LCA of infrastructure for district energy

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Sammendrag

Norsk Fjernvarme har gitt NORSUS i oppdrag å finne klimagassbelastning knyttet til fjernvarme infrastruktur. Norsk Fjernvarme ønsker klimagassfaktorer for råmaterialer brukt i infrastrukturen til distribusjon av fjernvarme, bestående av rør, energisentraler og kundesentraler.

Metoden som er brukt for å komme frem til klimagassfaktorer er livsløpsanalyser (LCA). LCA er en metode for miljøvurderinger som er basert på ISO-standarder ISO 14040 (ISO, 2006b) og ISO 14044 (ISO, 2006c).

Livsløpsanalyser av et produkt er definert som en systematisk kartlegging og evaluering av påvirkninger på miljø og på ressursforbruk gjennom en definert del av eller hele livsløpet til et produkt. En LCA inkluderer miljøpåvirkninger fra utvinning av råvarer, produksjon, transport, bruk og avfallshåndtering. LCA kan brukes til forskjellige formål, for eksempel å sammenligne forskjellige produkter eller tjenester som oppfyller samme funksjon, identifisere muligheter for forbedring i et produksjonssystem og som beslutningsstøtte.

Klimagassfaktorene er beregnet med LCA-programmet SimaPro. LCA-databasen ecoinvent er brukt til bakgrunnsdata for råmaterialene. I analysene er IPCCs karakteriseringsmetode for klimaendringer IPCC 2013 GWP 100a brukt (IPCC, 2013). Den inneholder IPCC sine karakteriseringsfaktorer for tidshorisont 100 år. Klimagassfaktorer er gitt per kg råmaterialer som brukes til infrastruktur i fjernvarmenettet.

Disse faktorene er testet på to fjernvarmeanlegg av ulik størrelse (anonymiserte, kalles DH Facility A og DH Facility B i rapporten). For disse anleggene er det beregnet klimagassutslipp fra infrastruktur for anlegget i sin helhet og per kWh. Infrastrukturen er delt opp i distribusjonsrør, kundesentraler og energisentraler.

De to anleggene som er brukt som case er med hensikt ulik i størrelse og årlig distribusjon av varme. DH Facility B er større enn DH Facility A både når det kommer til mengde råmaterialer brukt til infrastruktur og årlig varmeleveranse. DH Facility A leverer årlig omtrent 20% av varmen som DH Facility B leverer, mens den totale mengden råmaterialer i DH Facility A tilsvarer 16% av mengdene brukt hos DH Facility B. Dette fører til en forskjell i klimapåvirkning per anlegg på omtrent 40 tonn CO_2-ekvivalenter, mens klimagassutslipp per kWh varme levert til kunde er 2,3 g CO_2-ekv/kWh for infrastruktur hos DH Facility A mot 3,1 g CO_2-ekv/kWh for infrastruktur hos DH Facility B.

Summary

Norsk Fjernvarme has commissioned NORSUS to find the greenhouse gas (GHG) load associated with district heating infrastructure. Norsk Fjernvarme has requested GHG factors for raw materials used in the infrastructure for distribution of district heating, consisting of pipes, thermal energy plant and district heating substation.

The method used to find the GHG factors is life cycle analysis (LCA). LCA is a method for environmental assessments based on ISO standards ISO 14040 (ISO, 2006b) and ISO 14044 (ISO, 2006c).

LCA of a product is defined as a systematic mapping and evaluation of impacts on the environment and on resource consumption through a defined part of or the entire life cycle of a product. An LCA includes environmental impacts from raw material extraction, production, transportation, use and waste management. LCA can be used for different purposes, such as comparing different products or services that fulfill the same function, identifying opportunities for improvement in a production system and as decision support.

The GHG factors are calculated with the LCA program SimaPro. The LCA database ecoinvent is used for background data for the raw materials. In the analyzes, the IPCC's characterization method for climate change IPCC 2013 GWP 100a is used (IPCC, 2013). It contains the IPCC's characterization factors for a time horizon of 100 years. Climate impact is given per kg of raw materials used for infrastructure in the district heating network.

These GHG factors have been tested at two district heating plants of different sizes: DH Facility A and DH Facility B. For these plants, GHG emissions due to the infrastructure for the plant as a whole and per kWh have been calculated. The infrastructure is divided into distribution pipes, thermal energy plant and district heating substation.

The two plants used as cases are, intentionally, different in size and annual distribution of heat. DH Facility B is larger than DH Facility A both in terms of the amount of raw materials used for infrastructure and annual heat delivery. DH Facility A annually delivers approximately 20% of the heat that DH Facility B delivers, while the total amount of raw materials in DH Facility A corresponds to 16% of the quantities used at DH Facility B. This leads to a difference in climate impact per plant of about 40 ton of CO_2 equivalents, while the impact per kWh of heat delivered to the customer is 2.3 g CO_2-eq / kWh for infrastructure at DH Facility A against 3.1 g CO_2-eq / kWh for infrastructure at DH Facility B.

