA
Boiler house	97	13	67	17
Pipelines	94	10	76	8
DH nodes	189	5	150	44
Solar PV	9	6	2	1

The authors assumed a cut-off for the process with low impact over DH lifetime, such as alcoholic thermometers, pressure gauge, warning tapes, labelling of heating unit, fasteners, wall brackets, anti-corrosion reagent, pipeline fittings, DH system testing, adjustment and startup, chimney installation. For the pipeline network modernisation compensating pillows, renovation of asphalt pavement and replacement of soil were excluded. In terms of the solar PV system delivery, adjustment and startup process was excluded from the model.

The lifetime for DH boiler house, pipelines and trench works was defined as 20 years. For surface boxes, flow limiting devices, heat meters and heat exchangers, the lifetime was set to 15 years while for pumps and taps to 10 years [27].

Inventory for scenarios with new DH for optimal design and modernisation includes the reconstruction of old DH by disabling four consumers from DH network in order to increase heat density in the network and thus reducing DH pipeline network length from 917 m to 491 m, change of DH node components and pipelines, change of boiler house, including furnace and other its components, and thus change in boiler heat production efficiency and reduction of power consumption for pumps. For insulation of pipelines in former DH pipelines stone wool was used, while in the new DH pipelines polyurethane foam insulation from industrial production was used. According to the pilot DH inventory, new boiler house was set in modular container and heat is produced in wood pellet boiler with automatic silo and storage area. The old boiler house did not have silo, and heat was produced in firewood boiler.

In the LCA study, the DH network pipelines were defined as materials and processes needed for the production of the DH network pipeline of specific sizes. According to DH network pipeline manufacturer certificates, the pipeline consists of three parts: inner part as a metal pipeline, middle part as insulation and outer part as plastic cover. The weight of materials needed for the pipeline can be calculated from the volume and density of the material. From the data available in inventory calculation of pipeline material weight was made according to Eq. (1):

$$V_n = (\pi \cdot R_n^2 - \pi \cdot r_n^2) \cdot \rho_n \cdot l \quad (1)$$

where

V Volume of pipeline material n, m3;

π Ratio of the circumference of a circle to its diameter, mathematical constant;

R Outer radius of pipeline material n, m;

r Inner radius of pipeline material n, m;

ρ Density of pipeline material n, kg/m3;

l Length of pipeline, m.

The overall pipeline was defined in the LCA model as the sum of the material weights estimated according to Eq. (1). The example for data about the size of pipelines used for the calculation of material weights from pilot DH inventory is shown in Table 3.

TABLE 3. EXAMPLES OF DH PIPELINE INVENTORY

Pipeline in new DH network inventory	Amount	Unit	Thickness of pipeline parts (mm)		
			Metal pipe	Insula-tion	PE cover
Heating pipeline d76/D160	12	m	5.5	40.0	4
Heating pipeline d60/D140	54	m	5	37.5	4
Heating pipeline d48/D125	222	m	4	36.0	4
Heating pipeline d33/D110	4	m	4	36.0	4
Corner d76/160 (α=90°) 1.00x1..00 m	2	p	5.5	40.0	4
Corner d48/125 (α=90°) 0.50x0.50 m	4	p	5	37.5	4
Corner d33/110 (α=90°) 0.50x0.50 m	2	p	4	36.0	4
Corner d60/140 (α=90°) 0.50x0.50 m	6	p	4	36.0	4

Note: Units measured in meters (m) and pieces (p)

Following assumption for the density of materials in pipeline were adopted: inner pipe steel density 8050 kg/m3, PUR insulation density 70 kg/m3, PE cover density 970 kg/m3. For pipeline connection parts is was assumed that insulation is 25 % and the cover is 75 % of connection total weight.

The data characterising the former DH was obtained for the reference year 2017 in terms of total heat production and electricity consumption of former boiler house and DH network pumps. For former boiler house and new boiler house fuel appropriate boiler of 300 kW was included in the model. The data contained in the scenario energy flow is shown in Table 4.

