Emission factors and methods used in climate impact assessments of energy use in Swedish heated buildings

Assessing district heating and electricity as energy source

Matilda Hinsegård & Louise Piltz Vitanc

Master thesis in Energy-efficient and Environmental Building Design
Faculty of Engineering | Lund University

Lund University

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

Examiner: Ulla Janson (Division of Building Services)

Supervisor: Karin Farsäter (Division of Building Services)

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Abstract

When the property- and building industry moves towards new solutions targeting reduced climate impact, this puts pressure on the building owners and companies to calculate the climate impact of buildings. It may seem easy, but there are various methods and guidelines to navigate around. This study addressed the issue of which emission factors for district heating and electricity are used in climate calculations of heating buildings today and how a climate calculation can have different results, depending on system boundaries and method guidelines that are followed.

To be able to answer the research questions, evidence was gathered through a pre-study, literature study and interviews with key people in the industry. Interviews were held to examine the problem more comprehensively. The material collected from interviews is presented in the result, together with a complication of the literature study findings. To discuss differences and similarities in the climate calculation methods and between the emission factors presented during the literature study and compilation of results, two case studies on district heating and electricity were conducted on a building with a heating need of 80 kWh/m^2, yr. In the district heating case study, three locations – Hässleholm, Linköping and Stockholm – were calculated to give a broader range of different fuel mixes. For electricity, the case study was grid-based.

The study showed differences in emission factors and methods based on the collected material. For emission factors related to district heating, it emerged from the discussion that there are differences in the weighting of global warming potential, allocation when combusted, presentation and names of the fuel, and different system boundaries. For the emission factors related to electricity, the study shows differences depending on included countries in the average mix. Emission factors for specific electricity sources, such as solar, wind, hydro, or nuclear power, differ significantly. The methods used for the climate calculation vary between if the method follows bookkeeping- or/and consequence perspectives, different scenarios for the future, how to present data and when the year of the data sources.

There are inconsistencies in the methods, system boundaries, and recommended emission factors for calculating module B6, resulting in ambiguity. Currently, there is no nationally accepted methodology for calculating the climate impact assessment, and there is a demand for standardized guidelines, according to this study.

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Matilda Hinsegård and Louise Piltz Vitanc

Abbreviations

CO_2 eq.	Carbon Dioxide Equivalent
GWP	Global Warming Potential
GHG	Greenhouse Gas
SBTi	Science-Based Target Initiative
LCA	Life Cycle Assessment
EPD	Environmental Product Declaration
PCR	Product Category Rules
COP	Coefficient of Performance
VMK	Värmemarknadskommittén (Heating Market Committee)
IPCC	Intergovernmental Panel on Climate Change

Definitions

Primary energy factor	The ratio between end-user consumption of electricity and primary energy consumption
Greenhouse Gas Protocol	Supplier of greenhouse gas accounting standards internationally.
Life cycle assessment	Methodology for assessing the environmental impact of a product over the entire period of its life
Scenario	In LCA a scenario is defined as a description of a possible future situation relevant to specific LCA applications. Based on assumptions about the future and shows development from present to future
B6	Life cycle stage B6 is the potential environmental impact of the operational energy use
Downstream emission	Emissions that occur downstream in the value chain, i.e., after use in the business. For example, waste management of sold products
Upstream emission	Emissions that occur upstream in the value chain, .e. before use in the operation. For example, manufacturing of purchased materials.
Good Environmental Choice	Certification from the Swedish Environmental Protection Agency, in Swedish “Bra Miljöval”
Residual mix	Set of electricity for which the origin is not verified with a guarantee of origin.
Direct emissions	Emissions under the direct control of the organisation
Indirect emissions	Emissions that occur outside the direct control of the organisation, for example, in connection with purchased goods and services

Table of content

1 Introduction

1.1 Background

One of today's biggest challenges is climate change. The construction and property sector are one of the industries that play an essential role in the transition to lower the climate impact from society. Globally, the sector shares an overall energy demand of 36 % and the emissions of carbon dioxide emissions (CO_2) from building operations dropped from 9.6 gigatons to 8.7 gigatons carbon dioxide emissions from 2019 to 2020. (United Nations Environment Programme, 2021, p. 15). According to the Swedish National Board of Housing, Building and Planning's environmental indicators, the Swedish construction and property sector accounts for 21 % of greenhouse gas emissions and 34 % of the total energy use nationally (Boverket, 2023).

Cold weather conditions in Sweden and high prices of natural gas in Europe drove up electricity prices in 2021, with prices reaching record levels. An increase in electricity prices also made fossil-based electricity generation more profitable after years of low prices, contributing to the increased use of fossil fuels. Despite the increased use of fossil fuels, greenhouse gas emissions were still lower in 2020 than in 2019 (Naturvårdsverket, 2022) Higher energy use due to cold weather also contributes to increased emissions. The greenhouse gas emissions from electricity- and district heating production account for about 8 % of Sweden's total emissions, corresponding to about 4 million tonnes of carbon dioxide equivalents (CO_2 eq.). Compared with 1990, the emissions have decreased by 38 %, even though the district heating production has increased by about 40 % due to the shift from burning fossil fuels (coal, natural gas, peat and especially oil) to mainly biofuels and waste. Compared to other countries, Swedish electricity- and district heating emissions are low (Naturvårdsverket, 2022).

When writing this report, new initiatives and methods are being developed to calculate the climate impact of heated buildings. Laws, standards, and regulations are being reviewed and updated. Internationally, Product Category Rules (PCR), which is predeterminate calculation rules for Environmental Product Declarations (EPDs), are being updated. The PCR for "electricity, steam and hot/cold water generation and distribution" is estimated for publication on 2023-05-15 (The International EPD System, n.d.). The Corporate Standard in The Greenhouse Gas Protocol (GHG protocol) has some years on its back, and since the standard was published, there have been many new developments and learnings, such as Science Based Targets Initiative (SBTi). Also, the trend toward net-zero targets and regulations concerning climate disclosure has grown, and corporations have gained extensive experience since the last standards were published. Therefore, a process has begun determining the need and scope for additional guidance based on the existing accounting and reporting GHG standards for all three scope emissions (Freeman, 2022). Until October 2023, Science-based Targets will develop targets for Buildings and publish the final deliverables, containing methods, tools, and guidance for companies in the building sector and other stakeholders. The content will be based on a previously developed method from Sectoral Decarbonization Approach for buildings to develop 1.5 °C-aligned resources and establish a global pathway for buildings' in-use and embodied emission to this temperature rise (Science Based Targets, n.d.).

The development of new or updated versions and rules also occurs within Sweden's national borders. The climate declaration launched in Sweden on the first of January 2022 sets requirements for life cycle analysis on the construction stages A1 to A5. However, The Swedish National Board of Housing, Building, and Planning (hereinafter referred to as "Boverket") will submit a proposal for an extended climate declaration in spring 2023. The extended climate declaration will add a limit value for A1 to A5 and demand a report of the climate impact over the entire life cycle, including the operational energy module B6 of a building. To manage this, Boverket need a prognosis for how electricity- and district heating will evolve in the upcoming 50 years and its climate impact. There is a need to develop national emission scenarios for energy carriers from which emission factors can be determined (Boverket, 2020, p. 133). According to Fossil-free Sweden (Fossil-fritt Sverige*),* the Swedish building- and construction industry has the potential to reduce its climate impact to half by 2030 with existing techniques, but to reach net zero or further, new techniques and innovations are needed (Fossilfritt Sverige, 2018, p. s. 5). This follows the latest IPCC (Intergovernmental Panel on Climate Change) report that claims that to reach the climate goals, the greenhouse gas emissions need to be halved by 2030 (Pallardy, 2022). However, the local initiative LFM30 (Local roadmap Malmö, Swedish: Lokal Färdplan Malmö) is going one step furtherwith an overall goal of a climate-neutral construction sector with net zero CO_2 emissions in Malmö by 2030 and a climate-positive sector by 2035. When writing this report, a method is being developed within LFM30 for climate calculation of life-cycle stage B6 in the management stage. Furthermore, education and online webinars about calculations for environmental impact from B6 are emerging. The shift seems to have changed from wanting to do what looks good, to doing what is correct.

When the property- and building industry moves towards new solutions targeting reduced climate impact, this puts pressure on the building owners and companies. Calculating climate impact on a building may seem easy, but there are various methods and guidelines to navigate around. This study addresses the issue of which emission factors for district heating and electricity are used in climate calculations of energy use in Swedish heated buildings today and how a climate calculation may have different results, depending on system boundaries and method guidelines that are followed.

1.2 Objectives

The study aims to investigate differences in emission factors for energy sources in district heating and electricity and how these differences impact a climate calculation. The objective is to study available methods for calculating module B6 of heated buildings and understand how their differences and recommendations on climate input data affect the output of the case studies. The mapping of emission factors and methods will be obtained to accepted methods in Sweden and based on surveys, literature study, and interviews with key people in both the energy- and building industry.

1.3 Research questions

- How does current climate calculations' emission factors and methods for energy sources to heat buildings, differ?
- How does the differences of emission factors and methods effect on a climate calculation of module B6?
- Is there a national method for calculating the climate impact of a heated building for module B6?

1.4 Limitations

The study circulates the concepts of environmental calculation, focusing on the life cycle stage B6 for heated buildings in Sweden. The calculations will be studied from the building sector perspective, and the work is limited to grid-connected heating with a focus on district heating and electricity since these two are the most common way to heat buildings in Sweden today (Energiföretagen, 2020). Since the study contains much information seeking, staying updated is essential. However, updates in reports, directives, regulations, or laws that after the last day of April 2023 are not to be considered in this report due to time limitations.

The case studies will not be generalized for the whole building sector, but the methods and the study of emission factors may be. For district heating, the fuels presented by Energy Companies' (Energiföretagen) fuel mix 2021 (presented in theoretical background, section 4.1.2) will set the limitation for which fuels to compare and to make sure the fuels are used in Sweden. Global warming potential (GWP) has been considered as climate impact category since it is the most common category used in life cycle assessment in Sweden.

2 Methodology

This chapter presents the study's methodological approach and data collection methods – literature study, interviews, and survey - and a description of implementation and validity.

2.1 Methodological approach

The study started with a pre-study to get acquainted with the studied field and to examine what has been done in the field prior to the study. Since the pre-study consisted of collecting a large assembly of literature and data, a methodology mimicking the funnel shape has been emulated. During the pre-study, three surveys were sent out to energy companies and life cycle assessment specialists through email and LinkedIn. The surveys led to interesting interviews with professionals in the field, and the authors also invited professionals for interviews via email. Once the pre-study had been conducted, the collected information could be narrowed down and followed into a literature study. The literature study investigated how the emission factors are produced for district heating and electricity and how the methods for calculating life cycle stage for module B6 can be conducted. Throughout the period of material collection, the authors relied on the most recent and updated information and data available.

Once the collection of data, through literature study and interviews, the compilation of the information began for the chapter of result. To enable a proper comparison of emission factors, and to highlight differences and similarities depending on methods and system boundaries, a case study on grid-level was performed. The case study was made by hand calculation, on both district heating and electricity. The case study is presented in the analysis.

The study is made on emission factors and standards that are used for climate calculation methods in Sweden. Hence the sources, that precents emission factors, and methods in this report will be written in Swedish. A Swedish/English glossary of the these are presented in Table 1.

Table 1: Glossary of Swedish/English designations.

Swedish	English
Miljöfaktaboken	Environmental Fact Book
Naturvårdsverket	The Swedish Environmental Protection Agency
Värmemarknadskommittén	The Heating Market Committee
Tidstegen	The Time Steps
Energiföretagen Sverige	Energy Companies Sweden
Boverket	The Swedish National Board of Housing, Building, and Planning
Klimatstegen	The Climate Steps
NollCO_2	ZeroCO_2

2.2 Pre-study

A pre-study was conducted to get familiar with the studied area and to investigate what has been done before. Three surveys were carried out, targeting experts who perform climate calculations and energy companies to determine how the industry performs climate calculations for heating.

Surveys

Part of the feasibility study involved sending out three questionnaires. The surveys were written and consisted mainly of listed questions with response options. All three survey was conducted to determine what methods, tools and databases are currently used to calculate the climate impact of heating buildings. The first questionnaire was mainly answered by people working with climate calculations reached from LinkedIn. Many Swedish energy companies are members of Energiföretagen and follow their method for calculating emission factors. 38 energy companies that were not members in Energiföretagen could be found when comparing

Sweden’s energy companies with the member list from Energiföretagen. The second survey aimed to include energy companies that are not members in Energiföretagen and was emailed to these 38 energy companies. The third questionnaire was emailed to eleven energy companies that offered the certification "Good Environmental Choice" from Naturvårdsverket.

2.3 Literature study

The literature study gave a theorical background to what methods that are used for climate calculations in Sweden and what emission factors they are based on. The purpose was to collect and summarize available literature of the chosen subject and consists of sources from public authorities, companies’ webpages, and scientific reports. When there were questions, e-mail was used to compliment the data that was missing. The sources of the literature collected are openly reported so that independent reviewers can understand the authors' starting points but also so that others in the field can use and build on the results of the study. A repetitive process of the literature review is an integral part of the work.

The methods and sources for emission factors included in this study were determined in parallel with the preliminary survey using the questionnaires and during the literature study. This study includes the methods and emission factors with a public and complete calculation methodology. The emission factors were found in parallel when investigating the methods.

2.4 Presentation of results

The result is divided into three parts, a compilation of emission factors and a compilation of methods is the first, which were separated to better understand the different factors affecting emission factors versus method. The collection of emission factors is divided for district heating and electricity as the system boundaries for these two are different. The third part was material collected from interviews which were put in a separate section to separate the results from experts' knowledge and thoughts from this report's literature review.

The district heating mix from Energiföretagen 2021 (Figure 3) was used to create the main headings for the emission factors for combustion. Fuels were then sorted underneath each title. When compiling the factors, there were many gaps in the table as the different sources that presents emission factors reported their data differently. Therefore, only a selection of the fuels was presented in the results for comparison. The entire table is presented in Appendix 1. Since Naturvårdsverket only presented carbon dioxide, methane, and nitrous oxide separately, these were weighted together to carbon dioxide equivalents according to IPCC AR5, which Naturvårdsverket refers to on its website; see Table 14 for exact values (Naturvårdsverket, n.d.b). The EPDs found for District heating was put in a separate table. One Click LCA provides a range of emission factors for district heating that are location dependent. However, this report only includes emission factors for the following locations: Luleå, Östersund, Stockholm, Linköping, Göteborg, Helsingborg, and Eslöv-Lund-Lomma.

The results from the literature study on electricity emission factors and methods were presented in separate tables.

It was not allowed to present Ecoinvent's raw data in this report according to their transfer of rights. The database was only compared with the other methods and emission factors in the chapter for analysis.

Interviews

Experts in their fields were interviewed to find out what methods are used and what opinions about them exist in the industry. The interview subjects were found through the survey that was performed in the pre-study. The interviews were also designed to gain a more in-depth understanding of how everything works together. Interviews were open-ended, meaning that the interviewee mainly controls what is brought up in the interview. However, the interviewers have ensured that it stayed within the scope of the study by limiting the questions and responses. The interview results were presented in a summarized text that the interviewed persons have approved. The material from the interviews is excluded from the analysis and will only be covered by the following discussion, since the analyse only treats the case studies. In Table 2, the interviewed persons are listed together with the organisation and area of operation.

Table 2: Interview persons with title, organisation, and the organisation's area of operations.

Interview Person (IP)	Title	Organisation	Area of operation
IP1	Energy Expert	Energiföretagen Sverige	Industry organisation that brings together energy companies
IP2	Environmental strategist	E.ON	Supplier of electricity, heating, and smart energy solutions to around 1 million private and business customers in Sweden
IP3	Environmental coordinator	Hedström & Taube	The group offers all types of project management in construction.
IP4	Lecturer and Energy Expert	Svensk Energiutbildning (Swedish Energy Education)	Offers seminars and courses for the construction and property sector.
IP5	Energy Policy Expert	Stockholm Exergi	Energy provider in Stockholm
IP6	Energy Expert	Boverket	Authority for planning, construction, and housing.

2.5 Analysis

The case study was conducted to analyse the results and to spread light on how the differences in a climate calculation, depending on which method and system boundaries that are used, affect the result of climate calculation of module B6.

The example building used 80 kWh/m^2, yr. for heating and was located to a grid for district heating and electricity in Hässleholm, Linköping and Stockholm. Where the m^2 is the heated floor area of a building with an energy demand of 80 kWh per m^2 and year. The calculation was done by hand according to the following equation for district heating.

$$Total\ Emission\ [kg\ CO_2 eq./m^2.yr] = Emission\ Factor, mix\ [kg\ CO_2 eq./kWh]\ \cdot\ 80\ [kWh/yr.]$$

The following equation was used to calculate the same heating need but for electricity that has a heat pump that had a coefficient of performance (COP) of 3.

$$Total\ Emission\ [kg\ CO_2 eq./m^2.yr] = Emission\ Factor, mix\ [kg\ CO_2 eq./kWh] \cdot 80\ [kWh/yr.]\ /\ COP\ 3$$

Some sources for emission factors and methods were excluded from the case studies. Naturvårdsverket and GHG Protocol's emission factors for combustion were excluded because of the incomplete life cycle assessment (LCA) data and because of no allocation. Klimatklivet emission factors for the combustion of fuels do not have an allocation on the emission factors and were therefore excluded. Tidstegen was also excluded because of the complexity of the calculation, which would have led to an unrealistic comparison to what was calculated in this report. Scenarios from NollCO_2 were not included because of the lack of scenarios in the other methods.

A hand calculation for the different district heating mixes in Hässleholm, Linköping and Stockholm were made using the emission factors from Värmemarknadskommittén (VMK). This to see how close it would be to the emission factors presented by Energiföretagen Sverige, which use the same source for emission factors. The content of the energy source mixes was taken from Energiföretagen's Excel sheet of Local Environmental Values and calculated to a total mix of the location, see the following equation.

$$Emission\ Factor, mix_{location} = \sum Fuel\ emission_{VMK} \cdot Percentage\ fuel_{location}$$

Waste mixes depend on the use of products in society. Since it may only sometimes be stated what exactly type of waste has been combusted, it was challenging to implement this in the calculation from Ecoinvent Database. The database presents a wide range of types of waste. However, if the values should be used, it would be necessary to clarify whether or not the waste was used for energy and combustion. Furthermore, with the uncertainty of not knowing which exact waste had been combusted for Hässleholm, Linköping and Stockholm, it was more justified not to include this aspect in the study. Furthermore, neglecting the waste content also created a better comparison to the climate impact from EPD since in these, the waste for combustion is in the system boundary for the original product and not the energy source.

3 Results from pre-study

The three surveys sent out to energy specialists and energy companies gave the authors an overview of the current situation and market. This result was used to give an input for the structure of the literature review.

Energy experts from LinkedIn
It was told from the survey targeting methods from energy specialists that eight out of nine are doing climate calculations, and five out of these are using One Click LCA for environmental measures. Other methods used were OpenLCA, Energiföretagen Sverige, EPDs, hand-calculations and the local roadmap LFM30. The most used database was the Climate database from Boverket (five out of nine), followed by Ecoinvent Database (four out of nine). Other databases used are Värmemarknadskommittén's climate values and Ökobaudat, a German database.

38 energy companies, non-members of Energiföretagen Sverige
The survey had a low uptake of responses, but the result showed that:

- A majority (five out of six) are members of Energiföretagen.
- One non-member and two members of Energiföretagen do not calculate their climate impact from energy use.
- Of the ones that calculate their climate impact, two use the method from Energiföretagen. The other one uses the GHG Protocol.
- All three energy companies that calculate their climate impact have an electricity mix of wind, solar and hydro, and two have cogeneration.

Energy companies with "Good Environmental Choice"
The response rate was higher from the survey targeting companies that have the "Good Environmental Choice" certification from Naturvårdsverket. Out of six answers, it was given that one of these does not use Energiföretagen's method for climate calculations. Instead, this company uses Naturvårdsverket's Excel file for stationary combustion. The five companies that use Energiföretagen's approach also use an additional calculation method. Two out of five use the GHG Protocol, and three use the Climate Accounting Action (Klimatbokslut) from Profu. The emission factors come from fuel samples, the national inventory report, directly from the supplier, climate accounts and GHG Protocol. All companies contributing to the survey use standardised values when calculating climate impact; four also use their own measured values. Common to all respondents is that they measure their emissions from bio-oil; otherwise, their measures vary depending on the energy source. Regarding which emissions are most often measured, carbon dioxide was the answer in most of the responses.

4 Theory

This chapter presents three sections. The first section, 4.1. gives a theoretical background and explain relevant information needed for section 4.2 and 4.2. The second section, 4.2, presents relevant sources that presents emission factors for district heating and electricity and the third, 4.2, presents the methods associated with calculating B6 of heated buildings. Sections 4.2 and 4.3 are connected in that 4.3 are methods based on the emission data presented in the second section and needed to perform the calculation of the heated building.

The structure of chapter 4 can be explained in Figure 1, where section 4.1. is the piece needed to understand details in 4.2 and 4.3.

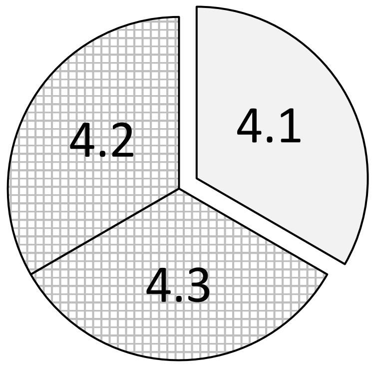


Figure 1: Connection of the sections of chapter 4.

4.1 Theoretical background

4.1.1 Calculation of potential climate impact

To calculate the potential climate impact from a process or product during its whole life cycle – from raw material extraction to the point where the product no longer is used and must be disposed of – life cycle assessment (LCA) can be used. With a LCA, it can be clarified which stage of the building's life cycle has the most significant environmental impact, and the result can be used to design and build with less climate impact. The life cycle of a building can be divided into four phases: the product phase (A1 – A3), the construction production phase (A4 – A5), the use phase (B1 – B7) and the final stage (C1 – C4). Within this report, the limitation is to module B6, which deals with the operational energy in terms of heating (Boverket, 2019).

The carbon dioxide equivalent (CO_2 eq.) is a measure of greenhouse gas emissions that considers the varying ability of different gases to contribute to the greenhouse effect. In the compilation, CO_2 eq. are used as a standard unit, meaning that other gases' warming potential needs to be translated into this standard unit. A weighting is made per tonne emitted where, for example, methane (CH_4) contributes 28 times more to the greenhouse effect than carbon dioxide (Naturvårdsverket, n.d.b).

Application of life cycle assessment

Today, national, and international standards, methods and tools assess life cycle assessment and measure and manage greenhouse gas emissions from companies or organisations' operations. Different ways of environmental reporting set guidelines and requirements to follow. Profu, an independent research and consultant company in energy, environment, and waste management, provides an extended climate accounting action (Klimatbokslut) that follows the international standard of GHG Protocol but adds a comprehensive description of changes in the surrounding environment. With the extended description, companies can capture all the climate benefits that the company provide in the surrounding environment. Climate accounting identifies where the climate impact exists, how it has changed over the years and where future measures should be implemented to reduce the climate impact further. Climate accounting presents two perspectives - bookkeeping and consequence perspective – that can be used for environmental accounting for an organisation (Profu, 2021).

When disclosing an LCA, choosing a perspective that fits the purpose is essential since the result from a bookkeeping or consequence perspective can significantly differ (Profu, 2021). From a bookkeeping perspective, all the environmental impacts connected geographically and temporally to a product should be documented (Janson, et al., 2019). The environmental impact consists of historical average values and can be used to monitor and distribute energy and emissions (Profu, u.d.). This means that the total impact of all products documented from a bookkeeping perspective should add to the same impact in the real world. The bookkeeping perspective for electricity and district heating often includes an average value of the total energy production within the system boundaries (Janson, et al., 2019). Unlike the consequence perspective, avoided emissions are not included in the bookkeeping perspective; the company's products and services do not affect the surroundings (Profu, 2021). The principal with consequence perspective is to analyse the companies' societal consequences. For example, it also includes considering if the company production has requested benefits and how these benefits would have been produced if the company closed their production (Profu, 2021). The consequence perspective is used when analysing the possibility and determining the margin effect of a building's energy use, which means analysing the last added fuel or energy source (Erlandsson, et al., 2018). Margin perspectives are often used for consequence analyses for electricity and district heating. The consequence perspective is also known as the decision perspective (Janson, et al., 2019). The schematic Figure 2 illustrates the system boundaries between the two perspectives.

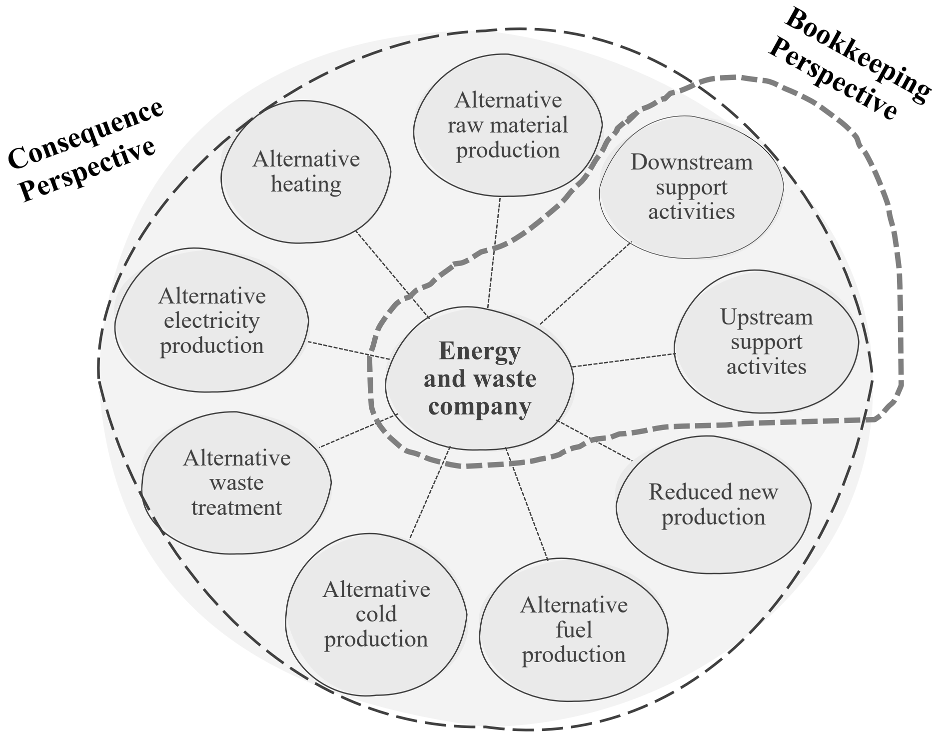


Figure 2: System boundaries of consequence- and bookkeeping perspective. Inspired by (Profu, 2021).