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1 Introduction

In Norway, the use of district heating is increasing, and in 2019 the annual district heat production totaled to 6.6 TWh (SSB 2020 https://www.ssb.no/statbank/table/04727/tableViewLayout1/). Per January 1st 2020 a ban on oil fired boilers came into force, thus, there was a substantial increase in district heating for private households. Even though there has been a large increase in district heating in Norway, it does not account for more than about 3% of the total end-use of energy in Norway.

Through the network organization Norsk Fjernvarme, emissions of greenhouse gases (GHG) due to production of district heat is provided free of charge. Emissions factors are available on the webpage www.fjernkontrollen.no, and is documented in Klimaregnskap for fjernvarme 2020 (Torstensen, 2020).

This report documents the work related to the analysis of infrastructure for district heating. First, this report gives a brief introduction to LCA method in general, followed by a presentation of specific method choices and assumptions for this case. Thereafter the results on climate change due to production of infrastructure for district heating are displayed. The results are given both as the climate emission per kg of each raw material and per kWh heat delivered to customers. The climate emission per kWh has been calculated based on data from two district heating systems: one large and one smaller producer. These two cases are meant to work as examples, and other district heating systems can have results deviating from these numbers.

Several district heating facilities also provide district cooling. Materials used in the infrastructure are similar. When the materials are the same, the emissions factor per kg material can be used to calculate the climate impact of district cooling infrastructure also. The emissions factors for the materials are given in AR.10.21 (confidential) (Soldal and Modahl, 2021).

The project period was from January 2020 to May 2021. NORSUS has performed the environmental analysis in dialogue with Norsk Energi and Norsk Fjernvarme. Norsk Energi has given data on infrastructure materials and Norsk Fjernvarme has given data on annual production of heat.

2 Method

In this study, the impact on climate change by distribution of district heating is analyzed using life cycle assessment (LCA). LCA is a method for environmental assessments that is based on ISO standards ISO 14040 (ISO, 2006b) and ISO 14044 (ISO, 2006c).

Life cycle assessment of a product is defined as a systematic mapping and evaluation of impacts on the environment and resource consumption throughout a defined part, or the entire life cycle, of the product. An LCA includes the environmental impacts due to raw material extraction, production, transport, use and waste management. LCA can be used for different purposes, such as comparing different products or services that fulfil the same function, identifying opportunities for improvement in a production system, and as decision support (Baumann and Tillman, 2004). An important reason for applying LCA is to avoid so-called problem shifting between life cycle stages or environmental impact categories.

The LCA methodology consists of four main steps. In the first step, the purpose of the study and functional unit is determined, as well as the system boundaries of the system of interest. The next step is data collection, i.e. collecting information on material and energy use, emissions and waste streams for each life cycle phase. The third step consists of calculating mass and energy balance and quantifying environmental effects by converting emissions into potential effects in different environmental impact categories. In the fourth and final step, interpretation of results, the results are discussed as the basis for conclusions and possible further work. This is an iterative process, and the interpretation phase will often make the LCA-practitioner revisit any of the other phases (Figure 1).