TABLE 4. ENERGY FLOWS UN DEFINED SCENARIOS

Scenario	Total heated area	Produced heat	Consumed fuel	Consumed elec-tricity
Scenario 1	4067 m²	524.76 MWh	119.74 t of wood pel-lets	4.58 MWh from grid
Scenario 2	4067 m²	524.76 MWh	119.74 t of wood pel-lets	2.46 MWh from grid and 2.12 MWh from solar PV
Scenario 3	4067 m²	532.57 MWh	121.52 t of wood pel-lets	4.58 MWh from grid
Scenario 4	4467 m²	984.00 MWh	404.09 t of firewood	44.39 MWh from grid

Wood pellet consumption was estimated for equivalent operation conditions as in case of former DH for the reference year 2017, considering the parameters of new DH in terms of total heated area and increase in efficiency due to new boiler installation and pipeline insulation.

The produced heat consists of the consumed heat and heat losses. The consumed amount of heat for each scenario is calculated as the sum of the heat consumption for all connected building before and after reconstruction. Heat loss has been determined according to the methodology described in [41] by taking into account the particular heating network parameters and temperature levels. Heat consumption and heat loss have been determined for the average climate conditions in Gulbene (heating season 209 days, average heating season temperature –1.4 °C according to previous LBN 003-15 regulation). The fuel consumption is obtained according to Eq. (2):

$$B = \frac{Q_i}{Q_{z,i}^{d} \cdot \eta_i} \qquad (2)$$

where

B Fuel consumption for fuel *i*, tones per year;

Q_i Produced heat, MWh per year;

Q_{zd} Lowest calorific value for fuel *i*, MWh/tones per year;

H Boiler efficiency for fuel *i*.

The efficiency of the new boiler was considered as 91.3 % according to nominal load and lowest cal-orific value for pellets 4.8 MWh/tones aligned to the manufacturer's certificate.

The power consumption data of new and old boiler house has been used to determine the specific power that is necessary to produce and transfer 1 MWh of heat. This indicator has been applied for both high and low temperature regimes due to the assumption that supply and return temperature difference will remain constant in both scenarios.

In scenario two electricity from solar panels is generated throughout the year, but since the consumption of DH during the summer is almost close to zero, the electricity is not used in this period. It is assumed that surplus electricity in summer is consumed for other needs than DH, therefore is not assign to this scenario, while during winter solar PV generates electricity according to solar PV area and monthly irradiation. This generated electricity considered to substitute part of the electricity coming from a country mix.

3.3. Impact assessment

The aim of this case study is to assess a wide range of environmental impacts of DH development scenarios. For this purpose, impact assessment was performed with SimaPro 9.0 software. This software allows to use a number of impact assessment methods can be applied to calculate results depending on the purpose of the project. The Standard impact assessment procedure, according to ISO standards 14044, includes characterisation, damage assessment, normalisation, weighting and addition steps.

For this study, the IMPACT 2002+ version 2.14 method was used. This method includes 14 midpoint environmental damage categories: Human toxicity, Respiratory effects, Ionizing radiation, Ozone layer depletion, Photochemical oxidation, Aquatic ecotoxicity, Terrestrial ecotoxicity, Aquatic acidification, Aquatic eutrophication, Terrestrial acid/nutrients, Land occupation, Global warming, Non-renewable energy and Mineral extraction. The scores of these 14 midpoint categories is assigned to impact respective endpoint category:

1. Damage to human health is expressed as Disability Adjusted Life Years (DALYs);

2. Damage to Ecosystem Quality is expressed as the loss of species over a certain area (PDF);

3. Damage to Resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels (MJ);

4. Damage to climate change, expressed in terms of overall CO2 equivalent, excluding biogenic carbon impact.

The overall environmental damage scores are normalised to one scale and expressed as the number of equivalent persons affected during one year per unit of emission. To each damage category is assigned an equal weight. The final environmental profile is based on a final normalized and weighted single score as a cumulative value of from each impact categories.

