Exploring the payback period between Scope 3 CO_2e emissions and building operational CO_2e emissions in Dutch renovation projects: pre- and post-renovation analysis

Student: Arno Lamtink -2675897

Supervisor: Patricia Rogetzer

Second supervisor: Matthias de Visser

UNIVERSITY
OF TWENTE.

Preface

This thesis represents the culmination of my research on the environmental impact of renovation projects in the Dutch building sector. As a student at the University of Twente, I have been passionate about sustainability and the role of the building industry in reducing CO_2e emissions. This thesis allowed me to look deeply into these topics and understand the relationship between project emissions and the operational phase of a building's lifecycle. The followed research methodology helped me to develop a practical tool to assist building organizations in the Dutch building sector by measuring Scope 3 project emissions. Understanding the relationship between project emissions and a building's lifecycle's operational phase helps management identify hotspots and make informed decisions about sustainable practices in renovation projects for Scope 3 activities.

Throughout this research, I have worked with a team of dedicated professionals who provided guidance and support at every stage. I would like to express my gratitude to my supervisor, Patricia Rogetzer, for her valuable insights and feedback during the project and her expertise. This helped me to structure the thesis and get to the core of the subject. Secondly, I want to thank my second supervisor, Matthias de Visser for his opinion about my thesis. I also want to thank the staff of Kormelink b.v. for sharing data and providing me with feedback during the project. This made it possible to come up with a solution that contributed to the problem of estimating CO_2e emissions during renovation projects.

I hope that my thesis will contribute to the ongoing discourse on sustainability in the building environment and provide a practical tool for stakeholders in the Dutch building sector to estimate their carbon footprint of renovation projects and make sustainable decisions based on the outcome of it.

Abstract

This thesis explores the relationship between Scope 3 activities, referring to the direct greenhouse gas emissions within an organization value chain, during renovation projects, and the subsequent reduction in emissions during the operational phase of a building's lifecycle, leading to a payback period on CO_2e emissions, in the context of the Dutch building sector. The study provides a comprehensive understanding of the environmental impact of renovation projects and develops a practical tool to calculate the total CO_2e emissions for Scope 3 in renovation projects. By conducting a literature review and an empirical study, the research addresses the gaps in the existing knowledge and provides insights into the relationship between Scope 3 project emissions and the performance on the operational phase of the building's lifecycle, pre- and post-renovation in the Dutch building sector.

The theoretical contribution of this study lies in advancing the understanding of the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre- and post-renovation, while the practical implications can be applied to long-term sustainability management. Based on the outcome of the research, hotspots were identified within Scope 3 activities, where management can take the most valuable sustainable practices. The developed tool can be adapted to organization-specific data, helping management identify their specific hotspots and make informed decisions about sustainable practices in renovation projects.

The findings of this study have important implications for stakeholders in the Dutch building sector, offering a practical solution to analyze CO_2e emissions and see the hotspots where the emissions are set free in Scope 3 activities to reduce the environmental impact of renovation projects. The study also discusses the research design, identifies the limitations of the research, and provides recommendations for further research.

In conclusion, this thesis provides a comprehensive analysis of the relationship between Scope 3 project emissions and operational CO_2e emissions of a building's lifecycle pre- and post-renovation in Dutch building renovation projects. The developed tool offers a practical solution for building organizations to identify emission hotspots and implement sustainable practices, ultimately contributing to long-term sustainability management. The findings have significant implications for stakeholders, guiding informed decision-making to reduce the environmental impact of renovation projects.