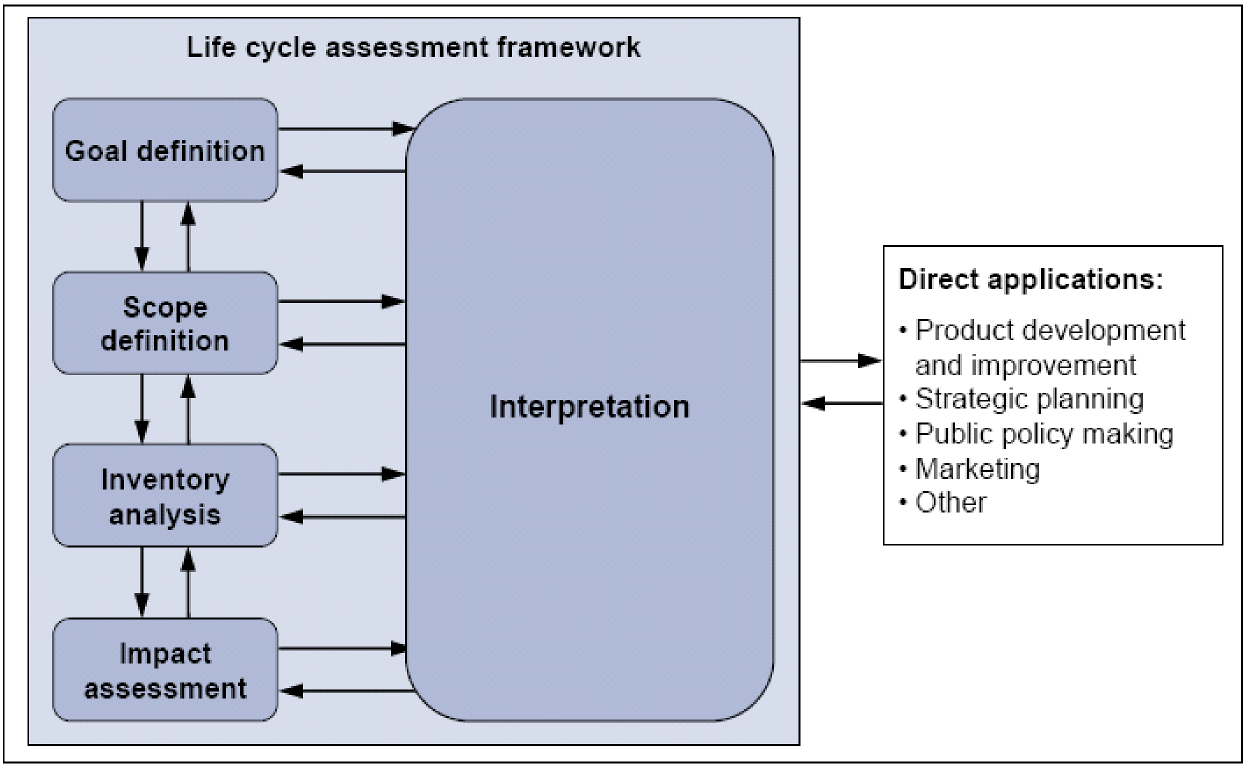

Figure 1 Frame work for life cycle assessment (ISO, 2006b).

When performing an LCA, a model of the product system is constructed. System boundaries define which unit processes to be included in the analysis. A unit process is a production activity in the life cycle of a product for which inputs and outputs are quantified. When the LCA includes all of a product's life cycle stages, i.e. from raw material acquisition through production, use, recycling and final disposal, it is referred to as a cradle-to-grave. LCA methods may also be used for parts of the life cycle, like cradle-to-gate that includes life cycle stages until the factory gate when the product is ready for distribution (i.e. raw material acquisition and production). Other possible system boundaries are gate-to-gate or specific parts of the life cycle.

LCA is used for development of environmental product declarations (EPD) according to international standards, with ISO 14025 giving the general guidelines for how LCAs are translated into EPDs (ISO, 2006a). An EPD is an independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products. In order to make the information comparable, there are specific rules that define how the EPD shall be developed for specific products or product groups. These rules are called Product Category Rules (PCR). Amongst other things, the environmental impact categories to be calculated and reported are given by the PCR.

LCA can also be used to calculate greenhouse gas emissions (GHG) according to the Greenhouse gas protocol. The GHG protocol divide the life cycle emission of climate gases into three different scopes:

- Scope 1 emissions: direct emissions of GHG from own operation (combustion of fuel and chemical processes).
- Scope 2 emissions: indirect emissions of GHG due to production of electricity, steam, heat and cooling consumed by the reporting company.
- Scope 3 emissions: all other indirect emissions that occur in a company's value chain. This includes emissions from upstream suppliers of energy carriers and other raw materials, as well as emissions connected to the use of the product downstream of the company.