4. Results

The total environmental impact and damage category score of each scenario is presented in Fig. 2. in terms of ecological profile (Eco-indicator points, kPt) with reference to the selected Functional unit.

Scenario 2 has the lowest impact on the environment for all the considered categories, i.e. 0.791 kPt; while scenario 4 has the most impact on the environment for all the categories, i.e. 1.561 kPt. Scenarios 1 and 3 have a close single score result of 1.119 kPt and 1.134 Pt, respectively. This means that there that for temperature decrease form 90/60 °C to 60/35 °C in pilot DH environmental impact decrease is small. When implementing solar PV in pilot DH the environmental impact decrease is more significant.

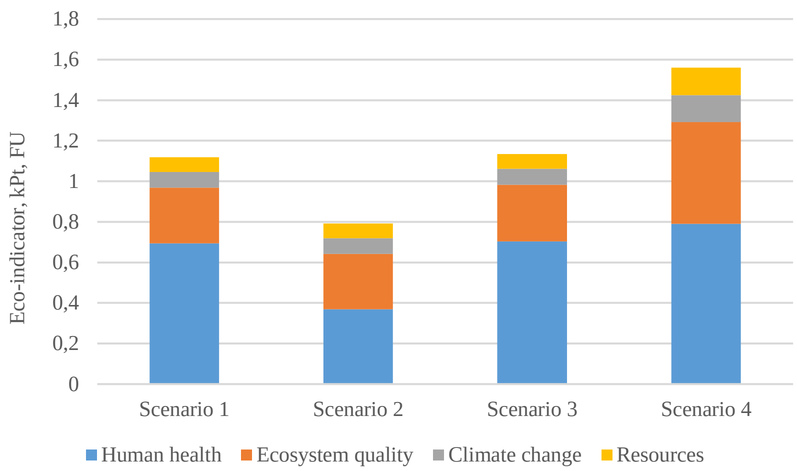

Figure 1. Impact assessment score for scenarios.

Overall, the highest impact in all scenarios is observed for human health category, followed by ecosystem quality category. Scores for climate change category are slightly higher than for resource category in all scenarios.

Fig. 3 shows the contribution to a single score per part of DH in every scenario. The highest contribution to scoring in all scenarios is from energy flows. For scenario 2 the contribution to the score is lower because of solar PV implementation. However, solar PV installation is accounted in boiler house part for scenario 2, so the for this scenario is higher for boiler house part than other two new LTDH and DH in scenario 1 and 3. Scenario 4 for old DH stands out with the highest score in all categories with exception of nodes.

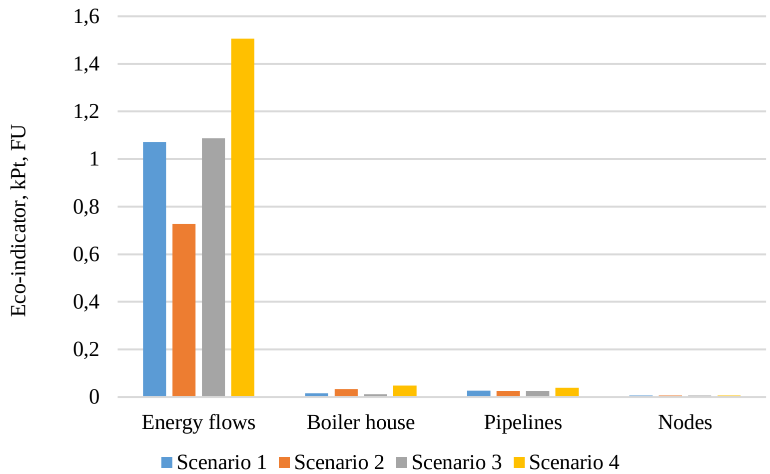

Figure 2. Impact assessment score per part of DH.