4.1.2 Heating needs of buildings

In heating systems, the heat is generated by converting an energy source into heat or by using fuel for combustion. Depending on the location of the building and access of energy systems, different options for heating can be available for a building. A building needs to be located close to a district heating line and to have a water-borne heating system to use district heating. When a building is connected to a heat pump, electricity can also be used for heating the building (Energimyndigheten, 2022).

District heating is Sweden's most common form of heating, with production by municipal and private energy suppliers in heating plants. More than half of all homes and premises in Sweden use locally produced district heating for heating (Enskog Broman, 2018). In a district heating or combined heat and power plant, water is heated and distributed through a network of pipes to local homes connected to the grid. District heating utilizes resources that would otherwise be lost and burn various forms of residues, such as from forestry, wood waste or waste which can come from households or businesses. District heating networks also enable the utilisation of surplus heat from local industries or data centres (ibid). In Figure 3, the fuel mix for Sweden in 2021 are presented. Today, district heating and co-generation are mainly produced from renewable fuels and recycled energy. In EU, half of the energy demand is used for heating and cooling of residential and industrial buildings, and 75 % of that energy comes from fossil fuels (Rydegran, 2017).

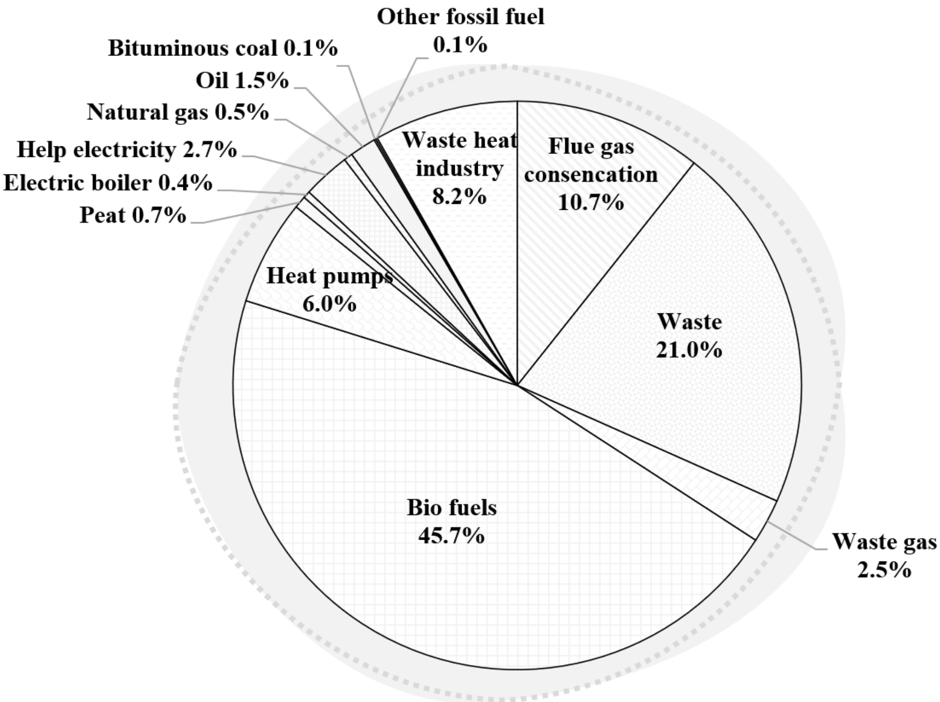


Figure 3: Shows the origin of the energy supplied for district heating production in Sweden in 2021. Based on Energiföretagen statistics from 2021 (Khodayari, 2022).

When discussing energy, distinguishment needs to be made between renewable and non-renewable energy sources. Since hydropower, wind power and solar power are constantly replenished, they are considered renewable energy sources. More than half of the electricity produced in Sweden in 2021 comes from renewable sources, where the greatest part comes from waterpower (43 %), followed by nuclear power (31 %), wind power (17 %), heat power (9 %) and solar power (1 %) (Statistikmyndigheten, 2022). Electricity can be generated as heat power through a cogeneration plant, which is an installation that use cogeneration technology to produce electricity and district heating. In contrast to thermal power plants, cogeneration plants utilize more of the thermal energy supplied. A cogeneration plant can run on virtually any fuel (Boverket, 2023) (Rydegran, 2017).

In the context of environmental assessments, allocation refers to the distribution of an environmental value for an energy facility to different products from the same activity, such as allocating carbon dioxide emissions and the amount of primary energy used in a combined heat and power plant are allocated to electricity and heat respectively. All allocation involves a subjective choice, as there are no scientific guidelines on how to correctly allocate an allocation. There will be a lack of credibility if several allocation methods are used for the same purpose. Therefore, the industry must have the same perception of how to allocate environmental values. Everyone must use the same method, so it is transparent and stable over time (Energiföretagen, 2022). Several organisations recommend an alternative method for calculating environmental impacts of cogeneration, which allocates emissions between electricity and heat in a way that ensures a fair distribution of emissions between the two. This approach ensures that the relative environmental benefits of cogeneration are the same for both electricity and district heat production (Energiföretagen, 2022).

Environmental labels for electricity and district heating offer customers an alternative to the environmental profile. "Green electricity" or "Green district heating" are examples of allocation where the energy use originating from a specific energy source is preserved in the shared network. However, the climate impact is not reduced until the energy sources in the district heating network or electricity network are replaced by fossil-free ones. Agreements on green electricity and district heating are market-based instruments to show that consumers drive the development towards renewable and fossil-free energy sources. The risk of using allocated emission factors is that it is believed that the building's climate impact is less than it is and that climate measures are not needed (Warfvinge, n.d.). The Sweden's Society for Nature Conservation's origin-labelled electrical energy is called "Good Environmental Choice " (In Swedish: "Bra Miljöval") and puts strict requirements on how the electricity is produced. The label presents the climate impact of the energy. The climate calculations are partially based on official EPDs from power producers in the Nordic countries (Naturskyddsföreningen, n.d.)

In terms of electricity, an average value for the entire electricity production can be used. The aim is to strictly account for the total direct emissions supplied within a specific geographical area. However, an average value cannot be used to describe how emissions are affected by changes in electricity production or consumption. For example, the average value cannot be used in climate accounts. Several variants of averaging values for electricity production are commonly used as Swedish or Nordic average electricity. Another variant is the "Nordic residual mix", which is similar to the average Nordic electricity. It excludes the so-called origin-labelled electricity and, left for the environmental assessment, all other remaining electricity. Since the origin-labelled electricity is renewable, the Nordic residual mix has higher emissions than the Nordic electricity average, and the Swedish electricity average (Profu, 2021, pp. 33-34).

4.2 Relevant sources for emission factor's

4.2.1 Environmental fact book (Miljöfaktaboken)

Miljöfaktaboken is a collection and presentation of general emission factors for fuel and energy sources used in electrical and heating systems and for transports in Sweden. Miljöfaktaboken was published in 2011 and contained data based on a literature study from previous studies; no new measurements of emission data were created for Miljöfaktaboken. The report presents emissions to the air during the production and distribution stage of fuel and conversion to energy for Swedish conditions. Miljöfaktaboken has studied 70 individual energy supply chains in total and has many tables with emission factors for different fuels and energy sources presented as potential of climate impact (g CO_2 equivalents per MJ fuel and MJ electricity) and primary energy use (MJ/MJ). The fuels and energy sources included in the report are energy crops, bio-oils, waste fuels, fossil fuels (solid and liquid), wood fuels, recycled wood chips, biofuels, electricity, and solar heating and the emission factors for these are presented in Table 3 (Gode, et al., 2011). Miljöfaktaboken does not recommend a specific method for allocation or calculation of climate impact. The RES-directive calculation method from 2009 is used to calculate the total carbon dioxide equivalents. The weighting of the following factors is 1 for carbon dioxide (CO_2), 296 for nitrous oxide (N_2O), and 23 for methane (CH_4), calculated per weighted unit of the emission factors (Gode, et al., 2011, p. 8). According to Miljöfaktaboken (table 70 in the book) industrial waste heat has no emissions of greenhouse gases (ibid, p. 113).

Table 3: Emission factors from table 67 in Miljöfaktaboken for combustion to heated buildings (Gode, et al., 2011, p. 104). The unit is converted from [g CO_2 eq./MJ] to [g CO_2 eq./kWh].

Fuel	Production and distribution [g CO_2 eq./kWh]	Use [g CO_2 eq./kWh]	Total [g CO_2 eq./kWh]
Branches and treetops	0.5	0.1	0.6
Logs	0.7	0.1	0.8
Thinning wood to wood chips	0.5	0.1	0.6
Forest chips	0.7	0.1	0.7
Bark	0.4	0.1	0.4
Chips, sawmill residues	0.4	0.1	0.4
Pellets	1.0	0.4	1.4
Wood briquettes	1.2	0.4	1.6
Willows	2.1	0.1	2.2
Pine tar oil	0.0	0.1	0.1
Domestic waste- Swedish average	0.3	10.3	10.6
Domestic waste - 75 % out sorted organic waste	0.2	11.5	11.7
Flammable bulky waste	0.2	6.8	7.0
Paper- wood- plastic (PTP)	0.2	6.6	6.8
Mixed operational waste	0.3	7.1	7.4
Recycled wood	0.2	0.0	0.3
Bituminous coal	0.0	0.0	29.7
Heating oil (EO1)	1.6	20.7	22.3
Heating oil (EO2-5)	1.6	21.2	22.9
Natural gas	3.3	15.9	19.2
Peat	3.1	29.7	32.8
Windfarms (Vattenfall 2010)	1.0	0.0	1.0
Hydropower (Vattenfall 2010)	0.4	0.0	0.4
Nuclear power (Vattenfall 2008)	0.3	0.0	0.3
Solar heating	3.8	0.0	3.8

4.2.2 The Swedish Environmental Protection Agency (Naturvårdsverket)

Naturvårdsverket is a government agency in Sweden that conducts and coordinates the country's environmental work. The agency is responsible for proposing and implementing environmental policies and carries out assignments on behalf of the Swedish Government relating to the environment nationally, internationally and in the EU. Naturvårdsverket's core operations are organised into five departments (Naturvårdsverket, 2023):

- Environmental Planning and Compliance Department
- Climate Action Department
- Natural Environment Department
- Circular Economy Department
- Sustainable Development Department

Combustion

Operators within EU ETS (EU Emissions Trading Systems*)* - the cornerstone of the EU's policy to tackle climate change and reduce greenhouse gas emissions cost-effectively (European Commission, n.d.) shall submit a verified emission report to Naturvårdsverket by 31 March each year, following the year in which the emissions occurred. The emissions must be reported in the European Commission's IT system EU ETS Reporting Tool, and all operators included in the EU ETS must therefore have access to this tool. In the emissions report, the operator registers its stationary facilities. Related to this work, they fill in facility location, industriousness, quantity type of fuel/material and unit of the quantity in addition to a variety of other information about the facility and the operator. An independent accredited verifier must verify the emissions report; verification is a third-party check to ensure that monitoring and reporting from the companies are consistent across all EU member states (Naturvårdsverket, n.d.a). Naturvårdsverket recommends conversion factors from the IPCC's fifth assessment report (AR5), which should be used in national reporting of greenhouse gases. The global warming potential (GWP) are set to 1 for CO_2, 28 for CH_4, and 265 for N_2O (Naturvårdsverket, n.d.b).

Naturvårdsverket collects average emission factors for Sweden annually in an Excel document, factors for district heating and electricity are presented in Table 4. This is based on the Swedish national calculation of greenhouse gases (Naturvårdsverket, n.d.b). The emission factors are put together from different measurements and literature studies depending on the emission factor affected (Naturvårdsverket, 2023). The measures can come from the EU ETS reporting tool and industries' internal measurements. The separation between the different lines of industries and sectors is based on the methodological guidelines from the IPCC and UNFCCC (United Nations Framework Convention on Climate Change) (United Nations, n.d.) The emissions from the Excel document are top emissions during combustion and are not a complete LCA for the fuel's emission. This means that addons in calculating emissions during transportation and production are necessary to get a full LCA (Naturvårdsverket, n.d.b). Stationary combustion factors are not allocated between electricity, district heat, and steam (Warmark, 2023).

Table 4: Stationary combustion for the electricity and district heating sector from Naturvårdsverket (Naturvårdsverket, 2023).

Fuel	**[g CO_2 eq./kWh]**	**[g CH_4 eq./kWh]**	**[g N_2O eq./kWh]**
Biogenic waste	211	0.01800	0.01440
Landfill/Landfill gas-/Biogas	335	0.00360	0.00036
Pine- and pine tar oil	274	0.00288	0.00216
Wood fuel	378	0.03960	0.01080
Fossil waste	140	-	-
Diesel oil above transport	-	0.00324	0.00216
Heating oil (EO1)	267	0.00324	0.00216
Heating oil (EO2-5)	274	0.00288	0.00216
Liquefied petroleum (propane and butane)	234	0.00360	0.00036
Liquefied Natural Gas	203	0.00360	0.00036
Natural gas	200	0.00360	0.00036
Bituminous coal	335	0.00360	-
Peat	379	0.03960	0.01800
Remaning fossil	252	0.01440	0.00108
Remaning biomass	-	0.03600	0.00360
Remaning not specified fossil	108	0.03240	0.00360
Remaning petroleum	216	0.00720	0.00288

The Climate Stride (Klimatklivet)

Klimatklivet is an investment support available for everyone except private people who have an idea about a physical investment to reduce society's environmental impact. Klimatklivet presents emission factors for the combustion of different fuels, an average emission factor for district heating and an average emission factor for electricity. Emission factors for fuels are first-hand taken from the Miljöfaktaboken and include greenhouse gas emissions for extraction, transport, conversion, and combustion, see Table 5. The average greenhouse gas emissions from district heating production are calculated on Energiföretagen Sweden's statistics with an average value for 2018 - 2020 and the emission factors in the Miljöfaktaboken, see Table 6. This is supposed to be used if local data is missing (Naturvårdsverket, 2022, p. 6). In terms of waste heat utilisation, it is not considered to cause any greenhouse gas emissions since there is no additional combustion of fossil fuels for the waste heat to be used instead of not. The waste heat is considered a by-product that would go to waste if not used (Naturvårdsverket, 2022). No allocation is addressed between electricity, heat, and steam for the combustion values and the weighting to global warming potential is according to RES-directive, 2009: 1 for CO_2, 23 for CH_4 and 296 for N_2O (Henning, 2023).

Table 5: Emission factors for extraction, transport, conversion, and combustion of different fuels Klimatklivet (Naturvårdsverket, 2022).

Fuel	[g CO_2 eq./kWh]
Heating oil (EO1)	288
Heating oil (EO2-5)	295
Liquefied petroleum (propane and butane)	259
Domestic waste	144
Natural gas	248
Bituminous coal	385
Peat	425
Operational-, bulky waste	94
Bark	5.8
Willows	28
Recycled wood	3.2
Chips, sawmill residues	5.8
Wood briquettes	21
Wood pellets	19
Remaining, ex forest chips	9.4
Raw pine oil	2.5
Pine tar oil	6.5

On behalf of Naturvårdsverket and Klimatklivet, IVL (The Swedish Environmental Research Institute) has, within the framework for SMED (Swedish Environmental Emission Data), produced an updated average emission factor for greenhouse gas emissions for electricity mix, using a bookkeeping perspective. The greenhouse gas emissions from electricity use used in Klimatklivet are based on calculating the Nordic electricity system's climate effect and an emission factor for the Nordic electricity mix (including Sweden, Norway, Denmark, and Finland), both for import and export. The hourly data for import and export with the Nordic system boundary has been collected from ENTSO-E (European Network of Transmission System Operators for Electricity). Countries connected to the Nordic grid are Poland, Germany, Russia, Netherlands, Estonia, and Lithuania. The emission factor for the electricity mix is an average of emission factors from 2016, 2017, and 2018. However, since the electricity flows may change quickly, with considerable investments in power plants coming up, there is reason to investigate the system boundaries for the following years. The allocation is made with an alternative product method, and the emission factors can be used for a whole life cycle assessment for the electricity (Sandgren & Nilsson, 2021). In Table 6, the average emission factors for electricity, and district heating, are presented.

Table 6: Emission factors from Klimatklivet, Naturvårdsverket (Naturvårdsverket, 2022).

Emission source	**[g CO_2 eq./kWh]**
Electricity	90
District heating, national average if the local value is missing	56

4.2.3 The Heating Market Committee *(*Värmemarknadskommittén*)*

Värmemarknadskommittén (VMK) consists of the Property Owners, HSB, Tenants' Association, Riksbyggen, Sweden's Public Service and Energiföretagen Sverige. Together they agreed on how the environmental impact of energy use for heating with district heating should be valued through a bookkeeping perspective. In the agreement, the companies have agreed on principles for environmental evaluation of changes in energy use based on a system view of society's energy supply. This system view means that several social objectives are considered, such as security of supply, competitiveness, and sustainability (Värmemarknadskommittén, 2022).

VMK presents two perspectives in the agreement. One for environmental declarations, bookkeeping perspective, and one to use when making decisions which lead to changed energy use, consequence perspective. The VMK consequence perspective is only a matter of principle. Each network should get an individual assessment to determine the environmental impact (Värmemarknadskommittén, 2022).

Climate assessment of district heating

The method for presentation of the environmental impact from property owners due to its energy use is to quantify the bought energy during a calendar year and multiply it with the environmental factors published by Energiföretagen for the specific grid of the location. Energiföretagen also supplies the average carbon dioxide factors from VMK (Table 7) to the district heating companies. The environmental performance through a bookkeeping perspective is calculated based on these factors, where the amount of used fuel in production is multiplied by its factors for carbon dioxide emissions and divided on the total delivered energy, using the amount of energy delivered to the end users (Värmemarknadskommittén, 2022).

VMK has three parameters that they believe are the most important; "Resource efficiency", "Climate impact" and "Share of fossil fuels". This report will only look at climate impact, which includes fossil carbon dioxide, methane, and nitrous oxide in the agreement; see Table 7. The emission factors for combustion are mainly taken from Naturvårdsverket, and the emission factor from the production and transportation of the fuel is mainly taken from Miljöfaktaboken. When it comes to waste heat (from e.g. industry processes), VMK follows the GHG calculation method, which states that emissions for the treatment of waste that becomes a resource in material recycling or in an incineration plant where electricity, heat, cooling, or steam is produced, are counted as zero CO_2 eq. (Värmemarknadskommittén, 2022). Waste heat from fume gas condensation is also considered as zero carbon dioxide emissions, according to Miljöfaktaboken.

When it comes to combustion of waste (from e.g., domestic waste, plastic waste, wood waste), VMK has an emission factor from VMK, which can be lower or higher if the energy company measures the emission in the combustion chimney. The calculation includes emissions from district heating grids bought by other district heating companies. Electricity is included in the calculation for production facilities, such as distribution pumps, pumping of waste heat and other similar facilities. A flat rate of 3.0% of sold district heating is used if data for help electricity is unavailable. In cases where the district heating company has used production or origin-specific electricity, this value is used. The Nordic residual mix from the Energy Markets Inspectorate (Energimarknads-inspektionen) from 2020 is used in other cases. Allocation between electricity and district heat in district heating production should be made according to the alternative product method (Värmemarknadskommittén, 2022). Weighting to global warming potential is made according to AR4 set to 1 for CO_2, 25 for CH_4 and 298 for N_2O (Khodayari, 2023).

Table 7: Emission factors from VMK (Värmemarknadskommittén, 2022).

	Combustion [g CO_2 eq./kWh]	Production and transport [g CO_2 eq./kWh]
Bituminous coal	370	14
Heating oil (EO1)	268	22
Heating oil (EO2-5)	275	22
Natural gas	200	45
Remaining fossil	275	22
Waste heat from industry and energy from fume gas condensation	0	0
Domestic waste	145	3
Landfill/Landfill gas-/Biogas	0.2	12
Steel industry gas waste	0	0
Primary wood fuel	4	34
Secondary wood fuel	4	7
Recycled wood	4	3
Pellets, briquettes, and powder	4	14
Biooil	1	4
Pine tar oil	1	4
Pine oil	1	19
Biogas	0	22
Remaining biofuel	1	34
Peat (district heating and electricity)	385	39
Electricity (Nordic residual)	372	-
Heat from heat pump minus electricity of heat pump	0	0

Method of environmental assessment for heated buildings through a consequence perspective

An environmental assessment when the energy use changes (e.g., lower energy use or changing the energy source after a renovation) according to the VMK agreement should be done with a consequence perspective, according to the following principles (Värmemarknadskommittén, 2022):

1. Parameters that shall be analysed for the environmental consequences when changing measures that affect energy use are “Resource efficiency”, “Climate impact” and “Share of fossil fuels”. Measures are performed in the same way as with the bookkeeping perspective.
2. The system perspective is calculated as northern Europe for the electricity and local environmental factors for district heating.
3. Long-term marginal values and how the values are affected by time should be used for the electric system and district heating and applied to the parameters presented in Stage 1. This will be the reference alternative for the changed measure.

4. The changed measures in question shall be compared to the situation if the action is not implemented, so-called alternative comparison.
5. The calculation method is to multiply the changed energy use (kWh electricity or/and district heating) during the lifetime of the changed measure with the margin values for the parameters in Stage 1.
6. Life span perspective shall be based on the changed measure's lifetime.
7. Forms of accounting measures, such as trading in origin-labelled renewable heat or electricity, should not be considered in the environmental assessment of the changed measure. Only the actual physical changes from the resulting change in energy use shall be used as the accounting measures.
8. The allocation between electricity and heat is irrelevant from the consequence perspective.
9. Regardless of whether the emissions are included in a trading system, the climate consequences shall be calculated with the margin value. This agreement only includes the changed energy use for the new decision and does not include a complete LCA.

4.2.4 The International EPD® System

The International EPD® System are the world's first and most extended operational EPD programme. It was initially founded as the Swedish EPD System by the Swedish Environmental Protection Agency and industry (The International EPD System, n.d.). With the help of Environmental Product Declarations (EPD) organisations and companies can objectively and transparent describe the total environmental impact of products and services from a life cycle perspective; from raw material extraction by manufacturing processes and use to waste management that includes all transport and energy use in the intermediate links. EPDs are third-party verified and can be applied for all types of products, such as transport, material, and energy sources (Gunnarsson, et al., 2021). Since EPDs are objective and transparent, they do not contain an assessment of environmental performance to say how the product compares to a specific target value or its performance compared to products within the same area. However, the results from an EPD can help spread understanding and can be used to compare products within the same area. A requirement for products to be comparable is that they follow the same rules and standards. Hence, predetermined calculation rules PCR (Product Category Rules) is the basis of how to calculate (ibid).

PCR "Electricity, Steam and Hot/Cold Water Generation and Distribution"
The PCR "Electricity, steam and hot/cold water generation and distribution" was last revised in 2021 in version 4.2 and is currently being updated, with publication expected for May 2023. The document is created within the framework of the International EPD® System for type III environmental declarations according to ISO standard 14025:2006. It provides product category rules for the assessment of the environmental performance of the product category as well as the declaration of this performance by an EPD. The product group includes technologies such as combustion based on fossil and renewable fuels, hydro- and wind power, nuclear technologies and ambient heat or electrochemical processes. The EPD can be produced for one and a defined set of conversion plants (The International EPD® System, 2021).

The validity of an EPD based on this PCR begins upon its registration and publication the official website for environdec. It will be valid for five years from the approval date indicated in the verification report or until the EPD is removed from the International EPD® System. During the validity period, an EPD must be updated and re-verified if there have been changes in technology or other circumstances that have resulted in:

- A 10 % or more increase in any of the environmental impact indicators,
- Mistakes in the declared information, or
- Significant changes to the declared information, content, or additional environmental information of the product

Table 8 defines specific rules, requirements, and guidelines for developing an EPD in a specific product category (The International EPD® System, 2021).

Table 8: Specific rules, requirements, and guidelines for developing an EPD.

Concept	Definition
Functional unit	"1 kWh net of electricity generated and thereafter distributed to the customer" and/or "1 kWh of steam or hot/cold water generated and thereafter distributed to the customer"
Reference service life	Given for different technologies: Combustion technologies - 40 years Ignition motor technologies – 30 years Nuclear technologies – 40 - 60 years Hydropower technologies Machinery (turbine, generator, etc.) – 60 years Pumping system in case of pumped storage – 50 years Power station building – 100 years Dams and waterways – 100 years Wind power technologies – 20 years Ocean technologies – 20 years Solar technologies – 30 years Electrochemical technologies Fuel cells – 20 years Ambient heat, waste heat from other processes and electricity Geothermal technologies – 40 years Heat pumps – 20 years Electric boilers – 30 years
System boundary	Cradle-to-grave.
Life cycle stages	Upstream processes (from cradle-to-gate) Core processes (from gate-to-gate) Downstream processes (from gate-to-grave)
System diagram	Illustrate the processes that are included in the product system, with upstream, core and downstream processes specified.
Cut-off rules	The environmental impact of a product system shall be determined by including data for elementary flows that contribute to at least 99 % of the declared environmental impacts, except for processes that are explicitly excluded from the system boundary. To ensure that cut-off rules are properly implemented, expert judgment based on similar product systems and a sensitivity analysis should be combined. This approach will help to understand the potential effects of uninvestigated inputs or outputs on the results.
Allocation rules	The sum of impacts for all individual products of a process must be equivalent to the overall impact of the process.
Data quality requirements	To conduct an LCA calculation, two types of information are required. Firstly, data related to the environmental aspects of the system being considered, such as materials or energy flows that enter the production system, which typically comes from the company conducting the LCA; this data should be as specific as possible and representative of the studied process. Secondly, data that relates to the life cycle impacts of the material or energy flows are required, which generally comes from databases; this data are classified into three categories: specific data, selected generic data and proxy data. Specific data shall always be used if available. There are specific rules for using generic data that are explained further in the PCR for "Electricity, steam and hot/cold water generation and distribution".