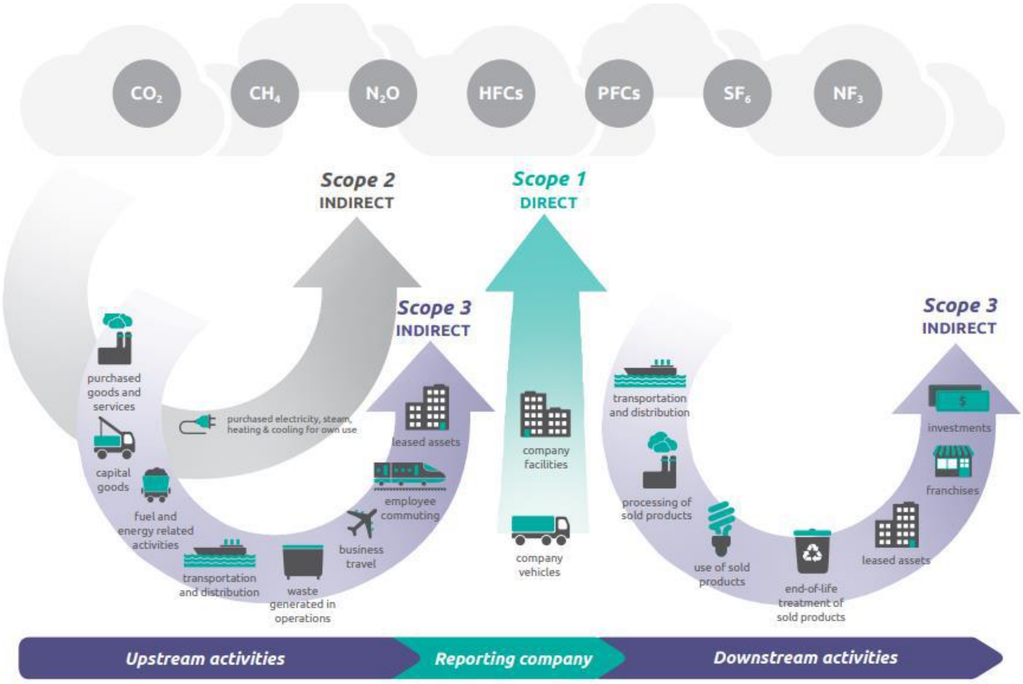

Figure 2 Overview of GHG Protocol scopes and emissions across the value chain (WRI/WBCSD, 2013)

The GHG protocol is an example of how the LCA method can be used to capture parts of product life cycles and for a single environmental indicator. Carbon footprint studies made according to the protocol have a specific organization as its scope, and scope 1 and 2 are designed to encompass those emissions directly linked to the organization's activities. Most organizations have less control over emissions under scope 3, but these include areas where organizations really can contribute to reductions of global greenhouse gas emissions. The reasons why these emissions are optional in the GHG protocol is that one organization's scope 3 emissions are another organization's scope 1 emissions and there is a danger of double counting. However, more and more companies report their scope 3 emissions, as they see the strategic benefits of knowing these.

2.1 System boundaries

Before one can make an LCA-model of a production processes or product life cycle, the system boundaries must be set. The system boundaries define which processes that belong to the system you want to analyze, and includes boundaries between nature and the technosphere (i.e the technical system, man-made), and boundaries between the technical system analyzed and other technical systems (Finnveden et al., 2009), in addition to boundaries in space and time.

Often the technical system to be analyzed is divided into a foreground system and a background system. The foreground system includes processes in the supply chain defined by the company whose product is being analyzed, and for this system, primary, site-specific data will usually be collected. The background system contains processes taking place in other technical systems, providing auxiliary materials or services. For the background systems, secondary data from databases, public references, or estimated data based on models are used (Li et al., 2014). Typically, an LCA contains specific data of energy use from the company doing the LCA (in the foreground system), while production data for the energy sources (in the background system) come from an LCA database.

2.2 Functional unit

The environmental load associated with a products life cycle is distributed linearly to a unit of reference, a so-called functional unit (FU). The FU is a quantitative description of a product or service that all input and output of the product life cycle is related to. The function can be related to performance or some properties of the product or service.

If the LCA does not include the cradle-to-grave, but parts of the life cycle, like cradle-to-gate, the functional unit is often referred to as a declared unit. If the product of interest is outdoor painting for instance, a declared unit can be 1 liter of paint, while the functional unit can be 1 m^2 of outdoor wall painted and maintained for 20 years. The functional unit will then include some information on coverage, expected lifetime and performance of the paint.

2.3 Databases and software for LCA

To be able to perform a life cycle assessment from cradle-to-gate or cradle-to-grave, a substantial amount of data is needed. As there are several materials and/or energy products, like electricity, concrete and steel, that are common input for many products, inventory data on these are gathered in databases. In addition to make the amount of data the LCA-practitioner have to collect manageable; they also enhance consistency in life cycle inventory (LCI) data. The ecoinvent database developed by ecoinvent, a non-profit organization in Switzerland, is the most extensive database available. The data is validated and kept updated, providing LCA experts with LCI data for a number of products and services. Although one must pay for access to ecoinvent data, the database has the advantage of being made by a non-profit organization, securing objectivity and no obvious bonds between the data provider and producing companies.

The ecoinvent database and other LCI-databases are incorporated into different life cycle assessment software, for instance SimaPro. SimaPro is developed by PRé Sustainability, Netherlands. The software helps building models of production processes and product life cycles and translates emissions and resource flows into environmental impacts.

3 Goal and scope of this study

3.1 Goal of the study

The goal of the study was to calculate the impact on climate change caused by production of district heating infrastructure. These calculations should form the basis for other district heating providers when calculating their impact on climate change.

3.2 System boundaries

The analysis includes all upstream processes for the acquisition of raw material and manufacturing of the infrastructure materials, and transport to the district heating facility. Excavation of trench lines and foundation area for the thermal energy plant is also included. Production of heat and assembly of the infrastructure is not included. Heat losses during transport of district heating pipes are, however, included indirectly (see chapter 3.3).

3.3 Functional unit

The functional unit is a measure of the function of the system investigated and provides a reference to which the inputs and outputs can be related. In this study the environmental performance is related to two functional units:

1. Production and transport of 1 kg of material used for district heating infrastructure.
2. Infrastructure related to delivery of 1 kWh district heat to customers.