Nodes have the lowest impact compared to other parts of DH. The model considered the same impact for nodes in all scenarios.

Table 5 shows the process's contribution to the total score for each scenario. According to this table, the energy flows account from 93 % to 96 % of scenario score. By studying the results from the perspective of contribution processes within SimaPro software, heat production with ash treatment was found to be the main contributors within energy flows of DH.

TABLE 5. CONTRIBUTION TO TOTAL SCORE OF SCENARIO PER PART OF DH

Part of DH	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Energy flows	96 %	93 %	96 %	94 %
Boiler house	1 %	3 %	1 %	3 %
Pipelines	2 %	3 %	2 %	2 %
Nodes	1 %	1 %	1 %	0.5 %

5. Conclusions

LCA contributes to raising awareness of environmental impacts that can be caused by DH systems. It provides insight on damages in several categories that are not captured by other available methods. It is thus an essential tool to cover the knowledge gaps of stakeholders involved in infrastructure planning and reconstruction.

This study aimed to assess the environmental impacts of different renewing/modernising scenarios of an existing DH system and an LTDH system, which also includes the application of solar PV. The study utilised the LCA methodology in SimaPro software. The main data were obtained from Ecoinvent 3 database and direct information received by the Municipality of Gulbene. Environmental Damage assessment was made according to the IMPACT 2002+ method.

The results showed that there is a major improvement in the environmental performance of DH from the modernisation of the boiler house. The scenario which implemented LTDH with supply and return temperatures of 60/35 °C and solar PV was found to be the best form environmental perspective among all the studied scenarios for DH modernisation. The highest contribution to environmental impact in all scenarios was from energy flows during the operation phase of DH. This study showed that construction and maintenance of DH compared to operation has much lower impact on environment.

One of the important findings of this study is that the implementation of LTDH alone does not show significant improvement in the environmental performance of DH heating. However, the study did not include a sensitivity analysis of results.

In all scenarios DH operation in terms of heat production and ash treatment showed the highest contribution to environmental impact. In the future, to deal with this issue, not just lowering the temperature of DH, but also the implementation of as solar thermal collectors and other low temperature sources such as heat pumps and excess industrial heat should be considered when designing new LTDH. The effect of this would change the required capacity of the boiler house and thus the amount of heat produced and ashes created.

It is important to note that in the current state of system the energy efficiency was not applied in dwellings, thus there lies the potential to improve the overall environmental performance of scenarios with LTDH compared to modernised DH with supply and return temperatures of 90/60 °C. Moreover, when modelling larger DH, it would be important to consider the variation of DH network electricity consumption due to the change of supply and return temperatures.

The results of this study provide information DH development scenarios with low impact on the environment. They can be used by municipality and public authorities involved in the planning process of infrastructure development.