Concept	Definition
Recommended databases for generic data	No specific database is recommended for generic data. Data should fulfil the requirements in row above, under data quality requirements.
Impact categories and impact assessment	According to the General Programme Instructions, the EPD shall state the default impact categories. Default impact categories are available on the website and should be updated in the EPD on a regular basis, based on developments in life cycle assessment methodology while ensuring stability of the market for EPDs.
Other calculation rules and scenarios	In the PCR, there is states rules and scenarios for upstream-, core- and downstream processes as well as for greenhouse gas emissions.

Regarding the content and format of EPD, it must be in line with requirements and guidelines in the standard ISO 14020 (named "Environmental labels and declarations – General principles"*)* and be verifiable, not misleading, accurate and must not include any judgments, opinions, or comparison with other products (ibid, page. 27) For more information about the guidelines, rules and recommendations, this report refers directly to the PCR "Electricity, steam and hot/cold water generation and distribution".

4.2.5 Greenhouse Gas Protocol

The Greenhouse Gas Protocol (GHG Protocol) was launched in 1998 and is a multi-stakeholder partnership with Geneva-based coalition of 170 companies, the World Business Council for Sustainable Development, the US-based environmental NGO, non-governmental organisations, governments, and others convened by the World Resources Institute. The mission of the GHG Protocol is to develop internationally accepted greenhouse gas bookkeeping and reporting standards. GHG Protocol's "Corporate Accounting and Reporting Standard" is a standard where companies can follow a step-by-step guide for reporting greenhouse gas emissions. The protocol also has cross-sector and sector-specific calculation tools, providing systematic guidance and electronic worksheets for calculating greenhouse gases (Greenhouse Gas Protocol, 2015). The agency also offers emission factors for stationary combustion and electricity, as shown in Table 9. These are default values used when companies cannot develop custom emission factors. They are based on the latest expansive data, mainly identical to the values from 2018 used by IPCC. The combustion data is collected from Emission Factors for Greenhouse Gas Inventories (EPA) (United States Environmental Protaction Agency, 2018) and contains no allocation for energy turned into district heat, electricity, or steam (Gillenwater, 2005). The electricity mix is from EI European Residual Mixes (Association of issuing bodies, 2018). The GHG Protocol recommends using custom values first-hand (Greenhouse Gas Protocol, n.d.).

Three scopes are described in the GHG Protocol to distinguish direct and indirect emission origins, enhance transparency, and offer tools for different types of organisations and climate policies and business goals (Greenhouse Gas Protocol, 2015). The emissions are divided into three scopes that are explained as:

- **Scope 1** includes direct emissions from bought and used fuel and propellant in the company's operation, e.g., the emission from the company's facilities and vehicles.
- **Scope 2** addresses indirect emissions from bought energy such as electricity, steam, heating, and cooling for own use.
- **Scope 3** concerns other indirect greenhouse gas emissions, both upstream and downstream activities.
    - Upstream activities include emissions from employee commuting, business travel, waste from operations, fuel & energy related, capital goods and purchased goods & services.
    - Downstream activities include transportation & distribution, processing of solid products, use of solid products, leased assets, franchises, and investments.

All emissions created by the company outside scope 1 and 2, are included in scope 3. The companies must report all emissions for Scope 1. Scope 2 and Scope 3 are optional according to GHG Protocol's Corporate Standard. The GHG method does not consider climate compensation or avoided emissions (Sandgren, et al., 2022).

The GHG Protocol has created a common language and relativity easy calculation principle for worldwide companies with different scopes, clarifying responsibility and availability. However, because of the still interpretable standards, it can be challenging to compare companies with each other (Sandgren, et al., 2022). According to the GHG Protocol, the disposer does not account for the impact of combusted waste on energy recovery. This means that preventative measures to decrease the amount of upstream waste are overlooked because of the need for more perception among the property owners. The GHG Protocol has a backway bookkeeping perspective showing the number of emissions the year accounted for (Sandgren, et al., 2022). GHG Protocols' emission factors for stationary combustion and electricity, are shown in Table 9.

Table 9: Stationary combustion and electricity factors from GHG (United States Environmental Protaction Agency, 2018). Unit conversion from [kg CO_2 eq./mmBtu] to [g CO_2 eq./kWh].

Fuel	**[g CO_2 eq./kWh]**
Bituminous Coal	321
Municipal Solid Waste	316
Plastics	263
Tires	300
Peat	388
Wood and Wood Residuals	324
Natural Gas	181
Landfill Gas	179
Other Biomass Gases	179
Distillate Fuel Oil No. 1	251
Distillate Fuel Oil No. 2	253
Distillate Fuel Oil No. 4	257
Ethane	204
Natural Gasoline	229
Petroleum Coke	350
Residual Fuel Oil No. 5	250
Residual Fuel Oil No. 6	257
eGrid Subregion - Residual Mix - Market Based, Sweden	37

4.2.6 The Time Steps (Tidstegen)

Tidstegen is a method and tool for making climate comparisons of different energy measures, e.g., in a renovation or new construction. Tidstegen is based on a technique developed in multiple science projects between 2013 and 2020, together with the government, researchers, and the property- and building industry. The tool provides a decision-making basis for various energy investments and serves as a standard method for the energy- and real estate industry; the tool calculates how differences in energy use during the operational phase affect the future greenhouse gas emissions in the energy system. Furthermore, the method is anchored with VMK and fulfils their agreement on how changed energy use should be climate assessed from a decision-making perspective. Central starting points for Tidstegen are consequence analysis (bookkeeping perspective in the annual report), higher time resolution than ordinary practice and life cycle perspective (Lätt, et al., 2019). Tidstegen has assumed a time perspective to 20 years since this can be considered equivalent to the lifetime of energy solutions in buildings. A too long-time perspective in energy system scenarios can according to the project group of Tidstegen lead to more uncertain results (Lätt, et al., 2019, p. 11)

To use Tidstegen, the user (such as the property owner or the consultant) can report data for the energy use in a building with the different energy solutions the client wants to compare. The tool contains the climate impact data for different fuels for electricity, district heating and cooling; the energy companies provide marginal production for district heating and cooling; IVL provides marginal production for the electricity system; and climate assessment for district heating, cooling, electricity, and fuels. The result and output of the tool come out in the form of a climate assessment of various energy solutions in the building and presents how much carbon dioxide emissions are reduced compared to the reference case. So far, the calculation from Tidstegen is done by the project group of Tidstegen, and the tool cannot be used self-sufficient. It is the consequence of a change that is analysed. Energy companies can also use Tidstegen for climate assessment of various investments in the district heating grid (Tidstegen, 2023). In Figure 4, the basic principles of Tidstegen are presented.

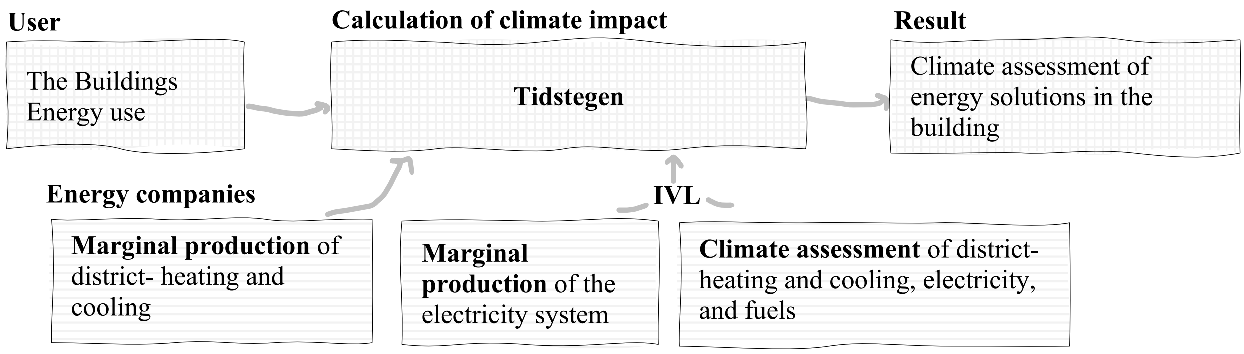


Figure 4: The methodology of Tidstegen.

Climate assessment for energy

The climate assessment for electricity, district heating and cooling are presented in the interim report within the project for "Tidstegen 5", which is a co-financing project between 2020 and 2023 with funding from the Foundation Institute for Water and Air pollution research (SIVL) and several energy companies. This report provides an update on the Tidstegen tool by incorporating new emission factors that affect the climate impact of marginal electricity, district heating and cooling production. These new values allow Tidstegen to reflect on the latest developments in the energy system, such as the pace of transition to more efficient energy production facilities and the increased knowledge of the environmental impact of various types of energy production (Nilsson, 2022).

Tidstegen incorporates emission factors resolved hourly to account for alternations in electricity use. These emission actors, measured in carbon dioxide equivalents per unit of energy, illustrate how the climate impact varies in response to changes in electricity use and is connected to the marginal production of electricity.

Adopting a forward-looking stance, various scenarios are employed to anticipate the long-term evolution of the climate impact of marginal electricity. Four distinct scenarios have been devised to forecast the evolution of the electricity system. These scenarios include “Ambitious Europe”, “Climate-neutral Nordic”, “Conservative”, and “Very Conservative”. These scenarios focus on predicting the hourly electricity production margin in Sweden while accounting for the connections to the European electricity system for 2020, 2025, 2030, 2040 and 2050. The central inquiry these scenarios aim to address is the impact of altered electricity use in Sweden on the operational margin of the European electricity system, given different scenarios. Based on the hourly series provided in the scenarios, emission factors were constructed for electricity (Nilsson, 2022).

The development of the electricity scenarios is based on four key factors, which are anticipated to influence the future electricity system significantly. These are presented in Table 10 and include:

1. The extent to which political signals, as reflected in the price of carbon dioxide, will be employed to mitigate the climate impact of the energy sector.
2. The level of public support for the expansion of solar and wind power
3. The projected growth in electricity demand, particularly about the demand for electro-fuels such as hydrogen and the electrification of industry
4. The feasibility of achieving carbon neutrality in the Nordic electricity system by 2050.

Table 10: Basic assumptions in the four electricity scenarios of Tidstegen.

	Scenarios			
	Very Conservative	*Conservative*	*Climate-Neutral Nordics*	*Ambitious Europe*
Price of carbon dioxide	Constant, €25/ton	Constant, €50/ton	Increasing, €100/ton year 2040	Sharply increasing, €140/ton year 2040
Acceptance of solar and wind power	Low	Low	Medium	Medium
Industrial electrification/demand for electro fuels	Low	Low	Medium	High
Nordic electricity system CO_2-neutral by 2050	No	No	Yes	Yes

The scenario “Very Conservative” represents a conservative prognosis for the European power system. It includes low solar and onshore wind power forecasts, mainly due to low public acceptance for expanding these sources. The carbon dioxide prices are assumed to remain constant at the 2020 level, i.e., €25/ton CO_2. At the same time, there is increasing electrification of the heating and transportation sectors, but the demand for electro fuels (Power-to-X) and electrification of the industry are low. Although the electricity sector exhibits a decrease in greenhouse gas emissions, the European power system will not be carbon-neutral by 2050. The European countries will not achieve their long-term goals for reducing greenhouse gases. The scenario “Conservative” closely resembles “Very Conservative” but with the difference that the price of carbon dioxide is assumed to remain constant at €50/ton CO_2. This scenario reflects the current policy situation in Europe. The “Climate-Neutral Nordics” scenario represents a scenario in which the Nordic countries become climate-neutral by 2050 while the rest of Europe achieves an 80 % reduction in greenhouse gas emissions by the same year. In this scenario, the transition to a climate-neutral energy sector depends on a higher carbon price, €100/ton CO_2 in 2040, and a faster deployment of solar and wind power than the two conservative scenarios. At the same time, there is an increased Nordic demand for electro fuels to reduce the climate impact of industry and long-distance transport, while in the rest of Europe, the demand for these products is lower. Compared to the other scenarios, where nuclear power is assumed to be phased out by 2040, 3 GW of nuclear power will still be present in the Swedish electricity system in 2050. The fourth and last scenario, “Ambitious Europe”, represents an ambitious development of the Nordic energy system. The Nordic countries become climate neutral and export affordable, renewable energy and low carbon electro fuels to Europe. This way, Europe can reduce its carbon footprint by

90 – 100 % from 2020 to 2050. The development of this scenario is driven by the highest carbon prices of all four scenarios (€140/tonne CO_2 in 2040). As a result of increased demand for electro fuels, such as hydrogen and ammonia, European electricity demand will increase by 90 % between 2020 and 2050 (Nilsson, 2022, pp. 9-10).

The Swedish electricity system is integrated with the rest of Europe in all four scenarios since it is closely interconnected with its neighboring countries. For the marginal data produced in Tidstegen, the aim is to answer the following question "How does a change in electricity use in Sweden effect the operating margin in the entire European electricity system when applying different scenarios?". In the new electricity scenarios, only the operating margin has been included to allow for a fairer comparison between the environmental impact of electricity, district heat, and cooling. The electricity production methods that are expanded or phased out in the long term have been assumed to depend on the factors captured in the four electricity scenarios that have been developed (ibid).

Emission factors

The optimization of the electricity system in the energy model Balmorel was based on emissions of greenhouse gases from fuel combustion (direct emissions). However, when calculating the final electricity production mix (outputs from Balmorel), life cycle assessment emission factors were used (including upstream emissions). The emission factors are primarily derived from Miljöfaktaboken (2011) for indirect emissions and Naturvårdsverket for direct emissions (2021). However, EA Energianalyse has made some amendments in instances where the emissions factors for certain fuels were not available in Miljöfaktaboken or Naturvårdsverket. The data supplied by EA Energianalyse can be utilised to revise the emissions factors for fuels and electricity production technologies in the future without requiring the development of new scenarios. Table 11 delineates the emissions factors for each electricity production technology utilised to generate the figures presented in this report. (Nilsson, 2022, p. 15). The hourly emission profiles for electricity use were calculated using the hourly marginal production for each year and scenario. The emission factors include the losses incurred during delivery to the end user. The average climate footprint for each year and scenario is lowest for the "Ambitious Europe" scenario and highest for the "Very Conservative" scenario (Nilsson, 2022, p. 17).

Table 11: Emission factors for electricity production technologies 2022, used in Tidstegen (Nilsson, 2022).

Type	Emission factor 2022	Unit
Domestic waste	41.41	[kg CO_2 eq./GJ]
Biogas	6.11	[kg CO_2 eq./GJ]
Biomass	10	[kg CO_2 eq./kWh]
Bio-oil	23.06	[kg CO_2 eq./GJ]
EO2-EO5	82.5	[kg CO_2 eq./GJ]
Nuclear power	5.89	[kg CO_2 eq./kWh]
Coal	108.61	[kg CO_2 eq./GJ]
EO1	80.56	[kg CO_2 eq./GJ]
Natural gas	69.17	[kg CO_2 eq./GJ]
Pellets	5.56	[kg CO_2 eq./GJ]
Solar power	27	[kg CO_2 eq./kWh]
Bituminous coal	108.61	[kg CO_2 eq./GJ]
Straw	10.83	[kg CO_2 eq./GJ]
Peat	116.11	[kg CO_2 eq./GJ]
Hydro power	10.52	[kg CO_2 eq./kWh]
Wind power	14.71	[kg CO_2 eq./kWh]
Wood waste	3.06	[kg CO_2 eq./GJ]

Climate assessment district heating

In the method of Tidstegen, emission factors associated with the fuels used in the marginal production of heat and cooling are used. During the fifth step of Tidstegen, the emission factors for different fuels were updated, and some new ones were added. When updating the emission factors, conversion factors are set to 1 for CO_2, 29.8 for CH_4, and 273 for N_2O were used, corresponding to the 100-year values for Global Warming Potential used by IPCC's sixth assessment report. For the climate impact of the production and distribution of different fuels, emission factors from Miljöfaktaboken are used to a large extent in Tidstegen. The emissions from using fuels, i.e., direct emissions from stationary combustion, primarily emission factors from Naturvårdsverket used in emissions reporting to the UNFCC (section 3.2.1) are used. The assumptions made for each fuel are presented in Table 12 below.

Table 12: Emission factors for the fuels, used in Tidstegen (Nilsson, 2022).

Fuels		**Sources**		**Assumptions**
	Emission factors 2022, [g CO_2 eq./kWh]	Production and distribution	Use	
Coal	391	Miljöfaktaboken	Naturvårdsverket	-
EO1	290	Miljöfaktaboken	Naturvårdsverket	-
EO2-EO5	297	Miljöfaktaboken	Naturvårdsverket	-
Natural gas	249	Miljöfaktaboken	Naturvårdsverket	-
Industrial waste heat	0	-	-	Rest product
Waste, Swedish (Decreased cooled heat)	0	IVL rapport B2398		This waste will be incinerated whether or not it is used for electricity or heat production.
Waste, imported (decreased electrical production)	71	IVL rapport B2398		This waste would have been used as energy fuel which is now replaced by fossil fuel combustion
Waste, imported (decreased landfill)	-46	IVL rapport B2398		This waste would otherwise have been landfilled.
Landfill and digestate gas	14	Miljöfaktaboken	Naturvårdsverket	Biogas from sludge
Waste gas from the steel industry	0	-	-	Rest product
Primary wood fuels	36	Miljöfaktaboken	Naturvårdsverket	Primary Salix
Secondary wood fuels	11	Miljöfaktaboken	Naturvårdsverket	Branches and treetops
Recycled wood	7	Miljöfaktaboken	Naturvårdsverket	Paper- wood- plastic for production and distribution
Pellets, briquettes, powder	20	Miljöfaktaboken	Naturvårdsverket	-
Bio-oil	4	Miljöfaktaboken	Naturvårdsverket	Larger part is organic oil
Pine tar oil	4	Miljöfaktaboken	Naturvårdsverket	Larger part is organic oil
Biogas	22	IVL rapport B2398	Naturvårdsverket	-
Other biofuels	39	Miljöfaktaboken	Naturvårdsverket	-
Peat	418	IVL rapport B2398		-

4.2.7 One Click LCA

One Click LCA was created in 2001 and is a calculating tool for life cycle assessments. It can be used in calculations for over 60 environmental certifications and has over 150 000 data points which undergo a ten-point verification reviewed by Building Research Establishment. It is the largest database of environmental construction data in the world and includes data on energy production. One Click LCA is used in over 100 countries and is also a tool that can make climate declarations according to Boverket's requirements (One Click LCA, n.d.a). All EPDs from the Swedish energy production company Vattenfall AB in One Click LCA have the text "The resource is missing impact categories in the source EPD". It is probably because the EPDs does not have emission factors for ODP (Ozone depleting substances) (One Click LCA, 2022). One EPD from Vattenfall AB with hydropower do not show the CO_2 eq. in the information text, which is why it is excluded from this report. All other EPDs from Vattenfall showed the CO_2 eq. and was included in this report. A summary of available EPDs is presented in the results.

4.2.8 Ecoinvent Database

Ecoinvent Database is a Life Cycle Inventory (LCI) database that currently contains more than 18 000 activities, also referred to as datasets and support various types of sustainable assessment. The database enables users to get more comprehensive understanding of environmental impacts of human activities and processes. The datasets contain information about the industrial or agricultural process that they model and measures the natural resources that are withdrawn from the environment, the emissions released to ecosystems, products demanded from other processes such as electricity as well as the products, co-products and wastes produced. The Ecoinvent Database covers a wide range of sectors such as the building and construction, energy, transport and waste treatments and recycling, among other industrial sectors (ecoinvent, n.d.). Each activity in the Ecoinvent Database relates to a geographic location and the aim is to cover activities in the most relevant geographies for the product or service studied. The geographic coverage depends on the quality and availability of the data and therefor, almost every activity in the database features a dataset that represents the process globally. Climate impact categories such as “climate change” and “human toxicity” are available in each dataset (ibid).

Each year the Ecoinvent Database are updated to include new, updated data as well as technical improvements. the release happens in the end of summer each year and most software tools with Ecoinvent Database integration are updated accordingly. When this thesis is written, the latest realise is Ecoinvent v.3.9.1 (ecoinvent, n.d.)

OpenLCA is an open source and free software tool that integrates Ecoinvent Database. The tool plays in the same league as commercial software LCA tools such as SimaPro and GaBi. The software is versatile and meet the needs of different user groups, such as in industry, consultancy, education, and research (OpenLCA, n.d.)

Emission data from Ecoinvent Database v.3.9.1 will not be presented in this study due to Ecoinvent rules and guidelines. The database was purchased and are not public data.

4.3 Methods to calculate life cycle module, B6, operational energy use

In this section, different methods to calculate climate change are presented. The focus is on the methods considering the life cycle module B6 for operational energy use and are well-established methods and tools used in the building industry.

4.3.1 Local Environmental Values by Energy Companies’ Sweden (Energiföretagen Sverige)

Energiföretagen Sverige is an organisation that brings together nearly 400 companies that produce, distribute, sell, and store energy. The organisation acts as the industry’s voice in the public debate and is a significant facilitator of climate change, as the energy sector is almost entirely fossil-free in its energy production. The energy companies work to enable a fossil-free society by 2045 through the energy industry and the electrification of society. They also drive change for a sustainable society and work to generate competitive advantages for Swedish companies through secure energy supplies (Hörnell, 2023). The local environmental values from district heating have been compiled by this organisation and are presented every year since 2009, including calculations for resource use, climate impact and the proportion of fossil fuels for production in each local district heating network. District heating customers, media, and other interested parties can then use the environmental values to see the environmental impact of district heating locally. The values can be used to report emissions to various environmental systems. How the values are used depends on the customer and the requirements of the various reports and certifications of buildings. The environmental values are presented in three perspectives: resource efficiency, climate impact and share of fossil fuels. Other environmental impacts factors, such as particulate matter and acidification, are not included in the environmental values (Khodayari, 2022). The calculations are based on the conditions of the previous year and the agreement between Energiföretagen Sverige and VMK, hence the method reference to section 4.2.3 where the three perspectives are explained. The values are presented with life cycle assessment and include emission factors from Naturvårdsverket and Miljöfaktaboken.

4.3.2 Climate Database by The Swedish National Board of Housing, Building, and Planning (Boverket)

The climate database is developed by Boverket, enabling the construction industry to retrieve generic climate data for resources in the construction phase to the climate declaration. The climate database was updated on 25 January 2023 with new products and updated climate data (Boverket, 2023). Table 13 presents the climate indicators for electricity (Swedish mix) and district heating (Swedish average). The climate database was updated on 25 January 2023 with new products and updated climate data (Boverket, 2023).

Table 13: Climate indicators for calculation in climate declaration, derived from the Climate Database (2023).

Product	**Product standard**	**Emission factor GWP-GHG, typical value**
District heating, Swedish average	EN 15804	56 g CO_2 eq. /kWh
Electricity, Swedish mix	EN 15804 A1	37 g CO_2 eq ./kWh

District heating, Swedish average
The data is a representative average for Swedish district heating, and the emission factor is taken from Naturvårdsverkets' calculations in Klimatklivet (2022) for a Swedish average. The product should be used as district heating purchased from a local network for several purposes (Boverket, 2023). The average emission factor is based on the statistics from Energiföretagen, between 2018 and 2020, and emission factors in Miljöfaktaboken (Naturvårdsverket, 2022).

Electricity, Swedish mix
The data used for environmental impact from electricity is based on Swedish electricity mix, where exports and imports have been considered. The emission factor is an average value from 2015 to 2017, published by IVL rapport C433 (2019) and is based on annual statistics from ENTSO-E. The calculation of the climate impact of the electricity mix has been made considering the methodology of the Fuels Directive (98/70/EC), the Clarification Directive establishing calculation methods and reporting requirements for fuels ((EC) 2015/652) and the Renewable Energy Directive ((EU) 2018/2001). The calculations follow EN 15804 and the Swedish Energy Agency's recommendations on how the environmental impact of electricity production should be reported and used. The LCA tool GaBi and upstream LCA data for electricity, based on processes representative of Swedish plants, have been used for the calculations. As emissions from annual production differ between years, the calculation has been made for a three-year average using the years 2015 – 2017 (Boverket, 2023).

Climate declarations
From the first of January 2022, the Swedish government requires climate declarations to be made when buildings are constructed, and the climate database can be used to retrieve generic climate data for resources in the construction phase. The climate declarations present a calculation of the greenhouse gas emissions from a building during the construction phase, modules A1 to A5. The emissions that occur during the building's operating time in the form of energy use are not included in the declaration. The declaration aims to reduce the climate impact of the construction of buildings and is an integral part of the roadmap for a climate-neutral construction industry by 2045. The intention is to increase awareness and knowledge of the climate impact of buildings by identifying and calculating their climate impact. The requirement has served to steer the industry towards increased knowledge of life cycle analysis and does not impose any requirements on what climate impact is allowed: the climate declaration is a method. It does not contain any limit values yet (Boverket, 2022). Limit values covering the construction phase (A1 to A5) are proposed to be introduced in 2027, and more

building components than the legislative proposal from 2022, such as B2, B4, B6 and C1 to C4. The limit values also mean laying a more excellent foundation for development towards a climate-neutral construction industry, according to the national climate target for 2045. Furthermore, a calculation period of 50 years will be the practice in the 2027 version of the climate declaration; this harmonises with most countries in the Nordic region and Europe. The calculation period is also in line with the fact that buildings are renovated extensively after that time (Boverket, 2020, p. 43). Regarding what calculation tool to use for the climate declaration, Boverket does not impose any requirements for software or database. The choice of calculation programme is free, assuming that the calculations are carried out with climate data by the rules and that all the required information is included in the declaration. Furthermore, a climate declaration may use generic climate data from the Boverkets climate database or specific climate data for construction products (EPDs) (Boverket, 2021).