3.4 Data and impact assessment

The analyses in this study were carried out using SimaPro Flow. This is an online LCA modelling tool developed by PRé Sustainability. In SimaPro Flow the latest version of the ecoinvent LCI-database is included. For this analysis, ecoinvent version 3.6 *allocation cut-off by classification* was used for background system and emissions data (Wernet et al., 2016). The background system includes all upstream processes (production processes and transport for the infrastructure materials), while the foreground system includes information on amount of the different materials used and annual production of heat. Data for the foreground system has been delivered by Norsk Energi and Norsk Fjernvarme.

The materials used in the district heating infrastructure and the selected processes from ecoinvent that represents these materials are given in Table 1. The materials are used for pipes, district heating substation and thermal energy plant, in different amounts. Climate change impact due to excavation for pipeline network and construction of district heat facilities are also given. Transport from production to construction site is included through the use of market-processes from ecoinvent.

Table 1 Materials used in the district heating infrastructure, with the selected ecoinvent processes.

Materials used	ecoinvent process(es)
Black steel	*Market for steel, unalloyed (GLO)*[1] and *Sheet rolling, steel (RER)*[2].
Stainless steel	*Market for steel, chromium steel 18/8 (GLO)* and *Hot rolling, steel (RER).*
Rock wool	*Market for stone wool, packed (GLO)*
Polyurethane	*Market for polyurethane, rigid foam (RER).*
Aluminum	*Market for aluminium, wrought alloy (GLO)* and *Market for metal working, average for aluminium product manufacturing (GLO).*
Brass	*Market for brass (CH)*[3] and *Contouring, brass (RER)*
Copper	*Market for copper (GLO)* and *Wire drawing, copper (RER)*
Polyethylene	*Market for polyethylene, low density, granulate (GLO)* and *Extrusion, plastic pipes (RER).*
Polyvinyl chloride	*Market for polyvinylchloride, suspension polymerized (GLO)* and *Extrusion, plastic film (RER).*
Concrete	*Market for concrete, 35MPa (RoW)*[4]
Excavation	*Excavation, hydraulic digger (RER)*

Two district heating plants have been used as case studies to get a range for the climate impact for the facility as a total and per kWh heat delivered. The annual heat production is calculated as an average over 4 years for DH Facility B (2017-2020) and over two years for DH Facility A (2018-2019). The expected lifetimes of the materials are set to 30 years. In real life, some of the infrastructure will last shorter than 30 years and some will last longer than 30 years. Together with annual average heat production, expected lifetime is used to calculated lifetime heat production, and the impacts are distributed equally between the kWh heat delivered to customers during the lifetime of the infrastructure.

The two district heat facilities analyzed are of different size, both when it comes to materials used and heat delivered. Table 2 gives the use of infrastructure material and average annual heat production for the district heat facilities DH Facility A and DH Facility B.

[1] GLO=global
[2] RER=Europe
[3] CH=Switzerland
[4] RoW=Rest of the world, here referring to the world market, excluding Brazil, North-America and South-Africa.

Table 2 Materials used for production of infrastructure for district heating substation, thermal energy plant and distribution net for district heat facility A and B. Average annual heat production is also included.

Part of infrastructure	Materials/process	Unit	DH Facility A	DH Facility B
District heating substation	Black steel	kg	245 479	2 110 965
	Stainless steel	kg	4 238	47 913
	Rock wool	kg	38 175	330 006
	Aluminum	kg	2 520	21 636
	Brass	kg	1 187	13 416
	Cobber	kg	339	3 833
	Polyvinyl chloride	kg	509	5 750
	Concrete	ton	548	5 171
	Excavation	m^3	1 140	10 770
Thermal energy plant	Black steel	kg	1 024 455	3 060 308
	Stainless steel	kg	223	22 084
	Rock wool	kg	59 432	241 503
	Aluminum	kg	6 559	22 997
	Cobber	kg	37 438	55 512
	Polyethylene	kg	90 633	0
	Polyvinyl chloride	kg	2	9
	Concrete	ton	1 478	5 195
	Excavation	m^3	1 060	3 100
Distribution net	Black steel	kg	820 630	8 760 656
	Polyurethane	kg	162 449	1 609 125
	Cobber	kg	2 283	25 577
	Polyethylene	kg	182 562	1 939 975
	Excavation	m^3	41 279	442 266
Annual average heat production		MWh	101 440	518 642

For the assessment of the impact, the IPCC impact assessment method IPCC 2013 GWP 100a is used (IPCC, 2013). It contains the climate change characterization factors of IPCC with a timeframe of 100 years.

4 Results and discussion

The results in the chosen impact category are given for infrastructure for the two district heat facilities as a total and per kWh heat delivered to customers (Table 3). In Table 3 the results per district heat facility is given in tons CO_2-eqv, while the impact per kWh is given in g CO_2-eqv/kWh heat delivered to customers.

Table 3 Result for the impact category climate change for DH Facility A and DH Facility B. The results are given per facility and per kWh heat delivered to customers.