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Annex

Part of DH	Materials / Assemblies / Processes	Amount	Unit
New boiler house	Steel, low-alloyed	113.3	kg
	Steel, chromium steel 18/8	390.1	kg
	Concrete, sole plate and foundation	4.2	m3
	Sand	14	kg
	Polyurethane, rigid foam	21.5	kg
	Cast iron	23	kg
	Brass	0.4	kg
	Stone wool	1040	kg
	Flat glass, coated	4	kg
	Alkyd paint, white, without solvent, in 60 % solution state	3.6	kg
	Polyethylene, low density, granulate	5	kg
	Exhaust air outlet, steel/aluminium, 85x365 mm	3	p
	Ventilation duct, connection piece, steel, 100x50 mm	5	p
	Room-connecting overflow element, steel, approx. 40 m3/h	1	p
	Exhaust air outlet, steel/aluminium, 85x365 mm	1	p
	Ventilation duct, steel, 100x50 mm	5	m
	Ventilation duct, connection piece, steel, 100x50 mm	1	p
	Insulation spiral-seam duct, rockwool, DN 400.30 mm	4.95	m
	Intermodal shipping container	1	p
	Furnace, pellets, with silo, 300 kW	1	p
	Metal working, average for steel product manufacturing	113.3	kg
	Metal working, average for chromium steel product manufacturing	390.1	kg
	Metal working, average for metal product manufacturing	23.4	kg
	Extrusion, plastic pipes	3.6	kg
New DH pipeline network	Chromium steel pipe	10639.4	kg
	Polyurethane, rigid foam	816.8	kg
	Polyethylene, low density, granulate	2038.7	kg
	Concrete block	2901	kg
	Sand	323.5	kg
	Cast iron	283	kg
	Copper	15	kg
	Pitch	10	kg
	Alkyd paint, white, without solvent, in 60 % solution state	7.2	kg
	Gravel, crushed	570.2	kg
	Mastic asphalt	6733.8	kg
	Cable, three-conductor cable	5	m
	Concrete, sole plate and foundation	0.2	m3
	Metal working, average for steel product manufacturing	10639.4	kg
	Extrusion, plastic pipes	2038.7	kg
	Metal working, average for metal product manufacturing	283	kg
	Metal working, average for copper product manufacturing	15	kg
	Welding, arc, steel	6.4	m
	Excavation, hydraulic digger	515	m3
DH nodes	Steel, low-alloyed	256.8	kg
	Stone wool	1.2	kg
	Cast iron	132	kg
	Copper	9	kg
	Brass	61.6	kg
	Stone wool	1805.1	kg

	Alkyd paint, white, without water, in 60 % solution state	4.8	kg
	Cable, ribbon cable, 20-pin, with plugs	15	kg
	Metal working, average for steel product manufacturing	256.8	kg
	Metal working, average for metal product manufacturing	132	kg
	Metal working, average for copper product manufacturing	9	kg
	Welding, arc, steel	0.3	m
Solar PV plant	Photovoltaic panel, multi-Si wafer	54.99	m2
	Electronic component, active, unspecified	25.41	kg
	Inverter, 2.5kW	2	p
	Steel, unalloyed	112.5	kg
	Cable, three-conductor cable	155	m
	Electric connector, wire clamp	4	kg
	Photovoltaic plant, electric installation for 3kWp module	3.025	p
Pumps and taps	Brass	89.5	kg
	Steel, low-alloyed	72	kg
	Steel, chromium steel 18/8	264.3	kg
	Polyethylene, high density, granulate	17.4	kg
	Cast iron	145	kg
	Bronze	20.6	kg
	Flat glass, coated	4	kg
	Battery cell, Li-ion	0.9	kg
	Electronics, for control units	12.1	kg
	Metal working, average for steel product manufacturing	105	kg
	Metal working, average for chromium steel product manufacturing	264.3	kg
	Metal working, average for metal product manufacturing	165.6	kg
	Thermoforming	17.4	kg
Surface box and heat meters	Cast iron	12	kg
	Copper	0.8	kg
	Steel, low-alloyed	12	kg
	Steel, chromium steel 18/8	3.5	kg
	Brass	14.2	kg
	Electronics, for control units	23.3	kg
	Battery cell, Li-ion	1	kg
	Cable, ribbon cable, 20-pin, with plugs	15	kg
	Cable, three-conductor cable	5	m
	Polyethylene, high density, granulate	0.4	kg
	Polyethylene, low density, granulate	5	kg
	Polyurethane, rigid foam	1.2	kg
	Stone wool	1805.1	kg
	Metal working, average for steel product manufacturing	12	kg
	Metal working, average for chromium steel product manufacturing	3.5	kg
	Metal working, average for metal product manufacturing	27	kg
	Metal working, average for copper product manufacturing	0.8	kg
	Injection molding	5	kg