4.3.3 The Climate Steps (Klimatstegen)

Klimatstegen is a method that aims to reduce the climate impact of existing buildings. It comprises 20 climate key numbers or KPIs and targets facility managers and technical facility management. The Klimatstegen, which defines the building's status, includes “Started”, “Good”, “Very Good”, and “Climate-Optimised”. There are no limit values between the different statuses. It is not a certificate system, meaning that there are no third-party reviews to assess whether the building and facility management has undergone improvements. Instead, the focus is on implementing wise and improved efforts for the specific building based on its state and the capability of the facility managers. The Klimatstegen method guides the facility manager on the order of actions to be carried out and the number of resources needed. These actions vary from more straightforward, more budget-friendly options to more complex ones that require money, time, support, or expertise (Klimatstegen, 2023). Klimatstegen includes one specific climate key number, 1b, referred to as energy use and measured in climate impact (in kg CO_2 eq./m^2, Atemp). The manual climate key number outlines how the climate impact should be calculated for district heating and electricity. For district heating, the heating energy impact is calculated using the emission factor (in kg CO_2 eq./kWh) of the connected district heating plant to the building. The manual recommends using Energiföretagen’s yearly review of emission factors for each district heating company, which is available on their website.

District heating

In cases where a district heating company presents two emission factors (residual and green district heating), the residual emission factor should be used in the Klimatstegen. If the building has a heating system, Boverket’s climate database must be referred to determine the specific fuel emission factor. An alternative to Energiföretagen's annual emission factors is using Naturvårdsverket's emission registry. However, these factors require some manual adjustments and only account for combustion, not production and transportation of the fuel. EPDs can also be used but are showing lower values in some cases than Naturvårdsverket. Until new calculation rules are developed, Klimatstegen recommends using Energiföretagen's annual published emission factors (Warfvinge, 2023, p. 3)

Electricity

Regarding electricity, the climate impact is determined based on the Swedish electricity mix as per Boverket's climate database, which follows international calculation rules to prevent double calculation. To prevent accusations of "greenwashing" it is prohibited to use allocated emissions that result in deviations from national and international reporting rules in Klimatstegen. For example, it is not accepted to use green electricity, green district heating or “Good Environmental Choice” choice. Emission factors that incorporate harmful emissions, avoided emissions, or climate-compensated emissions are also not allowed (Warfvinge, 2023, p. 3).

After a year, the progress made will be monitored. To facilitate progress tracking, the difference in energy usage is multiplied by the emission factors from the previous year. The fundamental values are internally summarised each year and used to plan for new improvements (Warfvinge, 2023).

4.3.4 ZeroCO_2 (NollCO_2)

The environmental certification NollCO_2 was launched in the autumn of 2022 by Swedish Green Building Council (SGBC) as an add-on to their certification systems Miljöbyggnad, BREEAM-SE, LEED and Svanen. The certification NollCO_2 requires that the building's greenhouse gas emissions are reduced by setting limit values for greenhouse gas emissions from manufacturing the building components, from the construction processes and indirectly by limiting the building's energy use. Furthermore, the certification requires that the remaining climate impact of the building impact is balanced with climate measures, such as compensation, to reach net zero climate impact. NollCO_2 includes the entire life cycle of a building (A – C) after the functional life of 50 years has been reached (SGBC, 2023). Regarding limits in NollCO_2, a project-specific carbon limit is set for modules A1 - A3, a static energy carbon limit for modules A4 - A5 and an energy performance limit for module B6. The climate impact from the building and its elements must be calculated according to the standards SS-EN 15978 and SS EN 15804, and the unit of climate impact for one kg building element is set to 1 kg CO_2 eq./kg. In terms of expected building service life, this follows the guidelines from Boverkets new climate declaration for new buildings: the expected building service life is a 50-years after the building is put into operation (Stoll, 2022, p. 3)

In the net-zero model presented in NollCO_2, the embedded climate impact and energy and water use impact for the building's physical system boundary are balanced with climate actions, presented in Figure 5 below. These include the installation of renewable electricity, energy-efficient measures in existing buildings and carbon offsetting that meets the certifications environmental integrity criteria. A building that is certified with NollCO_2, therefore, has net zero climate impact.

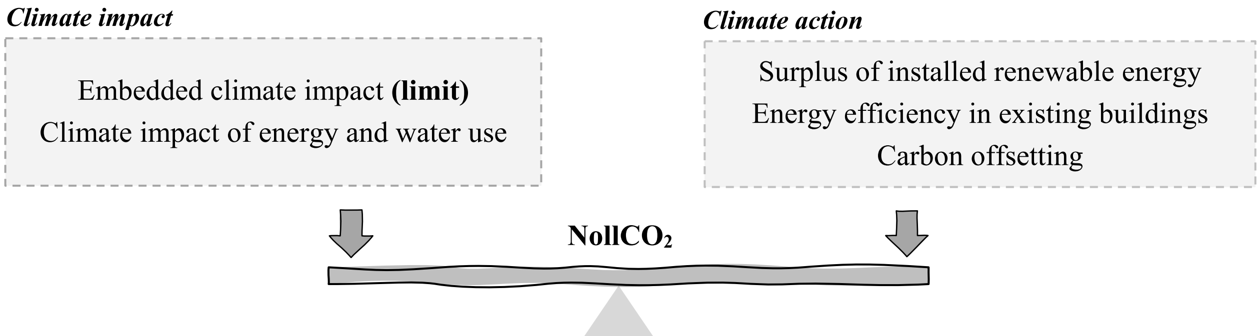


Figure 5: The methodology of reaching net zero balance in NollCO_2.

In NollCO_2, the building's energy use and module B6 are treated under the certification system indicator 6, aiming to design and construct buildings for low energy use and low climate impact of energy use. The climate impact of the supplied energy use in the building (not including operational energy) is reported in B6 as an annual climate impact. This is balanced on an annual basis to net zero in the certification system indicator 9**.** If technical equipment is used to produce renewable energy on the property used in the building, the life cycle impact of this is recognised as a one-off item under the upstream of B6.

The method for Indicator 6, regarding the climate impact of the building's energy use, follows different directions depending on whether the project has a specific energy agreement, available EPDs, self-produced energy or is using waste heat to heat the building.

When the project does not have a specific energy agreement, or EPD does not exist, generic climate data based on the energy production's life cycle climate impact will be used. This means that also renewable energy has a specific climate impact. The climate database from Boverket can be used for energy agreements in the “Energy and fuels” category. If the NollCO_2 project produces its energy, and where the production technique is a non-integrated part of the building, the following generic climate data from IPCC 2014 will be used, predicting that there is no available climate data for the following energy types from Boverkets Climate Database:

- Solar power 41 g CO_2 eq./kWh
- Wind power 12 g CO_2 eq./kWh
- Bioenergy 40 g CO_2 eq./kWh

There are other guidelines when the project has a specific energy agreement, supplier of waste heat or own technique for self-produced renewable energy. When there is an available EPD, the project can use the climate data under the conditions that it has been prepared according to PCR rules and the latest version for “Production and distribution of electricity, steam and hot and cold water”, “General program instructions for environmental product declarations” and ISO 14025 and ISO 14044. The latest version should always be used if available and the (GWP) in the EPD. When the supplier’s electricity agreement is certified with the label “Good Environmental Choice” from Naturvårdsverket, the following climate data can be used for each type of electricity contract:

- Wind 14.8 g CO_2 eq./kWh
- Hydro 8.6 g CO_2 eq./kWh
- Solar 30.5 g CO_2 eq./kWh

When waste heat is used for heating, this should be calculated and presented with its original energy carrier (SGBC, 2022, p. 45). The climate impact from waste and recycled energy should be presented as the impact of the original electricity or energy production that created the heat, based on the guidelines from GHG Protocols. In a NollCO_2 project, the initial energy production cannot be produced from fossil fuels (SGBC, 2020, p. 24).

The climate impact of producing the technical equipment for producing renewable energy used in the building should be presented in NollCO_2 according to the standard SS-EN 15978. A photovoltaic installation in the life cycle climate impact calculation should not be reported in A1 to A3 but according to EN 15978 in B6. In the certification, this climate impact is put under B6 upstream once and balanced to a net zero balance, with A1 to A5 and C1 and C4 in Indicator 9. If the technical equipment for renewable energy is an integrated part of building elements, it will be presented in the same approach as a non-integrated part. Biogenic carbon emissions in B6 are not included in NollCO_2, for example, a pellet boiler (SGBC, 2022).

Climate impact from electricity use

NollCO_2 regards both import and export in terms of electricity since a country has several transmission lines between itself and other countries. Statistics with hourly resolution on imports and exports are in the certification obtained from the ENTSO-E Transparency Platform. Regarding Swedish domestic electricity production, statistics with the hourly resolution are obtained from Swedish Power Grid (Svenska Kraftnät). The intensity of CO_2 eq. for individual types of power, such as wind power and coal, is obtained from the IPCC 2014 report. To calculate the CO_2 eq. intensity for the Swedish electricity mix, NollCO_2 has used data from 2018 according to the EU JRC method. This is done with a book-keeping perspective where the life cycle-based CO_2 eq. intensity is used for a type of production, domestic protection, imports/exports, and line losses. Since the intensity varies over the year’s hours, the calculation is done as an average over the year's hours. When all countries within the EU use the same calculation model over their country’s electricity mix and CO_2 eq. intensity, double-entry bookkeeping is avoided in the EU. The result of SGBC’s calculated CO_2 eq. intensity for the Swedish electricity mix, with data from 2018, is **22 g CO_2 eq. /kWh** of electricity used. The framework from NollCO_2 states that it is preferable not to use data older than five years in a life cycle assessment calculation (SGBC, 2020, p. 23)

Climate impact from bought electricity

In the NollCO_2 framework (section 4.2.1) it is stated how the climate impact of using energy should be calculated. The calculation is done by applying the CO_2 eq. intensity of the energy use to the energy use according to the equation:

$$Climate\ Impact\ [kg\ CO_2\ eq.] = Energy\ use\ [MWh] \cdot CO_2 intensity\ [kg\ CO_2\ eq./MWh]$$

Reference is made to the GHG Protocol Scope 2 Guidance, where reporting can be done using either the location- or market-based method. The difference is that the location-based method calculated an average value of the electricity network in which the project is located (and can be applied to all electricity networks). In contrast, the market-based method calculates the suppliers' specific CO_2 eq. intensity calculated according to Scope 2 criteria and reported using market instruments. The market-based approach can only be used when customers can choose between different electricity contracts. Market instruments are based on recognised standards for environmental declarations of energy figures, and those available to customers in Sweden are "good environmental choice" and "EPD". When such an agreement is used in a NollCO_2 project, the CO_2 eq. intensity reported in the agreement shall be used as climate data for the electricity. When there is no environmental declaration, the geographically based method for obtaining a value for generic climate data shall be used. The EU JRC model explained in a few paragraphs above is then used as the geographic method (ibid, s. 24)

The system boundary is the Nord Pool electricity market, as it is considered that virtually all trade in electricity within the Nordic region takes place through this market. The system boundary also refers to the countries on Nord Pool's market where Sweden is physically interconnected in terms of electricity transmission, with the countries Norway, Denmark, Finland, Poland, Germany, and Lithuania (SGBC, 2020, p. 25)

Climate impact from bought district heating

As with electricity use, generic climate data can also be used for district heating, with the geographical boundary in the calculation set to Sweden in NollCO_2. NollCO_2 presents a value for generic climate data and Swedish district heating of 60 g CO_2 eq./kWh, which should be used when the project's district heating contract does not have an EPD. The calculation is based on a report regarding electricity, gas, and district heating supply (2018) from Statistics Sweden (SCB) and the Swedish Energy Agency, and the emission data for power and heat production from Naturvårdsverkets' website for environmental statistics. According to Naturvårdsverkets' statistics, 83 % of the reported greenhouse gas emissions come from cogeneration, 16 % from district heating and 0.5 % from electricity production. For the calculation, SGBC has used the GHG protocol's tool "CHP_tool_v1.0" (SGBC, 2020, p. 24). The climate impact of grid-supplied renewable electricity is calculated using a different method than the climate impact of used electricity, using the GHG Protocol's "Project accounting" guide and "Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects". Grid-supplied renewable electricity is not a climate action in NollCO_2 (ibid, s. 24).

Validity of reference year

Within the framework of NollCO_2, a projection of the climate impact and value of climate action for a calculation period of 50 years are applied and calculated. It is necessary to start from the current climate value and calculate how this may change over 50 years and beyond. This is made possible by international and national energy system scenarios. The EU's goal is for the electricity network within the EU's borders to be climate neutral by 2050 while in Sweden by 2045. With the NollCO_2 tool for balance calculation, NollCO_2 has enabled a linear interpolation between the current and future climate values, where the future value is set to zero (ibid, page 28).

On-site produced energy

For climate impact savings from one on-site energy produced, energy reference values from IPCC are presented in NollCO_2. The emission factors for solar power are set to 41 kg CO_2 eq./MWh, bio energy 40 kg CO_2 eq./MWh, gas 490 kg CO_2 eq./MWh (SGBC, 2020, p. 30)

Prioritization of climate data

Since there is no complete set of generic climate data available in only one database for all products and materials, NollCO_2 refers to several databases of generic climate data. The reference is made in a certain order of priority, where the priority 1 database has higher priority than database 2 or 3.

- Priority 1 are given to product specific EPD. If there is an available EPD for the product or process, the GWP within should be used.
- Priority 2 are given to the Swedish climate database from Boverket, since NollCO2 are developed on the Swedish market.
- Priority 3 are given to the Finish Environmental Protection Agency's database co2data.fi. This climate database has priority 3 because the Swedish authority Boverket and the Finnish EPA have co-operated in the development of their respective database.
- Priority 4 is given to the German database "Ökobau.dat". which generic climate data are developed according to EN 15804+A2.
- Priority 5 is given to simplified life cycle emission (LCE) calculations.
- Priority 6 is given to the proxy EPD produced according to EN 15804+A2 for an equivalent product.

(SGBC, 2022, pp. 24 - 25)

5 Results

In this chapter, the information from the theory chapter is narrowed down into tables for sections 5.1 and 5.2, where emission factors and methods are compiled for an overview and to distinguish any potential differences. The emission factors can be considered as the core of the literature study, which is the methods used for calculating the climate impact of heating buildings. Figure 6 shows the concept of the results. The third section, section 5.3, presents the interview material collected during the research and can be considered separate from sections 5.1 and 5.2. This section is also excluded from the analysis and will only be covered by the discussion.

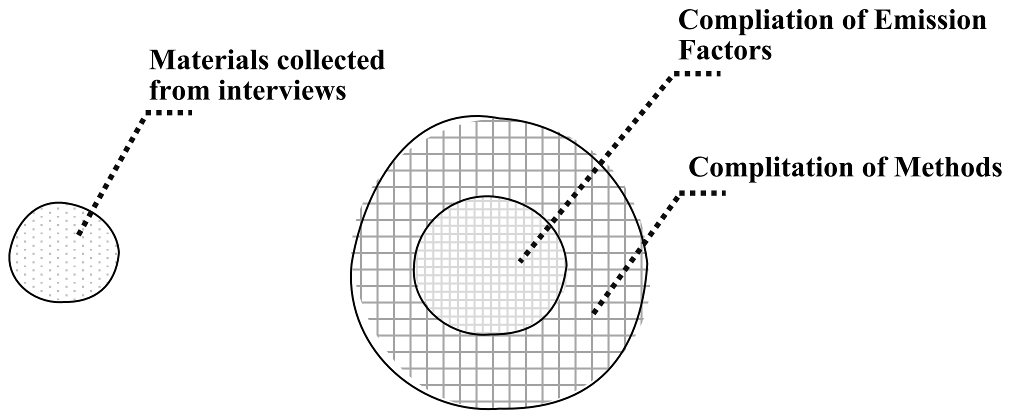


Figure 6: Schematic figure of the result chapter.

5.1 Compilation of emission factors

5.1.1 District heating

The whole compilation of emission factors is assembled in Appendix 1, by each source and by each fuel category. The table shows the source of all emission factors, what weighting has been applied (see Table 14 for weighting factors for CO_2, CH_4 and N_2O) and the life cycle stages on which the emission factors are based. Thus, the table gives a compilation of the emission factors available for district heating and each type of energy fuel. Since there are various names and groupings of fuels, it is challenging to place for comparison between the different sources of emission factors. Hence, Table 15, is a selection of the whole compilation. Average mixes, factors from One Click LCA and EPDs with complete mixes of district heating are presented separately in Table 16 and Table 17.

Table 14: Weighting factors for carbon dioxide, methane, and nitrogen oxides for carbon dioxide equivalents.

Nr.	CO_2	CH_4	N_2O	Source
1.	1	23	296	RES-directive, 2009
2.	1	25	298	IPCC AR4, 2007
3.	1	28	265	IPCC AR5, 2014
4.	1	29.8	273	IPCC AR6, 2021 and 2022

Table 15: Emission factors for district heating and each type of energy [g CO_2 eq./kWh]. The merged cells mean that all fuels to the left are included in the merged cell value. E.g., read 20 g CO_2 eq./kWh for a fuel that includes wood pellets and wood briquettes in Tidstegens' merged cell. As mentioned in the method and literature study, Ecoinvent is excluded in this result.

<table>
<tr><th></th><th colspan="3">Miljöfaktaboken</th><th>GHGP</th><th colspan="2">Naturvårdsverket</th><th colspan="3">VMK</th><th>Tid-stegen</th></tr>
<tr><td>Source</td><td colspan="3">Literature study from 70 individual energy sully chains (2011)</td><td>United States Environ-mental Pro-tection Agency EPA (2018)</td><td>Litera-ture studies and measure-ments (2022)</td><td>Klimat-klivet, based on Miljö-fakta-boken (2011)</td><td colspan="3">Miljöfaktaboken (2011) and Naturvårdsverket (combustion)(2022)</td><td>Miljö-fakta-boken (2011) and Natur-vårds-veket (2021)</td></tr>
<tr><td>Allocation between heat and electricity in co-generation</td><td colspan="3">No</td><td>No</td><td>No</td><td>No</td><td colspan="3">Alternative product method</td><td>Alternat ive product method</td></tr>
<tr><td>Weighting to CO_2 eq.</td><td colspan="3">1</td><td>3</td><td>3*</td><td>1</td><td>2</td><td>2</td><td>2</td><td>4</td></tr>
<tr><td>Lifecycle stage</td><td>Pro-duction and distri-bution</td><td>Use</td><td>Total</td><td>Com-bustion</td><td>Com-bustion</td><td>Extrac-tion, transport, conver-sion, and com-bustion</td><td>Pro-duction and tran-sport</td><td>Use</td><td>Total</td><td>Pro-duction, distri-bution, and use</td></tr>
<tr><td colspan="11"><u>Flue gas condensation</u></td></tr>
<tr><td>Flue gas c.</td><td></td><td></td><td></td><td>0.0</td><td></td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td></tr>
<tr><td colspan="11"><u>Waste</u></td></tr>
<tr><td>Domestic waste</td><td>0.3</td><td>10</td><td>11</td><td></td><td></td><td>144</td><td>3.0</td><td>145</td><td>148</td><td></td></tr>
<tr><td>Recycled wood</td><td>0.2</td><td>0.0</td><td>0.3</td><td></td><td></td><td>3.2</td><td></td><td></td><td></td><td>7.0</td></tr>
<tr><td>Biogenic waste</td><td></td><td></td><td></td><td>410</td><td>215</td><td></td><td>3.0</td><td>4.0</td><td>7.0</td><td></td></tr>
<tr><td colspan="11"><u>Waste gas</u></td></tr>
<tr><td>Landfill/ landfill gas-/Biogas</td><td></td><td></td><td></td><td></td><td>335</td><td></td><td>12</td><td>0.2</td><td>12</td><td></td></tr>
<tr><td colspan="11"><u>Biofuels</u></td></tr>
<tr><td>Branches and treetops</td><td>0.5</td><td>0.1</td><td>0.6</td><td rowspan="6">324</td><td rowspan="6">382</td><td rowspan="4">9.4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Logs</td><td>0.7</td><td>0.1</td><td>0.8</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Thinning wood to wood chips</td><td>0.5</td><td>0.1</td><td>0.6</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Forest chips</td><td>0.7</td><td>0.1</td><td>0.7</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bark</td><td>0.4</td><td>0.1</td><td>0.4</td><td>5.8</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Chips, sawmill residues</td><td>0.4</td><td>0.1</td><td>0.4</td><td>5.8</td><td></td><td></td><td></td><td></td></tr>
</table>

	Miljöfaktaboken			**GHGP**	**Naturvårdsverket**		**VMK**			**Tid-stegen**
Wood Pellets	1.0	0.4	1.4			19	14.0	4.0	18.0	20.0
Wood briquettes	1.2	0.4	1.6			21				
Willows	2.1	0.1	2.2			28				
Pine tar oil	0.0	0.1	0.1		274	6.5	4.0	1.0	5.0	4.0
Biogas				179			22	0.0	22	22
Remaining biomass					2.0		34	1.0	35	39
<u>Peat</u>										
Peat	3.1	30	33	389	385	425	39	385	424	418
<u>Natural gas</u>										
Natural gas	3.3	16	19	181	200	248	45	200	245	249
<u>Oil</u>										
Heating oil (EO1)	1.6	21	22	251	268	288	22	268	290	290
Heating oil (EO2-5)	1.6	21	23		275	295	22	275	297	297
<u>Bituminous coal</u>										
Bituminous coal			30	321	335	385	14	370	384	391
<u>Other fossil fuels</u>										
Remaining fossil					253		22	275	297	
Waste heat industry	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0

**The emission factors for Naturvårdsverket's combustion are weighted according to AR5, recommended according to Naturvårdsverket's website, see section 4.2.2.*

Klimatklivet from Naturvårdsverket, VMK and Tidstegen have sources from Miljöfaktaboken that is 12 years old (2011). Miljöfaktaboken, in turn, takes its data from literature studies and individual sources. GHG Protocol takes the emission data on EPA from 2018, and the Naturvårdsverkets emission factors for combustion are based on literature studies and measurements from 2022. VMK and Tidstegen uses allocated emission factors with the alternative product method. For weighing CO_2 eq., the sources that presents emission factors use different methodologies from 2007 to 2022.

When it comes to system boundaries, not all the emission factors are from a complete life cycle. GHG Protocol and Naturvårdsverket only account for combustion in their direct emission factors, while the others account for production, distribution, transportation, and use. Although data for some fuels have been removed for those that could not be compared with other sources that presents emission factors, it is still challenging to understand as it is and to determine what the different fuels contain. For example, the categorization of fuels can differ between different methods, but it is the same fuel to which they refer. Some categories have a collective name for several fuels. For example, recycled wood from Miljöfaktaboken may be a single category, while in the GHG Protocol, it may be included in biogenic waste. Further results of one specific fuel, Heating oil (EO1), is presented in Figure 7.

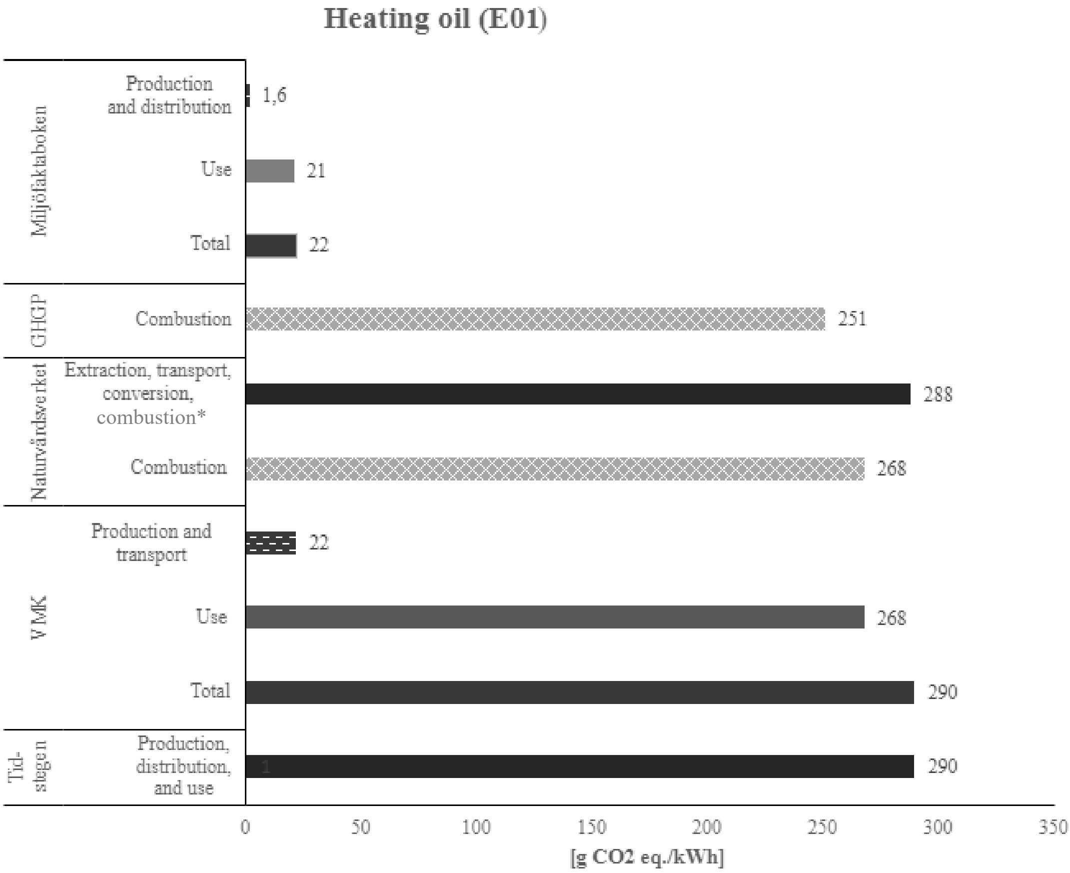


*Figure 7: Emission factors for the Heating oil (EO1) and different sources that presents emission factors. *Klimatklivet.*

Figure 7 compares the various factors in Heating oil (EO1). Production and transport/distribution (grey bar with a line) can compare with the value in the Miljöfaktaboken and the approximately fourteen times higher value in VMK. Even for use (grey bar), the value for Miljöfaktaboken is much smaller, about thirteen times smaller. Total values for a complete life cycle assessment (black bar) are compared in all sources that presents emission factors, except GHG Protocol (GHGP). Miljöfaktaboken has the lowest emission factor, followed by Tidstegen, VMK and the Naturvårdsverket which has the highest emission factor. However, this is something that varies for the other fuels. Miljöfaktaboken generally has ten times lower emission factors than Naturvårdsverket, VMK and Tidstegen, which the three lays generally close to each other. GHGP can be compared with Naturvårdsverkets' (combustion) slightly lower value for combustion (checked bar). The rest of the fuel values in Naturvårdsverket and GHGP do not follow the same pattern, but these values are generally close.