	DH Facility A		DH Facility B	
	In total	Per kWh	In total	Per kWh
	Ton CO_2-eqv/facility	g CO_2-eqv/kWh	Ton CO_2-eqv/facility	g CO_2-eqv/kWh
CC total	**6 951**	**2.3**	**48 304**	**3.1**
CC Distribution net	3 233	1.1	33 777	2.2
CC District heating substation	712	0.2	6 259	0.4
CC Thermal energy plant	3 006	1	8 268	0.5

The total climate change impact for the infrastructure at DH Facility A is 14% of the impact for the infrastructure for DH Facility B. This was expected as, DH Facility B is larger, both in materials used and heat delivered to customers. However, the difference in annual heat delivered is smaller than the difference in infrastructure material. The annual heat delivery in DH Facility A is 20% of the annual heat delivered in DH Facility B, while the total amount of materials used in DH Facility A is 16% of the amount used in DH Facility B. This gives a lower infrastructure climate impact for DH Facility A per kWh compared to DH Facility B. The infrastructure climate impact per kWh for DH Facility A is 73% of the impact per kWh for DH Facility B. DH Facility B is characterized with more infrastructure due to housing pattern in their area. The area where DH Facility B delivers heating contains many villas and small distribution networks with low energy delivery and high material use.

For comparison, the climate change impact of infrastructure for electricity from Norwegian hydropower was calculated. Infrastructure for production (i.e. dam and other infrastructure at site) and distribution contributes with 9.6 g CO_2-eq./kWh. The assessment is based on 12 hydro power stations that NORSUS has modelled in their LCA-software. Inundation is assumed to be part of the emissions related to the production of electricity, and not the infrastructure. Hence, it is not included in this number.

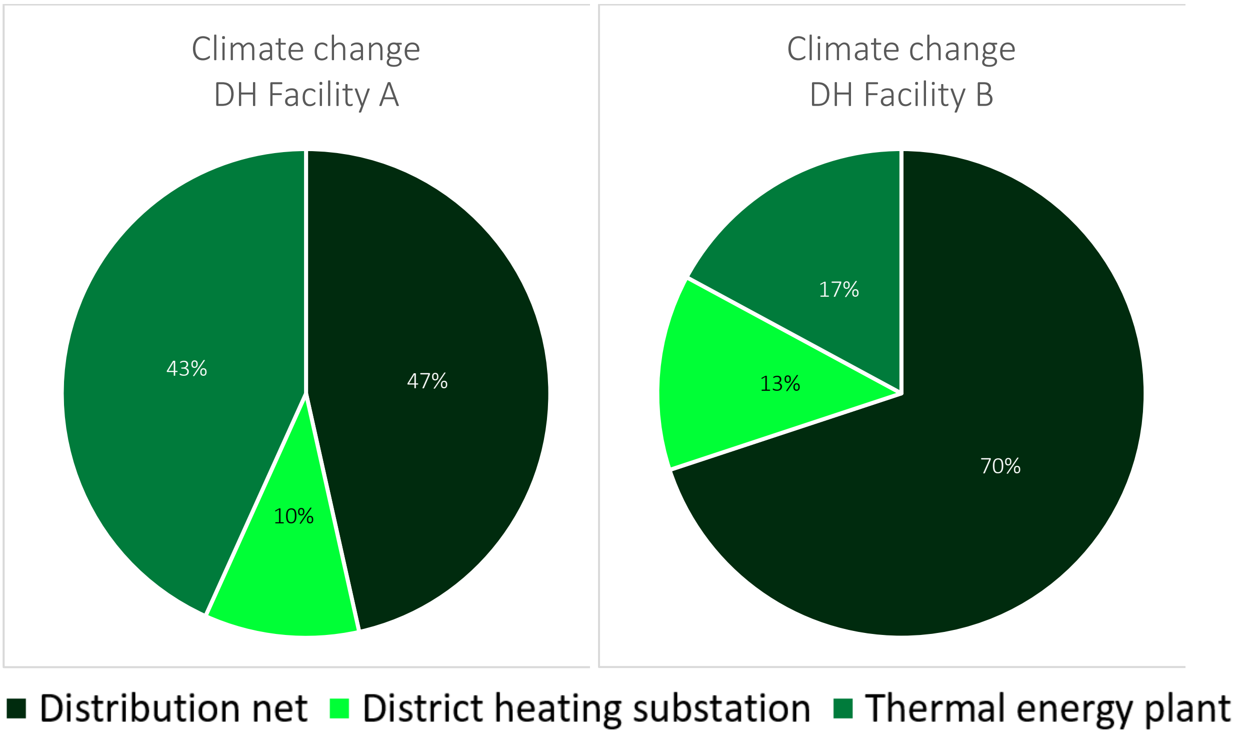

Figure 3 Distribution of the climate change impacts between distribution net, district heating substation and thermal energy plant for DH Facility A (left) and DH Facility B (right).