Naturvårdsverket and One Click LCA are two methods that present an average emission factor for district heating, displayed in Table 16. As mentioned in the methodology (section 2.4), according to guidelines, the Ecoinvent database is excluded from this compilation, even though they also present an average value.

Table 16: Average emission factors for district heating.

District heating average		
Source emission	**[g CO_2 eq./kWh]**	**Source**
Naturvårdsverket (Klimatklivet)	56.0	Energiföretagen (2018 - 2020) and Miljöfaktaboken (2011)
District heating, National Swedish mix, CO_2 only, One Click LCA	56.2	Boverket, version 02.03.000, 2022-5-20 (2021)
District Heat, Sweden, One Click LCA	34.5	LCA study for country specific district heating based on IEA, One Click LCA 2023 (2020)

The table shows that the emission factor from Klimatklivet is the same as the national Sweden mix from One Click LCA. The emission factor from One Click LCA regarding district heating, Sweden, has a lower value compared to the two other averages.

The EPD systems provides a specific global warming potential (GWP) for a particular combustion plant or grid, which means they cannot be assembled according to Table 16 above, where specific emission factors for different fuels are presented.

In Table 17 the emission data available from EPDs for district heating in Sweden are presented. With each EPD, dates for registration/version/validation and time representativeness, energy source, emission factor (g CO_2 eq./kWh), software, database, and system boundaries are presented.

Table 17: Emission data from EPDs, available for district heating in Sweden.

EPD with EPD-number	**Dates**		**Energy source**	**[g CO_2 eq./kWh]**	**Software/ Database**	**System boundaries**
Kraftringen, Lund-Lomma-Eslöv **S-P-06687**	Registration date	2022-09-12	From several conversion plants	11.1	GaBi LCA (10.6) / GaBi (2021.2), Ecoinvent Database 3.8 (2022)	Cradle-to-grave, excluding end use of the heat
	Version date	2022-09-13				
	Valid until	2027-08-24				
	Time representativeness	2020				
Kraftringen, Brunnshög, Lund **S-P-06688**	Registration date	2022-09-12	Recovered waste heat	15.6	GaBi LCA (10.6) / GaBi (2021.2), Ecoinvent Database 3.8 (2022)	Cradle-to-grave, excluding end use of the heat
	Version date	2022-10-20				
	Valid until	2027-08-24				
	Time representativeness	2020				
Hässleholm Miljö AB, Beleverket, Hässleholm **S-P-05636**	Registration date	2022-06-23	Fuels consists mainly of sorted combustible waste and biomass	35.5	SimaPro 9.3/ Ecoinvent 3.8	Cradle-to-grave (as defined in PCR)
	Version date	-				
	Valid until	2027-06-23				
	Time representativeness	2020				
Kraftringen, Örtofta **S-P-07523**	Registration date	2023-03-17	Biofuel	13.8	GaBi LCA (10.6) / GaBi (2022.2), Ecoinvent Database 3.8 (2022)	Cradle-to-grave, excluding end use of the heat
	Version date	-				
	Valid until	2028-02-20				
	Time representativeness	-				
Tekniska verken i	Registration date	2023-03-17	Mainly from energy recovery	11.0		Cradle to distributed
	Version date	-				

EPD with EPD-number	Dates		Energy source	[g CO_2 eq./kWh]	Software/ Database	System boundaries
Linköping AB, Linköping **S-P-08296**	Valid until	2028-03-16	of residual waste and renewable fuels such as woody biomass and bio-oil		SimaPro 9.4/ Ecoinvent Database 3.8	district heating to customer
	Time representativeness	2021				
Stockholm Exergi, Stockholm **S-P-05797**	Registration date	2022-11-18	District heating from mainly renewable or recycled energy	14.8	SimaPro 9.2/ Ecoinvent Database 3.7	Cradle to distributed district heating to customer
	Version date	2023-02-07				
	Valid until	2027-11-18				
	Time representativeness	2020				
E.ON Energiinfrastruktur AB, Slammertorps värmepumpar, Järfälla **S-P-05022**	Registration date	2022-05-04	Has two sea water heat pumps which takes energy from Mälaren	65.0	SimaPro 9.2/ Ecoinvent Database 3.7	Cradle to distributed district heating to customer
	Version date	-				
	Valid until	2027-05-02				
	Time representativeness	2020				
E.ON Energiin-frastruktur AB **S-P-05023**	Registration date	2022-03-17	District heating from industry waste heat	0.3	SimaPro 9.2/ Ecoinvent Database 3.7	Cradle to distributed district heating to customer
	Version date	2022-03-24				
	Valid until	2027-03-16				
	Time representativeness	2020				
E.ON Energiin-frastruktur AB, Sjölunda **S-P-03632**	Registration date	2021-06-15	Sjölunda Heat Pumps consists of 4 heat pumps that extract heat from purified wastewater, which would otherwise go out into the sea	6.1	SimaPro 9.1/ Ecoinvent Database 3.6	Cradle to distributed district heating to customer
	Version date	2021-08-19				
	Valid until	2027-06-01				
	Time representativeness	2019				

Since all the EPDs follows the same PCR system, the system boundaries and the software and database used are equal between each one. The software GaBi (version 10.6) is most frequently used as software in the EPDs, and when used, it is with the same version. The other software, SimaPro, is used in different versions (9.1, 9.2, 9.3 and 9.4). The earliest versions are used for the EPDs registered between 2021 and 2022, and the older ones for later registration years. In terms of databases, the Ecoinvent database is used in all EPDs available in Sweden. The latest version (3.8) is the one most frequently used. In terms of emission factors, E.ON stands for both the highest and lowest emission factor compared to all EPDs. The highest emission factor comes from a plant with water heat pumps and has an emission factor of 65 g CO_2 eq./kWh, and the lowest emission factor from industrial waste heat and with an emission factor of 3 g CO_2 eq./kWh.

Table 18 presents the emission factors collected from One Click LCA regarding district heating. The table presents what program, year and from which data source the emission factor has been collected/calculated. One Click LCA presents emission factors based on data provided by Energiföretagen, Boverket and EPDs and presents both district heating mix and location-based data. The table shows that the lowest emission factor is for the district heating in Helsingborg and Göteborg and the highest for Östersund.

Table 18: Data available in One Click LCA for district heating.

Data	Program	Year	Data source	[g CO_2 eq. /kWh]	Verified
District heating, national Swedish mix, CO_2 only	Boverket	2021	Boverket, version 02.03.000, 2022-5-20	56.2	Internally verified
District Heat, Sweden	One Click LCA, Upstream database: Ecoinvent	2020	LCA study for country specific district heating based on IEA, One Click LCA 2023	34.5	Internally verified
District heat, Luleå, Sweden	One Click LCA	2019	LCA study based on fuel data provided by Energiföretagen 2019 and Ecoinvent 3.6, One Click LCA Ltd (2022)	36.5	Internally verified
District heat, Östersund, Sweden	One Click LCA	2019	LCA study based on fuel data provided by Energiföretagen 2019 and Ecoinvent 3.6, One Click LCA Ltd (2022)	91.1	Internally verified
District heat, Stockholm, Sweden	One Click LCA	2020	LCA study based on fuel data provided by Energiföretagen 2020 and Ecoinvent 3.6, One Click LCA Ltd (2022)	30.8	Internally verified
Fortum Värme, City of Stockholm, Stockholm	One Click LCA, Upstream database: Ecoinvent	-	LCA study for country specific district heating based on Fortum Värme, OneClick LCA 2017	72.1	Internally verified
District heat, Linköping, Sweden	One Click LCA	2019	LCA study based on fuel data provided by Energiföretagen 2019 and Ecoinvent 3.6, One Click LCA Ltd (2022)	18.5	Internally verified
Tekniska Verken i Linköping AB, Linköping	One Click LCA, Upstream database: Ecoinvent	-	LCA study for country specific district heating based on Tekniska Verken AB, One Click LCA 2015	50	Internally verified
District heat, Göteborg Ale, Sweden	One Click LCA	2019	LCA study based on fuel data provided by Energiföretagen 2019 and Ecoinvent 3.6, One Click LCA Ltd (2022)	26.7	Internally verified
Göteborg Energi AB, Göteborg. Partille. Ale	One Click LCA, Upstream database: Ecoinvent	-	LCA study for country specific district heating based on Göteborg Energi AB, One Click LCA 2015	38.5	Internally verified
Göteborg Energi AB, Göteborg. Other: Good Environmental Choice	One Click LCA, Upstream database: Ecoinvent	-	LCA study for country specific district heating based on Göteborg Energi AB, One Click LCA 2015	0.035	Internally verified
District heat, Eslöv-Lund-Lomma, Sweden	One Click LCA	2019	LCA study based on fuel data provided by Energiföretagen 2019 and Ecoinvent 3.6, One Click LCA Ltd (2022)	0.0533	Internally verified
District heat, Helsingborg, Sweden	One Click LCA	2019	LCA study based on fuel data provided by Energiföretagen 2019 and Ecoinvent 3.6, One Click LCA Ltd (2022)	0.0354	Internally verified

5.1.2 Electricity

In this section, the emission factors for electricity are presented in Table 19. The table is organised with the methods, according to section 3.1.1, and a compilation of the emission factors that each method presents. Not all methods have specific emission data for nuclear, wind, power, water, and cogeneration or average, so the marked grey boxes mean no value exists for that electricity source. The electricity mix presents which system boundaries are considered for the emission factor.

Table 19: Emission factors for electricity.

Method	**Emission Factor – [g CO_2 eq./kWh]**							
	Nuclear power	**Wind power**	**Solar power**	**Hydro power**	**Co-generation**	**Mix**	**System boundary**	**Source**
Miljöfaktaboken	1	3.7		1.3				Vattenfall EPD (2011)
Naturvårds-verket						90	Nordic	SMED (statistics 2016 - 2018)
VMK						372	Nordic residual	Energimarknads-inspektionen (2020)
EPD	5.7	15.6		7.3	13.8			Nuclear, Vattenfall: GaBi, Ecoinvent 3.8 (version date: 2023) Wind, Vattenfall: Gabi, Ecoinvent, Thinkstep 2020
GHG Protocol						37	Market-based, Sweden	*Source not stated*
Tidstegen		14.71	27	10.52				IVL with factors derived from Miljöfaktaboken, EA Energianalyse
One Click LCA	2.8	12.8				1. National Swedish mix – 37.1 2. Electricity, Sweden - 41.8 3. Residual mix, Sweden - 180		Nuclear: Vattenfall EPD (2019) Wind: Vattenfall EPD (2019) Average 1: Boverket (2021) Average 2: mixes based on IEA, OneClick LCA 2023 (2020) Average 3: AIB 2019 and Ecoinvent Database 3.6, OneClick LCA 2021 (2019)
Ecoinvent Database	Specific emission data are presented in case study only.							

From Table 19, it is possible to see the emission factors that are available on the Swedish market for electricity. Some are for specific powers, and some are averages for Sweden, Residual mix in Sweden, Nordic, and Nordic residual. Since there are differences, in both power type, and system boundary of electricity system, it is rather difficult to extinguish similarities or trends in the emission factors. It is possible to see that the lowest emission factor found on the Swedish market today, is 1 g CO_2 eq./kWh and the highest 372 g CO_2 eq./kWh. The lowest is based nuclear power and based on Miljöfaktaboken. Other values for nuclear power are from EPD 5.7 g CO_2 eq./kWh and from OneClick LCA 2.8 g CO_2 eq./kWh. Both are based on an EPD from Vattenfall. The highest emission factor is based on an average from VMK and takes to account a Nordic Residual Mix from Energimarknadsinspektionen. Figure 8, shows a compilation of the average emission factors in terms of electricity.

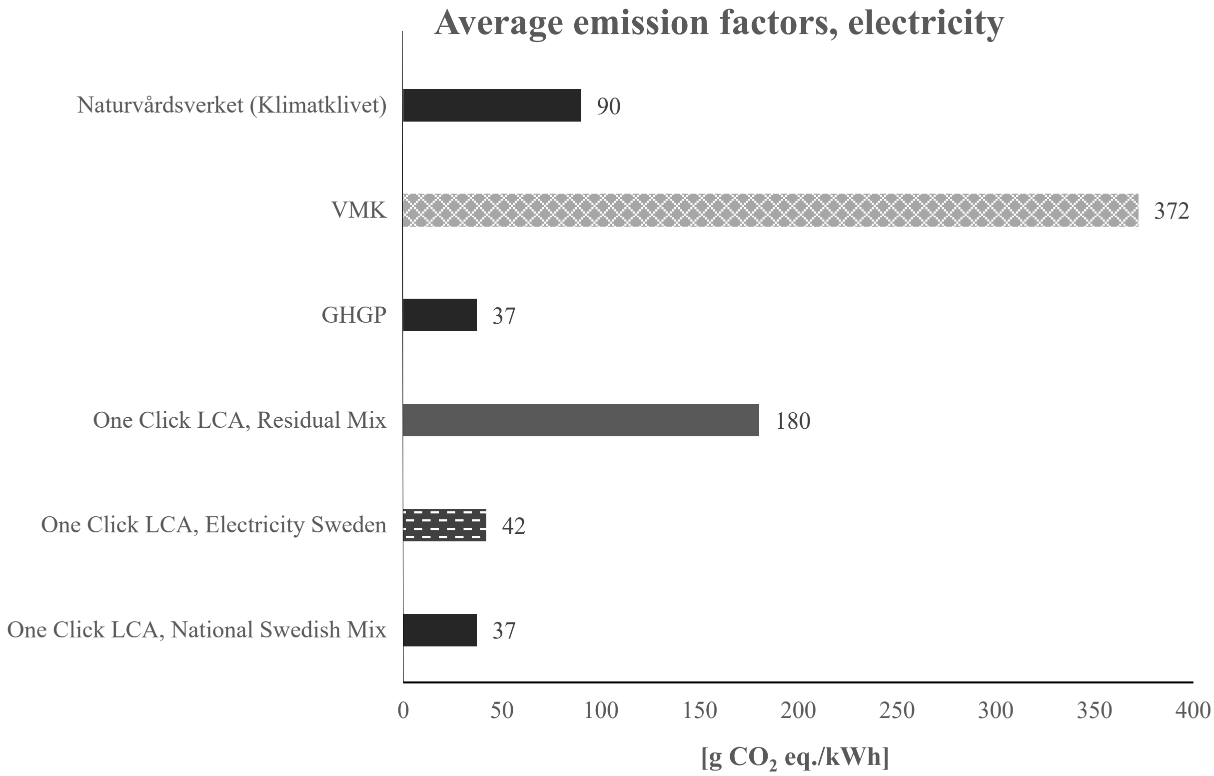


Figure 8: Average emission factors for electricity, based on different methods.

The figure distinguishes differences between the average values. It shows that One Click LCA presents the lowest average emission factor of 37.1 g CO_2 eq./kWh, similar to the average on Boverket's Climate Database (where the emission factor is 37 g CO_2 eq./kWh). One Click LCA presents two additional emission factors, whereas the residual mix is much higher than the others. GHGP presents an average of 37 g CO_2 eq./kWh, which correlates with the average from Boverket. However, the source of GHGP's emission factor has not been found during this study. The second most significant emission factor is presented by Naturvårdsverket, which considers a Nordic electricity mix from SMED statistics between 2016 and 2018. In Figure 9, a closer look is taken to wind power and the emission factors in the category.

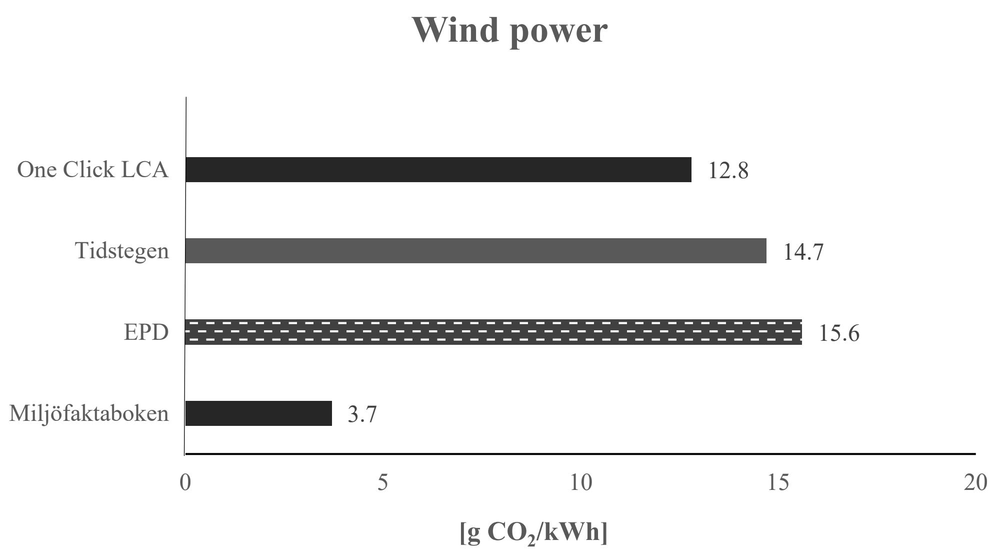


Figure 9: Compilation of emission factors regarding wind power.

From Figure 9 it is possible to see that the emission factor from One Click LCA, Tidstegen and EPD are quite similar while Miljöfaktaboken is four times lower. One Click LCA are based on the Vattenfall EPD from 2019 while Tidstegen base their emission factor on Miljöfaktaboken and EA Energianalyse. The highest emission factor is taken from Vattenfall's EPD for windfarms in Europe, that was registered in 2019 but updated in version 2022. This EPD are based on GaBi and Ecoinvent database, through Thinkstep.

Miljöfaktaboken and Tidstegen are based on the same source but still have a great difference. Similar, One Click LCA and EPD have the same source, but it still differs between their emission factors.

In Table 20 the emission data available from EPDs for electricity in Sweden are presented. The table follows the same structure as the one presented for the EPDs for district heating in the section above.

Table 20: Available EPDs regarding Electricity in Sweden May 2023. The EPDs has the functional unit: 1 kWh net of electricity generated and thereafter distributed to a customer connected to the medium voltage grid.

Energy company	Dates		EPD-number	[g CO_2 eq./kWh]	Software/Data base	System boundaries
Vattenfall, Wind farms in Europe	Registration date	2019-01-31	S-P-01435	15.6	GaBi and Ecoinvent Database (Thinkstep* 2020)	Upstream, downstream, construction and dismantling of wind farms. user stage of electricity at the consumer not included.
	Version date	2022-01-31				
	Valid until	2027-01-31				
	Time representativeness	-				
Vattenfall, is based on fourteen stations: thirteen in Sweden and one in Finland, hydropower	Registration date	2005-03-01	S-P-00088	7.3	GaBi and Ecoinvent Database (Thinkstep 2020)	Not specified
	Version date	2021-05-05				
	Valid until	2026-01-12				
	Time representativeness	-				

Energy company	Dates		EPD-number	[g CO_2 eq./kWh]	Software/Data base	System boundaries
Vattenfall, nuclear power plants	Registration date	2016-12-21	S-P-00923	5.7	GaBi (2019)/ Ecoinvent Database 3.8 (2020)	Cradle-to-grave
	Version date	2023-01-13				
	Valid until	2027-12-31				
	Time representativeness	2021				
Kraftringen, Örtofta, electricity from cogeneration	Registration date	2023-03-17	S-P-07523	13.8	GaBi/ GaBi (2022), Ecoinvent Database 3.8 (2022)	Cradle-to-grave
	Version date	-				
	Valid until	2028-02-20				
	Time representativeness	2020				

**Thinkstep is an organisation that offers software, data, and consulting services to measure environmental sustainability.*

Since all the EPDs follows the same PCR system, the system boundaries and the software and database used are equal between each one. The software GaBi (version 10.6) is most frequently used as software in the EPDs. In terms of databases, the Ecoinvent Database is used in all EPD. In terms of emission factors, the highest emission factor is from windfarms in Europe and the lowest from Vattenfall's nuclear power plants.

Table 21 presents the emission factors collected from One Click LCA regarding electricity. The table presents what program, year and from which data source the emission factor has been collected/calculated. For electricity, One Click LCA presents emission data for a Swedish mix and a Swedish residual mix. Some data are also based on EPD sources for nuclear and wind power. The lowest emission factor is for nuclear power and the highest for the residual mix.

Table 21: Data available in One Click LCA for electricity.

	Program	Year	Data source	[g CO_2 eq./kWh]	Verified
Electricity, national Swedish mix, CO_2 only	Boverket	2021	Boverket, version 02.03.000, 2022-5-20	37.1	Internally verified
Electricity, Sweden	One Click LCA, Upstream database: Ecoinvent	2020	LCA study for country specific electricity mixes based on IEA, One Click LCA 2023	41.8	Internally verified
Electricity, Sweden, residual mix	One Click LCA, Upstream database: Ecoinvent	2019	LCA study for country specific residual electricity mixes based on AIB 2019 and Ecoinvent 3.6, One Click LCA 2021	180	Internally verified
Electricity from Vattenfall's Nordic nuclear power plants (Vattenfall AB)	International EPD System S-P 00923, Upstream database: Ecoinvent	2019	EPD® Nuclear Power	2.8	Verified according to the requirement in ISO 14025 by a third party.
Electricity from Vattenfall's Nordic wind power (Vattenfall AB)	International EPD System S-P- 01435, Upstream database: Ecoinvent	2019	EPD® of Electricity from Vattenfall's Nordic wind power	12.8	Verified according to the requirement in ISO 14025 by a third party.

5.2 Compilation of methods

This section presents the essential selections from the literature study. In Table 22 the methods that can be used for calculating B6 for heated buildings are shown. Besides Energiföretagen, the climate database by Boverket, Klimatstegen and NollCO_2 are used. Tidstegen is a part of the comparison since Tidstegen presents specific emission factors and presents a particular method for calculating B6.

Table 22: Methods for calculating B6 for heated buildings.

	Energiföretagen	Climate Database by Boverket	Klimatstegen	NollCO_2	Tidstegen
Overall					
Perspective	Bookkeeping	Bookkeeping	Bookkeeping	Bookkeeping and Consequence	Consequence (bookkeeping perspective in annual report)
Limit value (of CO_2 eq-emission)	No	No (introduced 2027)	No	Yes	No
Reference period	No	No (introduced 2027)	No	50 years	20 years
Scenario	No	No	No	Yes, zero impact after 2045	Yes, four different scenarios for electricity with different outcome and three different waste scenarios for waste in district heating
District heating					
Emission factor	Local data depending on energy company and location. Data collected in excel file "Local environment values"	Average emission factor – 56 g CO_2 eq./kWh	Local data from Energiföretagen. Naturvårdsverket's Combustion emissions, with additional transport and production emission, is used if no local value	1. EPD 2.Generic Climate data from Boverket, average 56 g CO_2 eq./kWh 3. Average value 60 g CO_2 eq./kWh	Fuel-specific emission factor, which will be used for specific energy mix
Source (Publication year)	Based on VMK (2022) which takes their emission data from Naturvårdsverket (2022) and Miljöfaktaboken (2011)	Published by Boverket Climate Database. Average from Naturvårdsverket (2022). Based on average from Energiföretagen (2018 – 2020), which is based on older versions of VMK, Miljöfakta-	Energiföretagen (2022), which is based on older version of VMK and Miljöfaktaboken (2011) If no local value exists, Naturvårdsverket's combustion emissions are recommended	1. SimaPro/ GaBi/Ecoinvent Database (depends on creation of EPD) 2. Average from Naturvårdsverket (2022). Based on average from Energiföretagen (2018 – 2020), which is based on older versions of VMK, Miljöfaktaboken (2011)	Based on Naturvårdsverket statistics (2021), Miljöfaktaboken (2011) and IVL rapport B2398 (2020)

	Energiföretagen	Climate Database by Boverket	Klimatstegen	NollCO2	Tidstegen
		boken (2011) and older version of Naturvårdsverket's combustion statistics	(2022), latest data are requested	and older version of Naturvårdsverket's combustion statistics 3.Naturvårdsverket (2019), SCB, Energimyndigheten (2018), GHGP tool	
Electricity					
Emission factor	372 g CO_2 eq./kWh from VMK	37 g CO_2 eq./kWh from IVL	37 g CO_2 eq./kWh, from Boverket Climate Database	1. EPD 2. Generic Climate data from Boverket, 37 g CO_2 eq./kWh, or IPCC emission factors for sun, wind, or bioenergy (Presented in section 3.3.4) 3. Average value 22 g CO_2 eq./kWh	Depending on electricity mix, marginal production based on IVL
Source (Publication year)	Energy-market inspection (EI) (2020)	ENTSO-E Statistics (2015 – 2017)	Based on IVL C433 (2019), which on ENTSO-E Statistics (2015 – 2017)	1. SimaPro/ GaBi/Ecoinvent Database (depends on creation of EPD) 2. IVL (2019) and ENTSO-E Statistics (2015 – 2017), IPCC (2014) 3. EU JRC method (2018)	Miljöfaktaboken (2011), Naturvårdsverket (2021) and EA Energianalyse
Electricity mix	Nordic Residual	Swedish	Swedish	1. EPD based 2. Swedish 3. Swedish, Nord Pool*	European

From Table 22, it is possible to review that almost all methods use a bookkeeping perspective without setting limit value of CO_2 emissions. NollCO2 and Tidstegen have both a bookkeeping and a consequence perspective, but only NollCO2 has a limited value. The two methods also have reference period of 50 and 20 years. Tidstegen considers fewer reference years since the project group assumed it to be a safer estimation; as the literature review has shown. A too long-time perspective in energy system scenarios can lead to more uncertain results, according to the project group. Both NollCO2 and Tidstegen have scenarios that project the future climate impact and value of climate action. Within the framework of NollCO2, a calculation period of 50 years is applied and calculated for how this may change over the years and beyond. A tool in NollCO2 enables a linear interpolation between the current and future climate values, where the future value is set to zero. Tidstegen has four different scenarios for electricity ("Very Conservative", "Conservative", "Climate-neutral Nordics", and "Ambitious Nordics"), which focus on predicting the hourly electricity production margin in Sweden while accounting for the connections to the European electricity system for 2020, 2025, 2030, 2040 and 2050. For the use of waste in district heating, Tidstegen has also set different scenarios for the alternative use.

From the part of the table that considers district heating, it is challenging to compare those methods that have emission factors depending on mix of energy fuels or location of combustion plants; comparison of different energy mixes is therefor compared in the case study of this report.

NollCO$_2$ reports three different values for district heating, and using EPDs is priority one in the environmental certification scheme. Two average values are also presented. One comes from Boverket's Climate Database, which has a second priority in which data should be selected first. This value is 56 g CO$_2$ eq./kWh. NollCO$_2$ has produced a different average weight, based on the Naturvårdsverket, the Swedish Energy Agency and SCB statistics and using GHG tools. This value is 60 g CO$_2$ eq./kWh. Therefore, it is a difference, even if it is marginal. Coming back to the average from the Climate Database, this has a very long list of sources, and it originates partly from Miljöfaktaboken, which is from 2011. It is the oldest source, running between 2011 and 2022. Figure 10 show from which source each methods' emission factors originates from and shows that Miljöfaktaboken and the combustion emissions from Naturvårdsverket are used in most methods presented within this report.

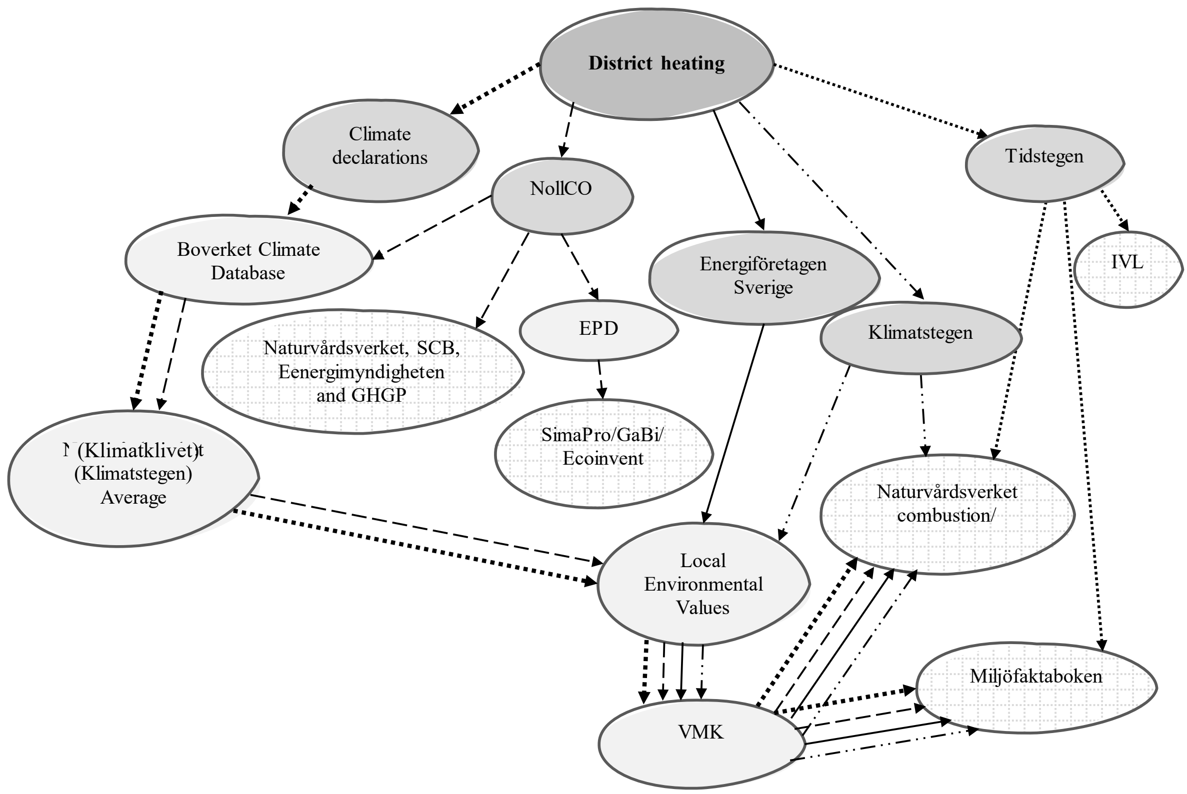


Figure 10: Methods and their connections in sources for district heating. Each method has its type of line to show what path it takes regarding origins. The checkered rings are the sources of the emission factors addressed in this report. E.g., Climate declarations have a line of bold dots that follows to the end source Naturvårdsverket and Miljöfaktaboken.

From the part of the table that considers electricity, it is possible to see that Boverket often is referred to as climate data. In both Klimatstegen and NollCO$_2$, the emission factor from Boverket's Climate Database, of 37 g CO$_2$ eq./kWh are referred to. However, in NollCO$_2$, EPDs are prioritized, and if there is a special energy agreement or the energy is marked as a "Good Environmental Choice", other values should be used. The average value that NollCO$_2$ has calculated by EU JRC Method is put to 20 g CO$_2$ eq./kWh. Highest difference in emission factor is between this number and Energiföretagen, which has an emission factor of 372 g CO$_2$ eq./kWh. In terms of Tidstegen, the emission factor of electricity depends on the electricity mix and applied scenarios; the emissions are calculated directly by the project group of Tidstegen. The sources of emission data are from 2011 to 2022, the same as for district heating. Miljöfaktaboken is also here the oldest source. Figure 11 show from which source each methods' emission factors originates from.

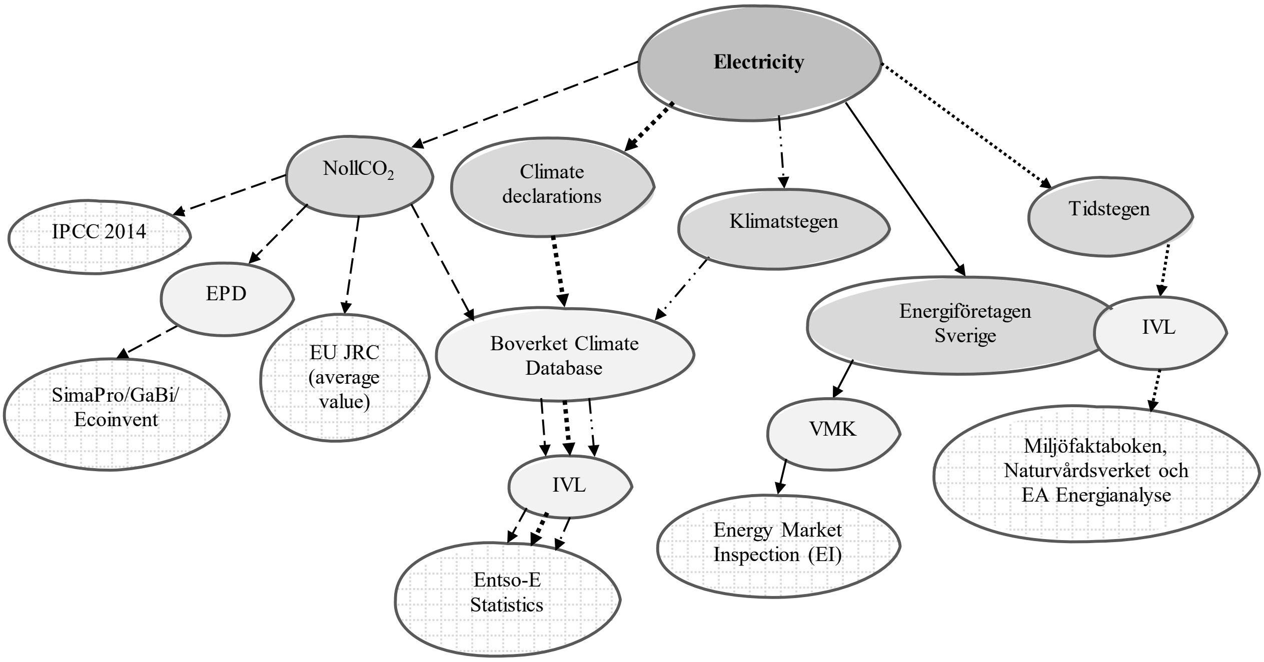


Figure 11: Methods and their connections in sources for electricity. Each method has its type of line to show what path it takes regarding origins. The checkered rings are the sources of the emission factors addressed in this report. E.g., Climate declarations have a line of bold dots that follows to the end source ENTSO-E Statistics.

5.3 Material collected from interviews

Through the interviews, discussions have been made regarding different methods for calculating the environmental impact of a building's heating. The interviews have circulated mainly about VMK and NollCO_2, but also opinions about GHG Protocol, EPD systems, and Miljöfaktaboken have been collected. The interviews have been held with several energy and LCA experts from the industry's private and public sectors. Read more about the methodology followed for the interview in section 2.4.

Discussions regarding the methods to collect emission factors

All interviewees agreed that suitable options are available today regarding the methods used for collecting emission factors. The methods that were especially highlighted were VMK which was considered an appropriate accounting method according to IP2, environmental strategist on E.ON. IP2 thinks the method is an easy way for energy companies to report their emissions and data. Based on the values from VMK, the local environmental values also seemed to have a good reputation.

IP1, energy expert from Energiföretagen, informs that emission factors for transport and production of fuels which, according to agreement with VMK, are taken from IVL's Environmental guidelines (Miljöfaktaboken) are old and not relevant. She continues that a lot has happened since IVL calculated the emission factors in 2011. A large proportion of transports within forestry and to the heat plants and machines for the extraction of fuels have been converted to fossil free solutions. Thus, using old values from IVL, means unreasonably high emissions from production of district heat networks. The solution according to IP1, is either update of the emission factors by IVL or to promote that heat networks report own measured emissions. The alternative that each company report own emission factors for extraction and the transport of their fuels are complicated and difficult to implement. However, they discuss enabling each network to report its total emissions from the production and transport of fuels and based on their report they can make a correction factor and adjust the emissions, IP1 says.

IP5, energy policy expert at Stockholm Exergi, thinks Miljöfaktaboken is still valid since the techniques for the combustion of fuels are still the same.
EPDs are also a popular source of emission factors. IP3, the environmental coordinator, uses it as much as possible when calculating climate impact. IP2 points out that EPDs are different compared to methods such as VMK, GHGP and Naturvårdsverket. In the later ones, they want to measure chimney emissions, where the emissions are allocated to energy produced. In the EPDs, the system boundary for waste is set differently; thus, the methodology differs, IP2 continues. One difference between the methods is how waste are treated.

Energy companies today, report emissions from waste incineration according to set methods such as VMK, GHGP and Naturvårdsverket. IP1 thinks that the way the emissions are reported gives an incorrect picture of the facts and does not contribute to reducing the amounts of residual waste sent to waste treatment and energy recovery. The energy purchasing customer has almost no available measures to reduce the climate emissions from energy recovery of residual wastes except for their own wastes, while plastic producers, consumers, businesses, and buildings together have full responsibility and measures available to reduce the amount of residual waste that are send to waste treatment and energy recovery, IP1 ends.

IP2 says they process waste since it is economically viable and has a social benefit. However, processing waste affects their emission accounts negatively. As an energy company, it is difficult to affect the reduction of waste in earlier stages since they process the product in the end-of-life stage, IP2 ends. IP5 says that in the EPD system, the product manufacturers and users are responsible for the impact of waste incineration. Due to the polluter pays principle, they shall report the result of incinerating the product. This provides the right incentive and sends a proper signal.

"*Within VMK and GHGP, waste is considered a fuel, meaning that the generated energy bears the climate impact. But people will not sort their waste better just because the district heating delivery look worse. In the EPD system, on the other hand, the actor that generates the waste, becomes responsible for reporting the climate impact and thus deciding whether to incinerate or recycle. It gives the right incentive; it sends the right signal - polluter pays*." – IP5.

IP1 says that the polluter pays principle is empowered to make those who are responsible for pollution responsible for paying for the damage done to the natural environment. Accordingly, the emissions from treatment and energy recovery of the waste must be charged to those who generate the wastes, not to those who use the unavoidable excess heat. The energy generated in waste incineration plants should be considered as waste heat provided that the waste has gone through collection, sorting, and material recycling and provided that the waste has not been possible to recycle or recirculate, IP1 continues. With that condition, the emission from the residual waste that has gone through sorting must be allocated to those who generated the waste.

IP4, lecturer and energy expert on Svensk Energiutbildning, thinks that emission factors from EPDs are a less good option than VMK for two reasons. Firstly, because EPDs can be used several years after they were made, VMK's data is updated annually. Secondly, the system boundary for waste combustion in district heating differs. Both options are available, e.g., between VMKs and EPDs, meaning that a comparison can have strange consequences, according to IP4. The total impact of an EPD will be much lower than if you were to compare the full effect from VMK with Good Environmental Choices. IP5 points out that EPDs report waste heat as zero impact for energy use.

Boverket uses data from EPDs for products, but not for energy. This can lead to double counting, according to IP5. He argues that it must be connected; the agency should use EPD method when computing the default for district heating and electricity values.

Regarding GHGP, IP5 says that this system is developed internationally and may not be suitable to apply at the Swedish level.

"*In GHGP, energy systems live their life and the waste sector its life. But in Sweden, these are linked together, and then the rules are not always well thought out.*" – IP5.

Regarding electricity, there needs to be more discussion. IP4 thinks there is no reason to calculate the European mix since imports are already included in the Swedish electricity mix. However, he emphasises that here, too, the system boundaries must be consistent, and the same electricity mix must be considered in climate calculations of B6 to be able to compare the outcome.

Climate calculation of heated buildings, life cycle module B6

In calculating life cycle module B6, interviewees agree that there are ambiguities in calculating the climate impact of a building's user stage. IP4 think it is essential that everyone counts in the same way, that authorities develop a scenario for the future, and that everyone counts on the same, regardless. IP3 agrees and thinks that one framework for everyone to use is needed, such as the climate declaration, since it would make it easier to compare. It needs to be clear for what purpose the different tools should be used. Otherwise, it is just a guess on which one to use, IP3 believes.

"*So much is happening in the calculation methods, and many people are trying to relate to the new without knowing what it means. It is a guessing game.*" – IP3.

Today, the different methods that can be used, use different reference periods and IP4 thinks having the same reference period for all is essential. This should not be chosen arbitrarily, he says. As IP4 continues, he also feels that requirements in terms of methodology and calculation guidelines will come later. IP6, energy expert on Boverket, confirms that the data provided on the Climate database is "good enough" to make a climate declaration. If requirements for climate limit values for buildings are introduced, the basis for the climate data should be more precise and only come from environmental product declarations but also better reflect Swedish conditions, where consideration is taken to the market shares of construction products on the Swedish market. When requirements for climate declarations were introduced, there were no requirements on how the climate calculation should be reported to Boverket, as is the supervisory authority over the quality of climate declarations. When limit values are introduced, it needs to be more apparent, according to IP6.

If the climate declaration is expanded to include the entire life cycle of the building, the use phase will be included, which means that the climate impact from the operating energy will be reported. To do that, scenarios are required for how electricity and district heating consumption will develop over 50 years and its climate impact. IP6 says that the Swedish Energy Agency is already tasked with developing scenarios for electricity consumption until the year 2050, but scenarios for district heating need to be developed.

It may seem challenging to know which emission data to use in which case. IP4 thinks that Boverket's figures are more reasonable to use than VMK. However, if you are looking for specific emission factors from unique district heating networks, IP4 thinks VMK is a more reasonable alternative.

IP6 says that the climate data for district heating in the climate database has been produced in dialogue with Energiföretagen. Boverket has chosen to have an average Swedish value instead of the climate impact from each individual district heating plant because it would risk the climate declaration focusing on the building's location instead of its characteristics, i.e., that a building should not be "penalized" if it is connected to a district heating network with higher emission or "benefits" if it is connected to a district heating network with lower emissions. IP6 also states that a strong motive for a Swedish average value is that it is consistent with national methods in the other Nordic countries and with the method developed by the EU's JRC method.

6 Analysis

This chapter presents the analysis from the literature study and result as two case studies on the grid level for district heating and electricity used for heating. The case studies present differences and similarities in the climate calculation methods and between the emission factors presented during the literature study and through the compilation of results. The study has, in both cases, been conducted on a building with a heating need of 80 kWh/m^2, yr.

The methods studied that present emission factors without allocation, incomplete scope of LCA, or are too complex to include, are excluded from the case studies. See methodology section 2.5, for further information.

6.1 Case study of district heating

A case study was conducted from the compilations of emission factors and methods presented in the result for district heating (Section 5.1.1). The study was made on three energy fuel mixes on cities in Sweden - Hässleholm, Linköping and Stockholm – and are presented in Table 23 below. Beneath this table, the result from the case study and following analysis are presented in Table 25.

Table 23: Energy fuel mixes of each location, based on local environmental values by Energiföretagen 2022. The underlined "recycled energy", "renewable" and "fossil" presents the total percentage of each category.

	Hässleholm	Linköping	Stockholm	Unit
Recycled energy	61.6	89.9	54.8	%
Industrial waste heat	0.8	-	-	%
Fume gas condensation	6.9	11.7	11.7	%
Heat from heat pump (net)*	-	-	16.7	%
Chips	4.6	17.7	2.5	%
Waste	49.4	59.2	23.9	%
Renewable energy	38.2	6.6	43.3	%
Secondary biofuels	35.4	2.5	18.7	%
Pellets, briquettes, and powder	-	-	5.8	%
Biooil and pine oil	0.01	1.3	8.4	%
Renewable energy to heat pumps	2.8	2.8	10.4	%
Fossil energy	0.1	3.5	1.9	%
Heating oil	0.1	2	1.9	%
Other fossil fuel	-	1.5	-	%

**Heat from heat pump (net) is heat from heat pumps excluded added electricity to heat pump*

The total emissions, calculated from emission factors from VMK and Ecoinvent Database, are the only values based on specific data and calculated according to a use of a mix of energy sources. Calculations for VMK's mixes is presented in Table 24. Specific values for Ecoinvent's mixes are not presented in this report because of restrictions from the license. All other emissions are based on averages or fixed values, available for each method. In Table 25, the total emissions of the heated building are presented, according to three different locations and methods.

Table 24: Calculated mixes for Hässleholm, Linköping and Stockholm according to Energiföretagen's content in the mix.

	VMK	**Hässleholm**		**Linköping**		**Stockholm**	
	Emission factor [g CO_2 eq. /kWh]	Percent	Emission [g CO_2 eq. /kWh]	Precent	Emission [g CO_2 eq. /kWh]	Precent	Emission [g CO_2 eq. /kWh]
Waste heat from industry	0.0	0.8%	0.0	0.0%	0.0	0.0%	0.0
Fume gas condensation	0.0	6.9%	0.0	13.0%	0.0	11.7%	0.0
Heat from heat pumps	0.0	0.0%	0.0	0.0%	0.0	16.7%	0.0
Recycled wood	7.0	4.6%	0.3	17.7%	1.2	2.5%	0.2
Waste	147.5	49.4%	72.9	59.2%	87.3	23.9%	35.3
Pellets, briquettes, and powder	18.0	0.0%	0.0	0.0%	0.0	5.8%	1.0
Secondary biofuels	11.0	35.4%	3.9	2.5%	0.3	18.7%	2.1
Bio oil and pine tar oil	5.0	0.0%	0.0	1.3%	0.1	8.4%	0.4
Electricity	372.0	2.8%	10.4	2.8%	10.4	10.4%	38.7
Heating oil	293.5*	0.1%	0.3	2.0%	5.9	1.9%	5.6
Remaining fossil fuel	297.0	0.0%	0.0	1.5%	4.5	0.0%	0.0
Emission of mix			87.8		109.6		83.2

This is an average between EO1 and EO2-5.

Table 25: Total emission of district heating depending on location and method.

Methods	**Hässleholm [kg CO_2 eq./m^2, yr.]**		**Linköping [kg CO_2 eq./m^2, yr.]**		**Stockholm [kg CO_2 eq./m^2, yr.]**	
Naturvårds-verket, Klimatklivet	4.480		4.480		4.480	
	Average Klimatklivet		*Average Klimatklivet*		*Average Klimatklivet*	
Energiföretagen /VMK	8.160	7.023	7.520	8.771	3.680	6.657
	Energiföretagen	*Calculated mix VMK*	*Energiföretagen*	*Calculated mix VMK*	*Energiföretagen*	*Calculated mix VMK*
EPD	2.84		0.880		1.184	
	S-P-05636		*S-P-08296*		*S-P-05797*	
One Click LCA	2.832		1.480	4.000	2.464	5.768
	Data from Helsingborg since data from Hässleholm were not available. Energiföretagen (2019), Ecoinvent 3.6, One Click LCA (2022)		*Energiföretagen (2019), Ecoinvent 3.6, One Click LCA (2022)*	*Tekniska verken Linköping, One Click LCA (2015) and Ecoinvent*	*Fortum Värme, Stockholm City, One Click LCA and Ecoinvent*	*Energiföretagen (2020), Ecoinvent 3.6, One Click LCA (2022)*
Ecoinvent Database (mix)	1.96		1.56		4.02	
	Mix from Ecoinvent		*Mix from Ecoinvent*		*Mix from Ecoinvent*	
Klimatstegen	8.160		7.520		3.680	
	Energiföretagen		*Energiföretagen*		*Energiföretagen*	

Methods	**Hässleholm [kg CO_2 eq./m^2, yr.]**			**Linköping [kg CO_2 eq./m^2, yr.]**			**Stockholm [kg CO_2 eq./m^2, yr.]**		
Climate database by Boverket	4.480			4.480			4.480		
	District heating, Swedish average, Boverket			*District heating, Swedish average, Boverket*			*District heating, Swedish average, Boverket*		
NollCO₂	2.84	4.480	4.800	0.880	4.480	4.800	1.184	4.480	4.800
	EPD S-P-05636	*District heating, Swedish average, Boverket*	*NollCO₂ generic data**	*EPD S-P-08296*	*District heating, Swedish average, Boverket*	*NollCO₂ generic data**	*EPD S-P-05797*	*District heating, Swedish average, Boverket*	*NollCO₂ generic data**

**Calculated by NollCO₂*

The table shows that when an average value is used in the climate calculation, based on Klimatklivet or Boverket, the total emission for the heated building is generally low compared to other methods. Furthermore, the total emissions when using data based on EPDs, are the lowest in all three locations. Paying a closer look to One Click LCA and Ecoinvent database, it is possible to see that there is a difference. For Ecoinvent, a large set of climate data is presented, and the user can arbitrarily choose the product or process that best matches the product. In One Click LCA, the choice comes down to the product's location, and no specific values are presented for each fuel in the energy mix. Here the human factor can influence the result of the climate calculation.

When emission data is taken from Energiföretagen or EPD, the total heating emission is the same. Klimatstegen recommends using Energiföretagens emission factors; therefore, the total emission is the same from Klimatstegen, NollCO$_2$ and Energiföretagen. In NollCO$_2$, EPDs are prioritized as climate data (when available), and the difference between using that and the average value from Boverket or the generic data from NollCO$_2$ is quite significant. However, the EPDs used in this case study consisted mainly of renewable and recycled energy sources, which have lower emissions than traditional energy sources. In Figure 12, Figure 13, and Figure 14 the researchers look closer into the specific energy mixes.

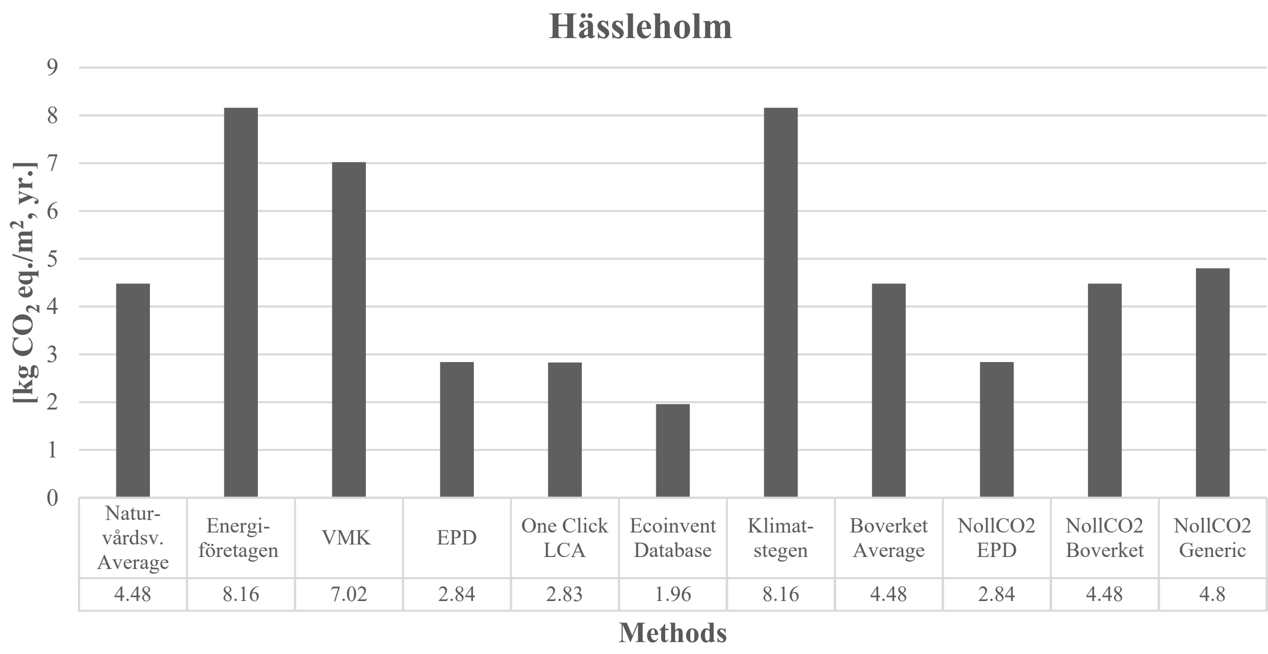


Figure 12: Total emission data for a building with a district heating need of 80 kWh/m^2, yr. in Hässleholm, depending on method used.