The raw material with the highest impact per kg is aluminum. The raw material that is the most burdensome in total, taken both amount of material used and climate change factor into account, is black steel (Figure 4 and Figure 5). The climate change impact per kg material used in the distribution network, district heating substation and thermal energy plant are given in AR.10.21 (confidential) (Soldal and Modahl, 2021).

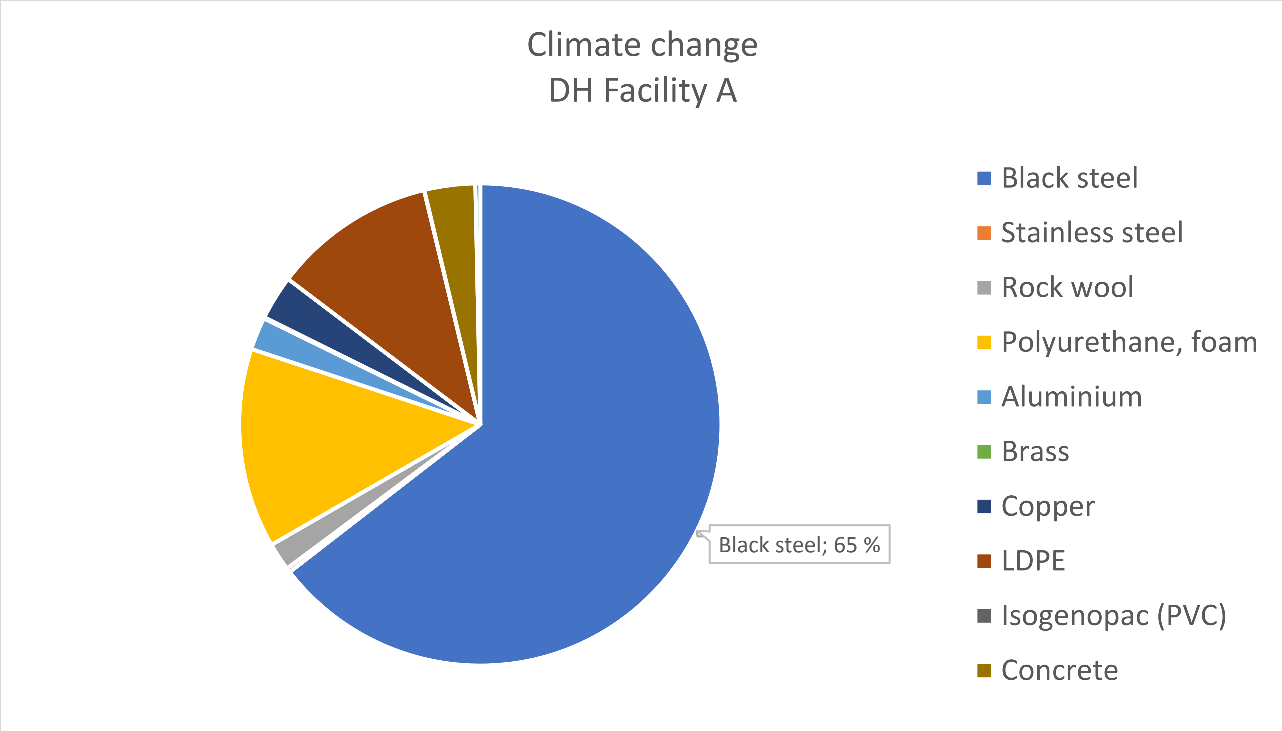

Figure 4 Distribution of the climate change impact divided between the different raw materials for DH Facility A. The impact is given for DH Facility A in total, i.e., distribution net, district heating substation and heat central combined.