Hässleholm contains an energy mix of around 62 % recycled energy and 38 % renewable energy, and 0,1 % fossil energy (according to Table 23). The total emission for the heating of the building ranges from 1.96 kg CO_2 eq./ m^2, yr. and 8.16 kg CO_2 eq./m^2, yr., with the highest emission from Energiföretagen and Klimatstegen (same data) and the lowest from the calculated mix with Ecoinvent database. The significant difference may be due to several factors. Firstly, Energiföretagen/Klimatstegen is based on VMK, which has an emission factor of 148 g CO_2 eq./kWh for waste combustion. In the calculated Ecoinvent mix, the waste was neglected due to the uncertainty of the energy companies waste mix that would be needed to choose correct emission factor. As waste accounts for 49%, it makes a big difference. Secondly, In the Ecoinvent database, the significant impact of emission results narrows down to the fuel choice. In the database, there is a wide range of options that match up reasonably well with the fuels available on the Swedish market, and thus, the choice depends on the one behind the keyboard, and it is a subjective judgement. In Energiföretagen the emission factors are fixed and well adapted to Swedish conditions.

EPD, One Click LCA, Ecoinvent, and NollCO_2 are the methods that have the lowest total emissions. Reason for this may be that all four methods are based on data from Ecoinvent, and that waste are not included in the system boundary (it is included in the life cycle assessment for the waste's origin product). Since no data was found in One Click LCA regarding Hässleholm, data from Helsingborg was used in the case study. Even though the total emission from this data is very similar to the EPD from Hässleholm, they are not based on the same emission source.

The averages from Naturvårdsverket, Boverket and NollCO_2 Boverket data gives the same total emission, with reason that all are based on the average for district heating, that Boverket present in their Climate Database. As the result has shown, Boverket's average are based on Energiföretagen's statistics between 2018 – 2020, which can be compared to the total emission from Energiföretagen, that is twice as much. Since the value from Energiföretagen is based on Hässleholm's fuel mix, this may induce a higher emission value than the Swedish average value, that contains a variety of all type of energy sources.

Energiföretagen and VMK have the same emission data source and mix, which should end up with the same total emission in this case study. The thinkable reason for the difference is that VMK's total emission is calculated by hand and that unknowable assumptions have been made in Energiföretagens' mix calculation. The same trend is spotted in Linköping and Stockholm.

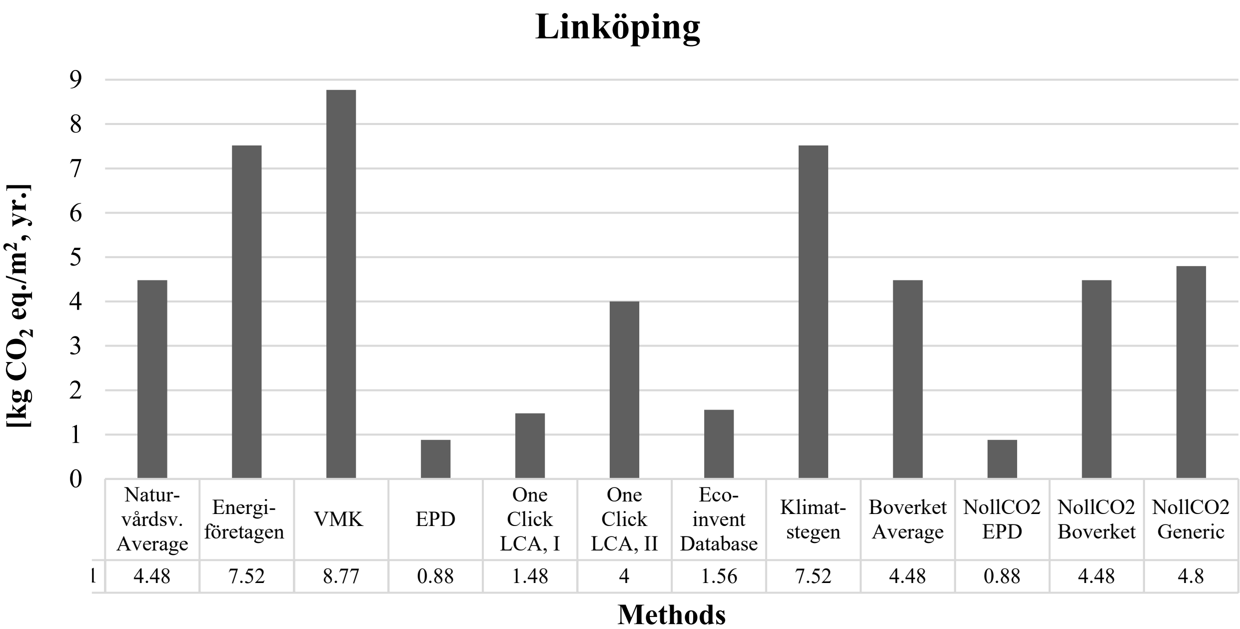


Figure 13: Total emission data for a building with a district heating need of 80 kWh/m^2, yr. in Linköping, depending on method used.

Linköping contains an energy mix of around 90 % recycled energy and 6.5 % renewable energy, and 3.5 % fossil energy. The total emission for the heating of the building ranges from 0.88 kg CO_2 eq./ m^2, yr. and 8.77 kg CO_2 eq./ m^2, yr., with the highest emission from Energiföretagen and the lowest from the specific EPD for Linköping combustion plant. The EPD in NollCO_2 are based on the same EPD for Tekniska Verken in Linköping and thus have the same total emission. The reason for the lower value could be the higher percentage of waste (60 %) in the energy mix, which is not included in the system boundaries for EPDs regarding district heating. The total emission from One Click LCA (II) are also based on the same EPD, however from 2015 instead of 2023. The older EPD seems to give a higher total emission of 4 kg CO_2 eq./kWh while the EPD from 2023 a total emission of 0.88 kg CO_2 eq./kWh.

Looking closer to the other value from One Click LCA (I), this is based on Energiföretagen from 2019, Ecoinvent and One Click LCA from 2019 and are the opposite compared to One Click LCA (II); here the older data are lower than the newer one. It is interesting to see the difference between the older data from One Click LCA, Energiföretagen (2019) at a total emission of 1.48 kg CO_2 eq./m^2, yr. with the newer data from Energiföretagen (2022) at a total emission of 7.52 kg CO_2 eq./m^2, yr. This means that when calculating with a method that recommends Klimatstegen or even requires emission factors from Energiföretagen, the value from One Click LCA could be used for a lower emission value.

VMK has the highest value which can be explained by the again high waste percentage of around 60% together with a higher emission factor of 148 g CO_2 eq./kWh. In terms of the average from Naturvårdsverket, NollCO_2 Boverket and Boverket, this follows the same trend as for Hässleholm.

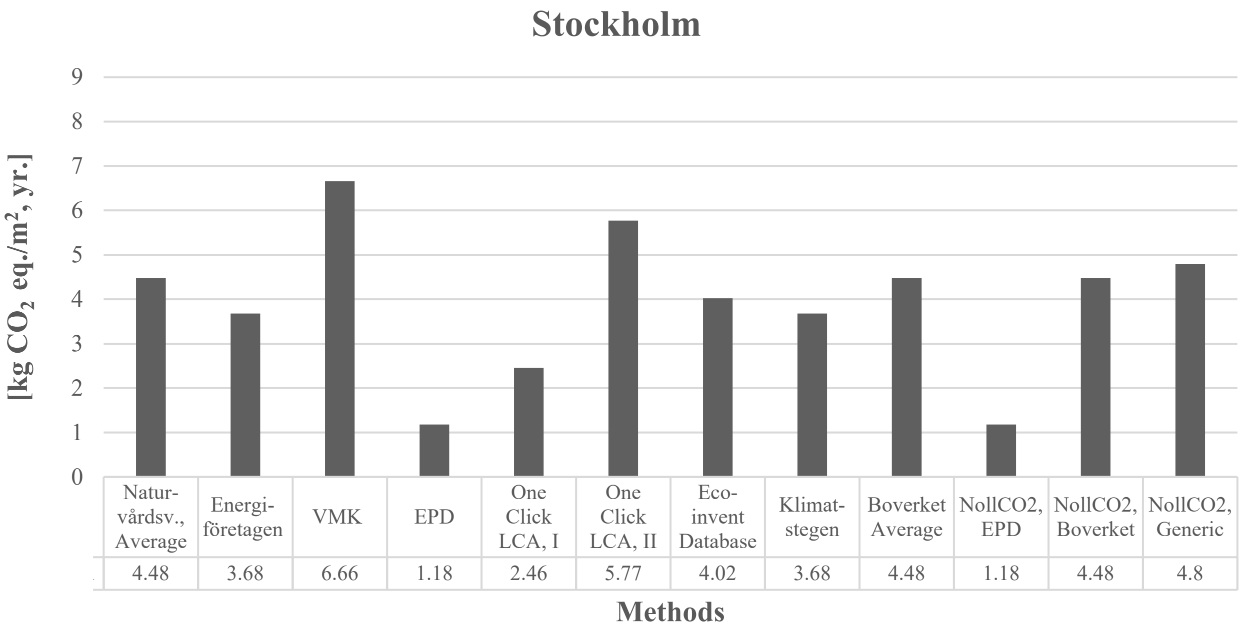


Figure 14: Total emission data for a building with a district heating need of 80 kWh/m^2, yr. in Stockholm, depending on method used.

Stockholm contains an energy mix of around 55 % recycled energy and 43 % renewable energy, and 2 % fossil energy. The total emission for the heating of the building ranges from 1.18 kg CO_2 eq./m^2, yr. and 6.66 kg CO_2 eq./m^2, yr., with the lowest emission from the specific EPD for Stockholm Exergi and the highest from VMK. Here again, the valuation of waste could play a part. The mix for Stockholm, which was retrieved from Energiföretagen, consists of around 24 % waste in the fuel mix. Comparing the total emissions in the graph with Hässleholm and Linköping, it is possible to see that there is less difference between the methods for Stockholm. There is reason to believe that the percentage of waste in the energy mix impacts this.

Another difference for the Stockholm mix is that Energiföretagen and Klimatstegen are below the average total emissions from Naturvårdsverket and Boverket. Ecoinvent has a more significant difference compared to the EPD than the other mixes.

One Click LCA II is based on Energiföretagen (2019), Ecoinvent, and One Click LCA (2022), which has one-third higher emissions than the newest emission data from Energiföretagen (2022). The reason for this could be updated values.

6.2 Case study of electricity

A case study was conducted from the compilations of emission factors and methods presented in the result for electricity (Section 5.1.2). The study was made on the electricity mix that the methods suggest and is presented in Table 26. The case study and analysis results are presented beneath the following table.

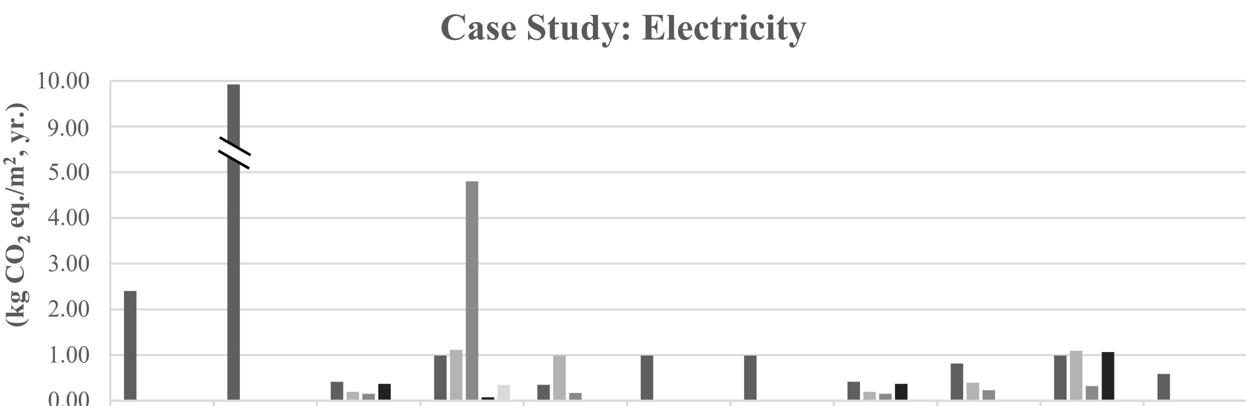
Table 26: Total emission of electricity depending on system boundary and method. COP (Coefficient of Performance) set to 3.

Methods	Total emissions [kg CO_2 eq./m^2, yr.] and source				
Naturvårdsverket	2.4				
	Average Klimatklivet				
Energiföretagen/ VMK	9.92				
	Help electricity, from Energy Market Inspection				
EPD	0.416	0.195	0.152	0.368	
	Vattenfall, Wind farms in Europe	*Vattenfall, is based on fourteen stations: thirteen in Sweden and one in Finland, hydropower*	*Vattenfall, nuclear power plants*	*Kraftringen, Örtofta, electricity from cogeneration*	
One Click LCA	0.99	1.115	4.800	0.075	0.341
	Electricity, national Swedish mix, CO_2 only	*Electricity, Sweden*	*Electricity, Sweden, residual mix*	*Electricity from Vattenfall's Nordic nuclear power plants (Vattenfall AB)*	*Electricity from Vattenfall's Nordic wind power (Vattenfall AB)*
Ecoinvent Database	0.347	0.987	0.171		
	Electricity I*	Electricity II*	Electricity III*		
Klimatstegen	0.987				
	Electricity, Swedish mix, Boverket				
Climate database by Boverket	0.987				
	Electricity, Swedish mix, Boverket				
NollCO_2					
When there is an EPD available (priority 1)	0.416	0.195	0.152	0.368	
	Vattenfall, Wind farms in Europe	*Vattenfall, is based on fourteen stations: thirteen in Sweden and one in Finland, hydropower*	*Vattenfall, nuclear power plants*	*Kraftringen, Örtofta, electricity from cogeneration*	
	0.813	0.395	0.229		

Methods	**Total emissions [kg CO_2 eq./m^2, yr.] and source**			
"Good Environmental Choice" by Naturvårdsverket	*Sun, generic data from NollCO₂*	*Wind, generic data from NollCO₂*	*Water, generic data from NollCO₂*	
When no specific energy agreement, or EPD available generic data is used	0.987	1.093	0.320	1.067
	Electricity, Swedish mix, Boverket	*Sun, generic data from IPCC 2014*	*Wind, generic data from IPCC 2014*	*Bioenergy, generic data from IPCC 2014*
Generic data from NollCO₂	0.5867			
	Swedish, Nord Pool			

**The electricity data are based on high and medium voltage, and renewable electricity*

From the table it is possible to read that the highest total emission was calculated with Energiföretagen/VMK:s average to 9.92 kg CO_2 eq./m^2, yr. and the lowest value from IPCC 2014/NollCO₂ of 0.229 kg CO_2 eq./m^2, yr. for water. Figure 15, clarifies the differences in quantity between the methods. The alternatives (1 – 5) in the graph, shows the methods that have more than one emission factor to calculate with.



	Naturvårds-verket	Energi-företagen, VMK	EPD	One Click LCA	Ecoinvent Database	Klimat-stegen	Climate database by Boverket	NollCO2, EPD	NollCO2, Good environmental choice	NollCO2, Generic data from Boverket or IPCC 2014	NollCO2, Generic data
Alt 1.	2.40	9.92	0.42	0.99	0.35	0.99	0.99	0.42	0.81	0.99	0.59
Alt 2.			0.19	1.11	0.99			0.20	0.40	1.09	
Alt 3.			0.15	4.80	0.17			0.15	0.23	0.32	
Alt 4.			0.37	0.07				0.37		1.07	
Alt. 5				0.34							

Methods

Figure 15: Total emission data for a building with a heating need of 80 kWh/m^2, yr. depending on method used.

Energiföretagen/VMK are the method that presents the highest total emission of electricity. Even though this value is used for help-electricity to district heating calculations, it is still interesting to see the significant difference between this and the other electricity mixes. The emission from Energiföretagen/VMK are based on a Nordic residual mix, produced by the Energy Market Inspection (Energimarknadsinspektionen). No other method considers a Nordic residual mix. This mix is higher than the Swedish and Nordic mix, which was confirmed in the literature study.

Looking closer to the methods that have a Swedish Mix, this are often based on Boverket's Swedish electricity mix. Klimatstegen, one of the averages on One Click LCA and NollCO₂ refers to Boverket climate data and all have a total emission of 0.99 kg CO_2 eq./m^2, yr. Boverket's electricity mix are produced on behalf of IVL, which has used statistics from ENTSO-E between year 2015 – 2017. One of the electricity mixes from Ecoinvent also presents a total emission of 0.99 kg CO_2 eq./m^2, yr. and most likely this is based on Boverket's electricity mix as well. The two other electricity mixes from Ecoinvent were chosen arbitrarily to match the available products on the Swedish market and all three values represented electricity mix with different system boundaries.

The greatest variation of total emissions within one method, One Click LCA presents. The lowest value is 0.07 kg CO_2 eq./m^2, yr. and are based on an EPD from Vattenfall Nordic Nuclear Powerplants (2019) and the highest value is 4.80 kg CO_2 eq./m^2, yr. from Swedish Residual Electricity Mix (2019). It is interesting to compare the EPD from Vattenfall Nuclear Powerplants (2023), with a total emission of 0.152 kg CO_2 eq./ m^2, yr., to the EPD regarding Nuclear Powerplants from One Click LCA (2019). These are based on the same EPD but still present different climate data. One reason for this may be that One Click LCA does not update their emission data regularly, which creates misleading information. The one that do the calculations can then choose the emission factor that is favourable, but still use the same EPD source.

7 Discussion

This study started by investigating the emission factors available for climate calculation of heated buildings today. The result summarised all the emission factors found during the literature survey, and it did not prove easy to compare and group together all the different fuels for district heating. There were ambiguities in which fuels were included in each grouping. For example, there were several names for different waste mixes, with some sources (that presents emission factors) dividing their waste into subcategories, such as recycled wood, domestic waste, and biogenic waste. All sources had emission factors in one of the respective categories, but they were not always the same. Therefore, it was considered possible that these sources treat the same waste but categorize them differently. Scattered data could also be found for the emission factors that could exist for electricity. Some methods presented only several sources for electricity, and some only average values, with different system boundaries. When comparing the methods presented for the climate calculation of a heated building, it was found that not all emission factors were likely to be used in such a calculation. The focus was thus on how the methods and emission factors could be used in a climate calculation and in what ways these could affect a climate calculation of module B6, operational energy use.

Energiföretagen is one of the five methods highlighted as a suitable method where to receive emission factors when calculating a heated building, according to interviews and surveys in this study. The emission factors presented by Energiföretagen Sverige are based on VMK's agreement and present a complete LCA, including production, combustion, and transport. Furthermore, the emission factors presented are based on geographical location and CHP plant, so finding local district heating data seems straightforward. In turn, VMK is based on emission factors from Naturvårdsverket and Miljöfaktaboken, of which alternative product method has been applied for allocation. In the interviews, VMK has been emphasised as an ideal method for reporting emissions and obtaining specific emission data. However, the age of Miljöfaktaboken has been criticised since it was published in 2011, and there have been changes in combustion techniques and efficiencies since then. One energy expert from the interviews thought that Miljöfaktaboken is old and irrelevant, as a large proportion of transports within forestry and to the heat plants and machines for the extraction of fuels have been converted to fossil-free solutions. According to this person, Miljöfaktaboken contains unreasonably high values from the production of district heating networks, and an update is seen necessary. Another solution, according to the result in the interviews, would have been to let the energy companies report their total emissions but to use a correction factor based on their report to adjust the emission values. Another expert in the interview group does not think that Miljöfaktaboken is outdated and believes that the technologies are still the same. It was also highlighted in the interviews that VMK places waste incineration on energy companies, like the Naturvårdsverket and GHG Protocol, which creates differences in climate calculation. This way of reporting emissions gives an incorrect picture of the facts, according to some of the interviewers, and does not reduce the amounts of residual waste sent to waste treatment and energy recovery. It was considered from the interviews that the responsibility to reduce the amount of waste lies with the producers of plastics, consumers, companies, and buildings together and that they are responsible for how much residual waste is sent to waste treatment and energy recovery.

In the case study, a comparison was made between Energiföretagen's local environmental values, and the emission factors presented in VMK and, unexpectedly, there was a difference in the climate calculation. For the three locations investigated, it was impossible to see a correlation that VMK is always higher than Energiföretagen in the climate calculation or vice versa. Therefore, one hypothesis is that the fuel mix likely influences the locally adapted values. Additionally, there is a possibility that if the energy company measures its own emissions, it would be included in the local environmental values presented in the Excel file by Energiföretagen, which could further impact the differences between VMK and Energiföretagen in the case study.

Regarding electricity, Energiföretagen and VMK have referred to the same emission factor for Nordic residual mix, which was found in the case study to be high above the other methods. From previous findings in the literature study, it is known that the residual mix is significantly higher in climate impact than a Swedish or Nordic average for electricity, so this was not very surprising.

It has also emerged that the Climate Database from Boverket uses the statistics of Energiföretagen to calculate the average value presented for Swedish district heating. This statistic is taken between 2018 and 2020 and has, in the case study, proved to be very neutral compared to the other methods; it is approximately midway between the highest and lowest value for all three locations investigated. In the interviews, it has been discussed the reasonableness of using an average Swedish value for district heating mix, as it can be considered unrepresentative for a specific district heating network that is limited to a geographical area and depends on the fuel mix available at the location where the energy is produced. In the case study, a calculation and comparison were made on the three different fuel mixes in Sweden, and it could be seen a noticeable difference depending on the location and mix, as well as if the method used to calculate the emissions from combustion. In the interviews, the disadvantage of using an average value was that it does not present the district heating mix that exists in the location for which the calculation is made. The advantage of an average value, emerging from the interview, was that municipalities do not suffer because they receive waste from another municipality by getting higher climate data. An average value could overlook this difference as some municipalities send their waste to other municipalities for incineration. It also emerged from the interviews that strong motives exist for using a Swedish average, as this follows the national methods in other Nordic countries.

As Boverket's average value is based on the statistics of Energiföretagen, it was also highlighted in the results that there is a very long list of sources for this average value and the longest of all the methods presented. Boverket's mean value refers to a mean value from Naturvårdsverket, which is based on Energiföretagen, which in turn is based on VMK and then Naturvårdsverket and Miljöfaktaboken, which dates to 2011 for production and transport. However, the interviews showed that the climate data presented in the climate database was considered good enough when the climate declaration was created. However, other values are now needed. Several people in the interviews emphasised that everyone who performs a climate calculation must follow the same method, that it is impossible to calculate on different types of emission data and limits, and that there is a demand for guidelines. The expert at Boverket states that when the new climate declaration is presented and if requirements for limit values are set, the basis for the climate data should be more precise and only come from environmental product declarations but also better reflect Swedish conditions. When the climate declaration was introduced, there were no guidelines on how to calculate for reporting to Boverket. However, when limit values are introduced, it must become more "apparent".

One method that uses both emission factors from Energiföretagen and Boverket is Klimatstegen. For district heating, Klimatstegen primarily refers to Energiföretagen, but Naturvårdsverket’s combustion emission factors can also be used if the emission factor is enforced with transport and production emission factors for a complete LCA. In the case study, for this reason, Klimatstegen got the equivalent total emissions for district heating as Energiföretagen and for electricity as Boverket. The Swedish electricity mix is initially based on statistics from ENTSO-E. Besides Klimatstegen, NollCO_2 refers to Boverket for electricity mix.

NollCO_2 is the method that provides the most hierarchy proposals; in addition to the average value from Boverket’s climate database, NollCO_2 has a generic value for district heating mix and electricity mix that is slightly higher than Boverket. One theory for this is safeguarding against something happening to the climate database. NollCO_2 also has generic data for specific and non-specific solar, wind, water, and bioenergy energy contracts. An interesting finding from the literature study is that the specific contract for solar electricity gives a higher value 30 g CO_2 eq./kWh than the electricity mix value 22 g CO_2 eq./kWh. At the top of the hierarchy list are EPDs, and the case study showed in many cases that EPDs were one of the methods with the lowest values. The difference between EPDs and the higher values from the case study is, as previously mentioned, the view of counting waste in energy recovery. A great discussion was held about this in the interviews. Most people thought that the emissions from incineration waste should be added to the origin products' EPDs as their end-of-life treatment. This would reduce the risk of double counting and follow the polluter pays principle. This would motivate manufacturers to design products to reduce product waste instead of pressurising energy companies that do not have the same scope for emission reduction. Due to the different treatment of waste emissions for district heating between EPDs and values from the climate database, there is now a significant difference between the total emissions in a calculation when using the NollCO_2 method. If there is no EPD for the district heating network, this difference increases significantly. An example of this is shown in the case study where the EPD for Linköping is 80% less than the value from the climate database.

In One Click LCA, a EPD can indirectly be used for a climate calculation. When examining the available data, it was discovered that some data is from older sources. The case study showed that an old (but still valid) version of an EPD for nuclear power was available in the One Click LCA. The older version had a lower value than the newer EPD. This meant that, on paper, it was possible to choose the same EPD but get a lower value with the One Click LCA version. It also turned out to be the opposite: a newer EPD for wind power had lower emission data than the EPD on One Click LCA. An EPD lasts for five years, which can be seen as a problem as the data used when the EPD was made can be considered old, as one interviewee pointed out. Therefore, one should consider when the EPD was last updated to ensure that old data is not used.

The EPDs all have in common that they are made on Ecoinvent Database, among others. In the case study a district heating mix and used electricity mixes in Ecoinvent to compare them with the other sources that presents emission factors. For electricity, very scattered data was found, where the highest emission value was the same as the emission value of the climate database. Finding a good waste mix for district heating was difficult as this varies significantly between the different energy companies. Therefore, the emission factor for waste incineration was neglected, following the same method used by EPDs for district heating. However, there was no apparent similarity between these two in the analysis. It depends significantly on who sits and chooses the emission data to be inserted. There is a wide range of data, which is excellent. However, it also means that it can differ depending on how you make your assumptions. It puts some pressure on the person doing the calculation. EPDs report whether they are third-party verified, minimising the risk of miscalculation.

Another difference from the other methods is that NollCO_2 has both an accounting and impact perspective. This is because they use data from an accounting perspective, i.e., data that is backwards looking. However, they also add a scenario that says that by 2045, emissions will be reduced to zero. Tidstegen is the only one that only has impact analysis. This method felt very well-planned and structured when researching about it in the literature study. The method has several scenarios to take a position on what will happen with electricity and waste management in the future. Compared with NollCO_2, Tidstegen have set the lifespan to 20 years instead of 50, which makes a big difference if a complete life cycle analysis had been calculated over an entire lifetime according to the methods. Like VMK, they present pre-allocated emission factors. However, since they have such a detailed impact analysis, it was not easy in this work to compare an electricity and district heating mix with the other methods. There would be too much uncertainty compared to if the Tidstegen had been allowed to calculate the emissions.

GHG Protocol was a source of emission data and method brought up when the surveys were conducted. Like Naturvårdsverket, they report emission factors for fuel combustion, and here it was possible to see similarities in the emission factors reported in this work. Regarding electricity, a similarity with the generic data from the climate database was found. This is a suitable method for companies to follow at an international level, but it was considered by one interviewee that this method is not entirely suited to Swedish conditions. GHG Protocol treats energy and waste separately, while in Sweden, the two have been combined, and energy is extracted from the waste through district heating. This is also why there is a difference in how emissions are reported between, e.g., EPDs that do not follow the GHG Protocol and VMK that follows the GHG Protocol guidelines.

8 Conclusion

How does current climate calculations' emission factors and methods for energy sources to heat buildings, differ?

Based on the findings of the study, the different methods and emission factors that are available for calculation of a heated building differs in a variety of ways. For emission factors, related to district heating, the study shows that there are differences in the weighting of the carbon dioxide equivalents as well as if the emission factor is allocated between heat, steam, and electricity. Furthermore, there are many types of fuels that are presented in different ways, which make it more challenging to compare and use. There are also differences in the system boundaries. For waste, the study shows that it is ambiguities whether waste should be calculated within the energy company's operations or with the actual waste producer. Lastly, a difference for emission factors in terms of district heating, is that some sources present emission factors that are specific for the energy company and with a specific fuel mix, while others have an average value for district heating.

For the emission factors related to electricity, the study shows that the included countries in the average mix significantly impact the average mix emission factor. The methods analysed in this thesis refer to a Nordic or Swedish mix. Emission factors for specific electricity sources, such as solar-, wind-, hydro- or nuclear power, differ significantly.

For the methods used for the climate calculation of a heated building, it is shown that the methods can sometimes follow bookkeeping- or/and consequence perspectives according to different purposes, that some methods have designed scenarios for future change regarding electricity and energy use, and that there is a difference in how methods present data and year of the data sources. Some methods refer to newer data but still present old, with lower climate impact than the origin source.

How does the differences of emission factors and methods effect on a climate calculation of module B6?

The conclusion is that comparing current emission factors and methods used for a climate calculation of module B6 is challenging and gives a significant difference in the result of the climate impact. This creates an uncertainty in the climate calculation that makes a comparison unrealistic and reduces credibility. When methods use different emission factors with different system boundaries, the comparison can become even more confusing, making it more severe for the ones making the climate calculations.

Is there a national methodology for calculating the climate impact of a heated building for module B6?

No, there is no national accepted methodology for calculating the climate impact assessment for module B6. The interviews have highlighted a demand for standard guidelines as there are ambiguities between methods, their system boundaries, and which emission factors are recommended. The closest national method of a life cycle assessment of a whole building is today the climate declarations by the Swedish authority Boverket. Boverket is currently developing a new version of climate declarations, which will hopefully include more specific methodology for calculating climate impact assessment of the operational use, module B6. As the study shows, national methodologies are needed to be able to compare Swedish buildings in the matter of module B6 under the same conditions.

Future studies

As a lot is going on in the development of the climate assessment of module B6 and especially with the upcoming climate declaration, it would be interesting to remake this study in a few years and see what improvements have been made. Hopefully, there will be less variation between methods and emission factors and a more standardised approach to target the operational energy use of module B6.

References

Association of issuing bodies, 2018. *European Residual Mixes.* [Online]
Available at: https://www.aib-net.org/sites/default/files/assets/facts/residual-mix/2018/AIB_2018_Residual_Mix_Results_v1_1.pdf
[Accessed 29 04 2023].

Boverket, 2019. *Introduktion till livscykelanalys (LCA).* [Online]
Available at: https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/livscykelanalys/introduktion-till-livscykelanalys-lca/
[Accessed 4 05 2023].

Boverket, 2020. *Utveckling av regler om klimatdeklaration av byggnader.* 50 ed. Karlskrona: Boverket.

Boverket, 2020. *Utveckling av regler om klimatdeklaration av byggnader,* Karlskrona: Boverket.

Boverket, 2021. *Beräkna byggnadens klimatpåverkan.* [Online]
Available at: https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/berakna/
[Accessed 12 04 2023].

Boverket, 2022. *Klimatdeklaration - en digital handbok från Boverket.* [Online]
Available at: https://www.boverket.se/sv/klimatdeklaration/om-klimatdeklaration/
[Accessed 12 04 2023].

Boverket, 2023. *Klimatdeklaration - en digital handbok från Boverket.* [Online]
Available at: https://www.boverket.se/sv/klimatdeklaration/om-klimatdeklaration/nyheter/boverkets-klimatdatabas-uppdaterad/
[Accessed 12 04 2023].

Boverket, 2023. *Miljöindikatorer - aktuell status.* [Online]
Available at: https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/miljoindikatorer---aktuell-status/
[Accessed 28 04 2023].

ecoinvent, n.d. *ecoinvent Database.* [Online]
Available at: https://ecoinvent.org/the-ecoinvent-database/
[Accessed 18 04 2023].

Energiföretagen, 2020. *https://www.energimyndigheten.se/nyhetsarkiv/2020/ny-statistik-over-energianvandningen-i-smahus-flerbostadshus-och-lokaler/.* [Online]
Available at: https://www.energimyndigheten.se/nyhetsarkiv/2020/ny-statistik-over-energianvandningen-i-smahus-flerbostadshus-och-lokaler/
[Accessed 16 05 2023].

Energiföretagen, 2022. *Miljövärdering 2022 - Guide for allokering i kraftvärmeverk och fjärrvärmens elanvändning.* [Online]
Available at: https://www.energiforetagen.se/globalassets/energiforetagen/statistik/fjarrvarme/miljovardering-av-fjarrvarme/hjalp-vid-berakning/guide-for-allokering-i-kraftvarmeverk-och-fjarrvarmens-elanvandning-2022.pdf
[Accessed 07 05 2023].

Energimyndigheten, 2022. *För dig med direkt- verkande el.* [Online]
Available at: https://www.energimyndigheten.se/energieffektivisering/husguiden---for-dig-som-vill-energieffektivisera-ditt/se-over-husets-uppvarmningssystem/for-dig-med-direktverkande-el/
[Accessed 06 05 2023].

Enskog Broman, L., 2018. *Energiföretagen.* [Online]
Available at: https://www.energiforetagen.se/energifakta/fjarrvarme/
[Accessed 06 05 2023].

Erlandsson, M. et al., 2018. *Byggnaders klimatpåverkan, timme för timme- idag och i framtiden,* ISBN nr: 978-91-88787-86-6: IVL Svenska Miljöinstutet.

European Commission, n.d. *Climate Action.* [Online]
Available at: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
[Accessed 05 04 2023].

Fossil Fritt Sverige, n.d. *Färdplaner för fossilfri konkurrenskraft.* [Online]
Available at: https://fossilfrittsverige.se/fardplaner/
[Accessed 03 05 2023].

Fossilfritt Sverige, 2018. *Färdplan för fossilfri konkurrenskraft - Bygg- och anläggningssektorn.* [Online]
Available at: https://fossilfrittsverige.se/wp-content/uploads/2021/10/Fardplan_for_fossilfri_bygg-_och_anlaggningssektor_20181228-1.pdf
[Accessed 29 03 2023].

Freeman, M., 2022. *Greenhouse Gas Protocol.* [Online]
Available at: https://ghgprotocol.org/blog/next-steps-process-update-existing-corporate-standards
[Använd 24 03 2023].

Freeman, M., 2022. *Greenhouse Gas Protocol.* [Online]
Available at: https://ghgprotocol.org/blog/ghg-protocol-assess-need-additional-guidance-building-existing-corporate-standards
[Accessed 24 03 2023].

Gillenwater, M., 2005. *CALCULATION TOOL FOR DIRECT EMISSIONS FROM,* WRI/WBCSD GHG Protocol Michael Gillenwater: Version 3.0.

Gode, J. o.a., 2011. *Miljöfaktaboken,* ISSN 1653-1248: VÄRMEFORSK Service AB.

Greenhouse Gas Protocol, 2015. *The Greenhuse Gas Protocol- A Coporate Accounting and Reporting Standard,* s.l.: World Buissness Council for Sustainable Development, Worls Recources Institute.

Greenhouse Gas Protocol, n.d. *Calculation Tools.* [Online]
Available at: https://ghgprotocol.org/calculation-tools-faq
[Accessed 12 04 2023].

Gunnarsson, J. et al., 2021. *Så ska företag arbeta med EPD - fördelar, råd och regelverk.* [Online]
Available at: https://www.ivl.se/download/18.556fc7e17c75c849332bdcb/1638697004377/FULLTEXT01.pdf
[Accessed 31 03 2023].

Henning, D., 2023. *Naturvårdsverket* [Email] (27 04 2023).

Hörnell, J., 2023. *Energiföretagen.* [Online]
Available at: https://www.energiforetagen.se/om-oss/
[Accessed 06 04 2023].

IVL Svenska Miljöinsitutet, n.d. *IVL.* [Online]
Available at: https://www.ivl.se/projektwebbar/klimatanpassad-och-cirkular-upphandling/vad-ar-lca-pcr-och-epd.html
[Accessed 31 03 2023].

Janson, U., Heincke, C., Fahlén, E. & Wahlström, Å., 2019. *Metoder för bedömning av klimatpåverkan i bygg- och fastighetssektorn- en översikt,* s.l.: Energimyndigheten- LÅGAN.

Khodayari, R., 2022. *Energiföretagen.* [Online]
Available at: https://www.energiforetagen.se/statistik/fjarrvarmestatistik/miljovardering-av-fjarrvarme/
[Använd 11 04 2023].

Khodayari, R., 2022. *Energiföretagen.* [Online]
Available at: https://www.energiforetagen.se/statistik/fjarrvarmestatistik/tillford-energi/
[Accessed 6 May 2023].

Khodayari, R., 2023. *Energiföretagen* [Email] (08 05 2023).

Klimatstegen, 2023. *Svensk Energiutbildning.* [Online]
Available at: https://svensk-energiutbildning.se/klimatstegen/
[Accessed 04 04 2023].

Lätt, A. o.a., 2019. *Miljövärdering av energilösningar i byggnader,* Report nr: B2337: IVL .

Lätt, A. et al., 2019. *Miljövärdering av energilösningar i byggnader - Tidstegen etapp III,* https://www.ivl.se/download/18.694ca0617a1de98f473638/1628416633393/FULLTEXT01.pdf: IVL Svenska Miljöinstitutet.

Naturskyddsföreningen, n.d. *Bra Miljöval.* [Online]
Available at: https://www.energi-sverige.se/media/6356/klimatp%C3%A5verkan-bra-milj%C3%B6val-el.pdf
[Accessed 07 05 2023].

Naturvårdsverket, 2022. *El och fjärrvärme, utsläpp av växthusgaser.* [Online]
Available at: https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-utslapp-fran-el-och-fjarrvarme/
[Accessed 28 04 2023].

Naturvårdsverket, 2022. *Klimatklivet - Vägledning om beräkning av utsläppsminskning.* [Online]
Available at:
https://www.naturvardsverket.se/499a34/contentassets/9db319015c994a9d88f64fffae725765/vagledning-berakna-utslappsminskning-2022-05-06.pdf´
[Accessed 23 03 2023].

Naturvårdsverket, 2022. *Klimatklivet - Vägledning om beräkning av utsläppsminskning.* [Online]
Available at:
https://www.naturvardsverket.se/499a34/contentassets/9db319015c994a9d88f64fffae725765/vagledning-berakna-utslappsminskning-2022-05-06.pdf
[Accessed 19 04 2023].

Naturvårdsverket, 2023. *Beräkna klimatpåverkan, vägledning, Genomsnittliga emissionsfaktorer för växthusgaser och värmevärden för Sveriges bränsleanvändning (xlsx 1,1 MB).* [Online]
Available at: https://www.naturvardsverket.se/vagledning-och-stod/luft-och-klimat/berakna-klimatpaverkan/berakna-direkta-utslapp-fran-forbranning/
[Accessed 06 04 2023].

Naturvårdsverket, 2023. *Naturvårdsverket.* [Online]
Available at: https://www.naturvardsverket.se/en/about-us/about-the-swedish-environmental-protection-agency/
[Accessed 24 03 2023].

Naturvårdsverket, n.d.a. *Stationära anläggningar, vägednng.* [Online]
Available at: https://www.naturvardsverket.se/vagledning-och-stod/utslappshandel/stationara-anlaggningar/rapportering-verifiering-och-overlamning/#:~:text=Alla%20akt%C3%B6rer%20som%20omfattas%20av,antal%20utsl%C3%A4ppsr%C3%A4tter%20%C3%B6verl%C3%A4mnas%20i%20Unionsregi
[Accessed 06 04 2023].

Naturvårdsverket, n.d.b. *Beräkna klimatpåverkan, vägldning.* [Online]
Available at: https://www.naturvardsverket.se/vagledning-och-stod/luft-och-klimat/berakna-klimatpaverkan/berakna-direkta-utslapp-fran-forbranning/
[Accessed 06 04 2023].

Nilsson, A., 2022. *Klimatbedömning av el, fjärrvärme och fjärrkyla - delrapport inom Tidstegen 5,* Stockholm: IVL Svenska Miljöinsitutet .

One Click LCA, 2022. *How One Click LCA deals with ineligible EPDs.* [Online]
Available at: https://oneclicklca.zendesk.com/hc/en-us/articles/360017122279
[Accessed 16 06 2023].

One Click LCA, n.d.a. *Vi är One Click LCA.* [Online]
Available at: https://www.oneclicklca.com/se/about-one-click-lca/
[Accessed 12 04 2023].

One Click LCA, n.d.b. *150,000 + data points: up-to-date, verified and localised.* [Online]
Available at: https://www.oneclicklca.com/support/faq-and-guidance/documentation/database/
[Accessed 12 04 2023].

OpenLCA, n.d. *The world's leading, high performance, open source Life Cycle Assessment software.* [Online]
Available at: https://www.openlca.org/
[Accessed 18 03 2023].

Pallardy, R., 2022. *IPCC Report Analysis: The Top Five Measures to Halve Emissions by 2030.* [Online]
Available at: https://journeytozerostories.neste.com/sustainability/ipcc-report-analysis-top-five-measures-halve-emissions-2030?gclid=CjwKCAjwoIqhBhAGEiwArXT7KyXCG2tODU-mts8RqHXCW-vKN5hP_Z7wNoAYRz7m657ZtpcyoLEYUxoC0PEQAvD_BwE#f467a885
[Accessed 03 05 2023].

Profu, 2021. *Klimatbokslut - Fördjupning.* [Online]
Available at: https://www.lidkopingenergi.se/wp-content/uploads/2021/11/Klimatbokslut-Fordjupning-2021-01-21.pdf
[Accessed 07 05 2023].

Profu, 2021. *Klimatbokslut- fördjupning,* s.l.: Version 2.5.

Profu, u.d. *Systemperspektiv: för att förstå konsekvenserna av beslut och handlingar,* u.o.: u.n.

Rydegran, E., 2017. *Energiföretagen.* [Online]
Available at: https://www.energiforetagen.se/energifakta/kraftvarme/
[Accessed 06 05 2023].

Sandgren, A., Görman, F., Johansson, S. & Wallander, A., 2022. *Scope 3 för bostadsföretagVägledning för beräkning och rapportering av klimatpåverkan enligt Greenhouse Gas Protocol,* Stockholm: IVL Svenska Miljöinstitutet.

Sandgren, A. & Nilsson, J., 2021. *Emissionsfaktor för nordisk elmix med hänsyn till import och export,* ISBN 978-91-7883-314-6: IVL Svenska Miljöinsitutet.

Science Based Targets, n.d. *Science Based Targets.* [Online]
Available at: https://sciencebasedtargets.org/sectors/buildings
[Accessed 24 04 2023].

SGBC, 2020. *NollCO2 Nybyggnad 1.0 Ramverk,* https://www.sgbc.se/app/uploads/2020/09/NollCO2-Nybyggnad-1.0-Ramverk.pdf: Sweden Green Building Council.

SGBC, 2022. *NollCO2 - Manual 1.1,* https://www.sgbc.se/app/uploads/2022/09/NollCO2-Manual1.1.pdf: Sweden Green Building Council.

Statistikmyndigheten, 2022. *Elproduktion och förbrukning i Sverige.* [Online]
Available at: https://www.scb.se/hitta-statistik/sverige-i-siffror/miljo/elektricitet-i-sverige/
[Accessed 06 05 2023].

Stoll, P., 2022. *Baseline and carbon limit values A1-A3 for new buildings,* https://www.sgbc.se/app/uploads/2022/09/NollCO2-baseline-och-gr%C3%A4nsv%C3%A4rden-v1.1-2022.pdf: Sweden Green Building Council.

The International EPD System, n.d. *Environdec.* [Online]
Available at: https://www.environdec.com/product-category-rules-pcr/get-involved-in-pcr-development
[Accessed 24 03 2023].

The International EPD System, n.d. *The International EPD System.* [Online]
Available at: https://www.environdec.com/about-us/the-international-epd-system-about-the-system
[Accessed 11 05 2023].

The International EPD® System, 2021. *ELECTRICITY, STEAM AND HOT/COLD WATER GENERATION AND DISTRIBUTION,* https://api.environdec.com/api/v1/EPDLibrary/Files/cbaa4849-ebea-41e7-3f0b-08d91f78ae38/Data: EPD International.

Tidstegen, 2023. *ivl.se.* [Online]
Available at: https://www.ivl.se/projektwebbar/tidstegen.html
[Accessed 04 04 2023].

United Nations Environment Programme, 2021. *Global Status 2021 Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector,* Nairobi: UNEP.

United Nations, n.d. *Reporting requirements.* [Online]
Available at: https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements
[Accessed 06 04 2023].

United States Environmental Protaction Agency, 2018. *GHG Emission Factors Hub.* [Online]
Available at: https://www.epa.gov/climateleadership/ghg-emission-factors-hub
[Accessed 29 04 2023].

Värmemarknadskommittén, 2022. *Överenskommelse i Värmemarknadskommittén 2022,* https://www.energiforetagen.se/globalassets/energiforetagen/statistik/fjarrvarme/miljovardering-av-fjarrvarme/hjalp-vid-berakning/vmk-overnskommelse-2022.pdf: VMK.

Warfvinge, C., 2023. *Energiutbildning.* [Online]
Available at: https://svensk-energiutbildning.se/wp-content/uploads/Del-3-Klimatnyckeltalen-fakta-Klimatstegen-vers-1.0-230127.pdf
[Accessed 04 04 2023].

Warfvinge, C., n.d. *Del 3 i Klimatstegen: Klimatnyckeltalen, KKPI-fakta.* [Online]
Available at: https://svensk-energiutbildning.se/wp-content/uploads/Del-3-Klimatnyckeltalen-fakta-Klimatstegen-vers-1.0-230127.pdf
[Accessed 07 05 2023].

Warmark, K., 2023. *Naturvårdsverket* [Email] (31 03 2023).

Appendix

Appendix 1: Emission factors for district heating and each type of energy.

The table was assembled as part of the result part of this study, for the emission factors that were collected for district heating during the literature study. Table and Table resents the weighting factors, similar to the result, and the emission factors for district heating in extended version (all fuels are included in the table).

Table 27: Weighting factors for carbon dioxide, methane, and nitrogen oxides for carbon dioxide equivalents.

Nr.	CO_2	CH_4	N_2O	Source
1.	1	23	296	RES-directive, 2009
2.	1	25	298	IPCC AR4, 2007
3.	1	28	265	IPCC AR5, 2014
4.	1	29.8	273	IPCC AR6, 2021 and 2022

Table 28: Emission factors for district heating and each type of energy [g CO_2 eq./kWh]. The merged cells mean that all fuels to the left are included in the merged cell value. E.g., read 20 g CO_2 eq./kWh for a fuel that includes wood pellets and wood briquettes in Tidstegens' merged cell. As mentioned in the method and literature study, Ecoinvent is excluded in this result.

	Miljöfaktaboken			**GHG**	**Naturvårdsverket**		**VMK**			**Tidstegen**
Source	Literature study from 70 individual energy sully chains (2011)			United Stated Enviro n- mental Protec- tion Agenc y EPA (2018)	Litera- ture studies and measur e-ments (2022)	Klimatkliv et based on Miljö- faktaboken (2011)	Miljöfaktaboken (2011) and Naturvårdsverket (combustion)(2022)			Miljö-fakta- boken (2011) and Natur-vårds- veket (2021)
Allocation between heat and electricity in co-generation	No			No	No	No	Alternative product method			Alternative product method
Weighting to CO_2 eq	1			3	3*	1	2	2	2	4
Lifecycle stage	**Pro- duction and distri- bution**	**Use**	**Total**	**Com- bustio n**	**Com- bustion**	**Extrac- tion, trans- port, conver- sion, and comb- ustion**	**Use**	**Pro- duction and tran- sport**	**Total**	**Prod-uction, distri-bution, and use**
Flue gas condensation										
Flue gas c.				0.0		0.0	0.0	0.0	0.0	
Waste										
Domestic waste	0.3	10.3	10.6			144.0	144.5	3.0	147.5	
Domestic waste - 75 % out sorted organic waste	0.2	11.5	11.7							

	Miljöfaktaboken			GHG	Naturvårdsverket		VMK			Tidstegen
Flammable bulky waste	0.2	6.8	7.0							
Waste, Swedish										0
Waste, imported (decreased electrical prod-uction)										71
Waste, imported (decreased landfill)										-46
Paper-wood-plastic (PTP)	0.2	6.6	6.8							
Plastics				262.8						
Mixed operational waste	0.3	7.1	7.4							
operational-, bulky waste						94				
Recycled wood	0.2	0.0	0.3			3.2				7
Biogenic waste				410.1	215.1		4	3	7	
Fossil waste					139.8					
Municipal Solid Waste				316.3					0.0	
Tires				300.2						
Waste gas										
Landfill/ landfill gas-/Biogas					335.0		0.2	12	12.2	
Landfill Gas				178.5						
Landfill and digestate gas										14
Steel industry gas waste							0	0	0	
Waste gas from the steel industry										0
Biofuels										
Branches and treetops	0.5	0.1	0.6	324.0	382.0	9.4				
Logs	0.7	0.1	0.8							
Thinning wood to wood chips	0.5	0.1	0.6							
Forest chips	0.7	0.1	0.7							

	Miljöfaktaboken			**GHG**	**Naturvårdsverket**		**VMK**			**Tidstegen**
Bark	0.4	0.1	0.4			5.8				
Chips, sawmill residues	0.4	0.1	0.4			5.8				
Wood Pellets	1.0	0.4	1.4			19	4	14	18	20
Wood briquettes	1.2	0.4	1.6			21				
Willows	2.1	0.1	2.2			28				
Pine tar oil	0.0	0.1	0.1		274.3	6.5	1	4	5	4
Raw pine oil						2.5				
Biooil							1	4	5	4
Biogas				178.5			0	22	22	22
Remaining biomass					2.0		1	34	35	39
Primary wood fuel							4	34	38	36
Secondary wood fuel							4	7	11	11
Ethylene				225.9						
<u>Electricity</u>										
Heat pumps							0	0		
<u>Peat</u>										
Peat	3.1	29.7	32.8	388.5	384.6	425	385.1	39	424.1	418
<u>Natural gas</u>										
Natural gas	3.3	15.9	19.2	181.2	199.9	248	200	45	245	249
Liquefied natural gas					203.6					
Ethane				204.2						
<u>Oil</u>										
Heating oil (EO1)	1.6	20.7	22.3	250.8	268.0	288	268	22	290	290
Heating oil (EO2-5)	1.6	21.2	22.9		275.0	295	275	22	297	297
Distillate Fuel Oil No. 2				253.2						
Distillate Fuel Oil No. 4				256.9						
Residual Fuel Oil No. 5				247.7						
Residual Fuel Oil No. 6				255.2						
Diesel oil above transport					0.7					
<u>Bituminous coal</u>										
Bituminous coal			29.7	320.8	334.9	385	370	14	384	391
<u>Other fossil fuels</u>										
Liquefied petroleum				211.4	234.6	259				

	Miljöfaktaboken			**GHG**	**Naturvårdsverket**		**VMK**			**Tidstegen**
(propane och butane)										
Remaning fossil					252.7		275	22	297	
Remaning not specified fossil					109.9					
Remaning petroleum				350	216.9648					
Waste heat industry	0.0	0.0	0.0	0.0		0	0	0	0	0

*The emission factors for Naturvårdsverket's combustion are weighted according to AR5, recommended according to Naturvårdsverket's website, see section 4.2.2.

LUND UNIVERSITY

Divisions of Energy and Building Design, Building Physics and Building Services
Department of Building and Environmental Technology