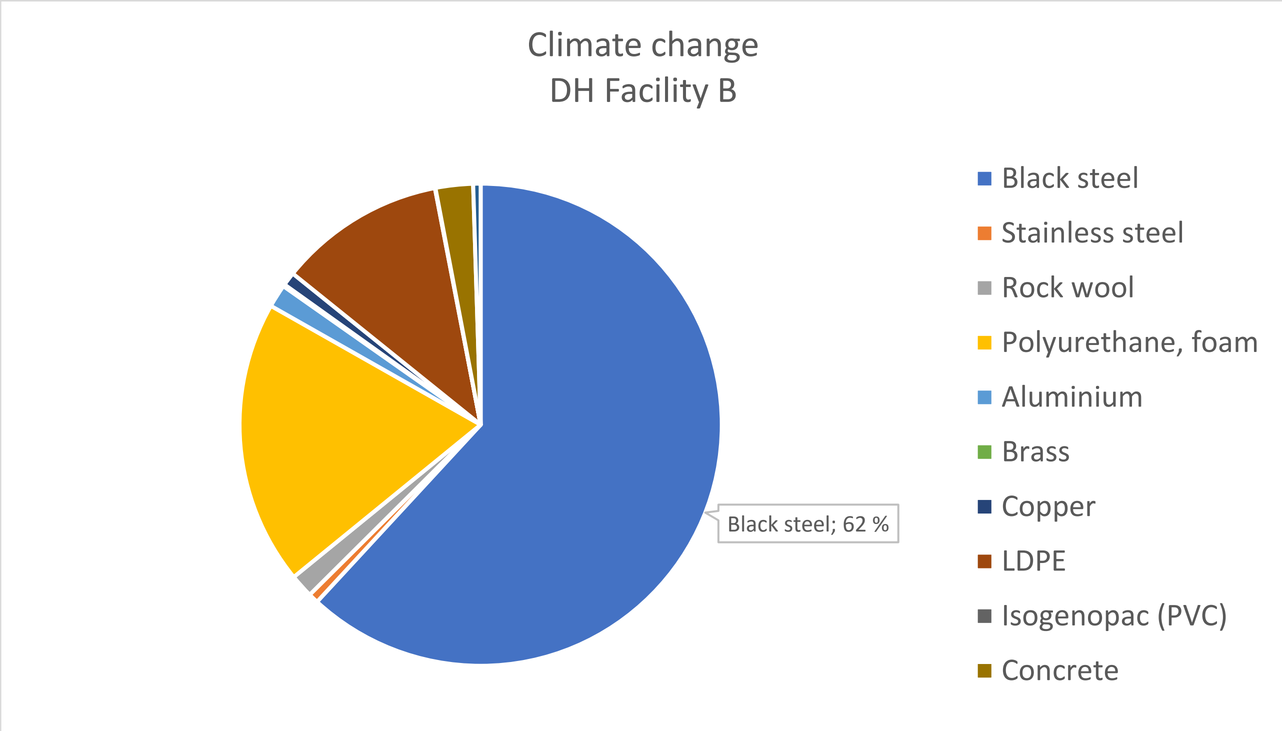

Figure 5 Distribution of the climate change impact divided between the different raw materials for DH Facility B. The impact is given for DH Facility B in total, i.e., distribution net, district heating substation and heat central combined.

4.1 District cooling

In this report, the focus has been on district heating infrastructure. However, the same materials are used for district cooling. For assessment of the climate change impact of district cooling, the emissions factors for the materials as given in AR.10.21 (Soldal and Modahl, 2021) can be used. In addition, ammonia is used in heat pumps as refrigerant. Some of this gas escapes, but it does not have climate impact when emitted. Production and transport of ammonia causes 1.99 kg CO_2-eqv/kg ammonia, and this must be included if this is used as refrigerant for the district cooling system. If other refrigerant is used, the correct emissions factor for production must be used, together with potential climate impact of direct emissions.

5 Literature

BAUMANN, H. & TILLMAN, A.-M. 2004. *The hitch hiker's guide to LCA : an orientation in life cycle assessment methodology and application,* Lund, Sweden, Studentlitteratur.

FINNVEDEN, G., HAUSCHILD, M. Z., EQVALL, T., GUINÉE, J., HEIJUNGS, R., HELLWEG, S., KOEHLER, A., PENNINGTON, D. & SUH, S. 2009. Recent developments in Life Cycle Assessment. *Journal of Environmental Management,* 91**,** 1-21.

IPCC 2013. Climate Change 2013: The Physical Science Basis, IPCC Working Group, Contribution to AR5 (the Fifth Assessment Report). Available at http://www.climatechange2013.org/.

ISO 2006a. EN ISO 14025 Environmental labels and declarations. Type III environmental declarations. Principles and procedures. Geneva, Switzerland: International Organization for Standardization.

ISO 2006b. ISO 14040:2006 Environmental management -- Life cycle assessment -- Principles and framework. Geneva, Switzerland: International Organization for Standardization.

ISO 2006c. ISO 14044:2006 Environmental Magament - Life Cycle Assessment - Requirements and guidelines. International Standardisation Organisation.

LI, T., ZHANG, H., LIU, Z., KE, Q. & ALTING, L. 2014. A system boundary identification method for life cycle assessment. *The International Journal of Life Cycle Assessment,* 19**,** 646-660.

Soldal, E. and Modahl, I. 2021. AR. 10.21 Climate change impact for the raw materials used in district heating infrastructure. Confidential.

TORSTENSEN, S. B. 2020. Klimaregnskap for fjernvarme 2020. Felles utslippsfaktorer for den norske fjernvarmebransjen – Oppdatering 2020. Norsk Energi.

WERNET, G., BAUER, C., STEUBING, B., REINHARD, J., MORENO-RUIZ, E. & WEIDEMA, B. 2016. The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment,* 21**,** 1218-1230.

WRI/WBCSD 2013. Technical Guidance for Calculating Scope 3 Emissions (version 1.0). Supplement to the Corporate Value Chain (Scope 3) Accounting & Reporting Standard.

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