Table of contents

List of abbreviations

BIM - Building information models

C2C - Cradle-to-Cradle

CH_4 - Methane

CO_2 - Carbon dioxide

CO_2e - Carbon dioxide equivalent

CSRD - Corporate Sustainability Reporting Directive

EC - European Commission

EPD - Environmental product declaration

ERP - Enterprise resource planning

ESG - Environmental, Social, and Corporate Governance

ESRS - European Sustainability Reporting Standards

GHG - Greenhouse gas

$GtCO_2e$ - One billion tons of carbon dioxide

GWP - Global warming potential

HFCs - Hydrofluorocarbons

HLCA - Hotspot and Life Cycle Assessment

IOA - Input-Output Analysis

ITS - Intelligent Transportation Systems

JIT - Just-In-Time

kWh - Kilowatt-hours

LCA - Life Cycle Assessment

N_2O - Nitrous oxide

NF_3 - Nitrogen trifluoride

OEF - Organizational environmental footprint

PFCs - Perfluorocarbons

SDGs - Sustainable Development Goals

SF_6 - Sulfur hexafluoride

SMEs - Small and medium-sized enterprises

WTW - well-to-wheel

1. Introduction

Nowadays, firms face new challenges in which sustainability is a major aspect of their operations. Firms must act toward creating a sustainable future. It is crucial to take sustainable actions in business operations and tackle climate problems now rather than delaying action. The longer we wait, the more difficult and expensive it will become to mitigate the negative impacts of climate change. Delaying sustainable practices also increases the risk of irreversible and catastrophic consequences, such as rising sea levels, extreme weather events, and species extinction, which could have severe implications for human well-being and the global economy (Welford 2016). Therefore, many firms already incorporate sustainability considerations into their business models (Begg, van der Woerd, and Levy 2018). Managers try to find ways to integrate sustainable aspects into the daily operations to positively impact both the company and society, so a sustainability strategy arises. This strategy is about the sustainable activities the firm carries out. Within the sustainable strategy, answers are given to questions about which aspects in the society the firm is creating an impact and value for, and what the stakeholders' expectations are.

Sustainability can become a problem if not incorporated into the business model, especially for large firms. Large firms are defined as companies that meet at least two of the following criteria: (1) more than 40 million in net sales, (2) over 20 million in the balance sheet, and (3) having 250 employees or more (RSM*,* 2023). Starting from 2025, these firms must comply with the Corporate Sustainability Reporting Directive (CSRD) under the European Union's regulations (RSM*,* 2023). When a firm is not able to report on the CSRD regulations it can get multiple sanctions. These can vary from fines to lawsuits to suspending licenses from the firm. On top of this, it can become worse for firms if they get sanctions that become public. The effect of negative publicity will lead to a bad reputation because they do not comply with the necessary regulations, which shows irresponsibility and untrustworthiness (Hur, Kim, and Woo 2014). The consequence is that customers boycott the firm and go to competitors, which directly affects the market position because of the loss of market share.

CSRD focuses on Environmental, Social, and Governance (ESG) indicators, providing stakeholders with information about a company's sustainability performance. Small and medium enterprises (SMEs) will also be required to report starting in 2027 based on data from 2026. Studies show that institutional investors are increasingly interested in the ESG performance of firms (Park and Jang 2021). Additionally, stakeholders pay more attention to the company's sustainability practices, putting pressure on firms to perform better (Haleem et al. 2022). This encourages firms to perform and implement sustainable management practices. The CSRD contains mandatory measures that provide stakeholders with insights into the sustainability practices of large firms. Firms can also choose to disclose more information about their sustainability practices, in addition to the regulations. Firms can have a look at the United Nations' Sustainable Development Goals (SDGs) to guide their efforts. These goals are adopted by the United Nations to address climate change by 2030 (United Nations, 2023).

1.1 Problem statement

In the environmental sector from the ESG, there are several points firms can report on. Looking towards the environmental sector, previous research has shown that the construction sector accounts for 33% of the worldwide greenhouse gas (GHG) emissions (Allwood, Cullen, and Milford 2010). GHG emissions are gases that are released into the atmosphere that contribute to the greenhouse effect and global warming. The most common greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (Means and Lallanilla 2021). CO_2 has the highest proportion of GHG gases, namely 76% (Global emissions, 2019). In Appendix A an overview is given about the global distribution of CO_2 emissions by sector. This shows that building operations, building materials, and construction are responsible for 39% of the total CO_2 emissions. Looking towards the CO_2 emissions in the construction sector, the government of the UK has researched the construction industry and shows that the amount that the construction industry contributes towards CO_2 emissions is relatively high. This comes forward through the analysis that the construction sector is one of the main sources of GHG emissions, it accounts for around 47% of the total CO_2 emissions in the UK (BIS 2010). While there may be some differences in the specifics of the construction sector's environmental impact in the UK and the Netherlands, such as the types of materials used or the specific pollutants emitted, it is clear that the sector impacts the environment in both countries. Looking at the sectors for the Netherlands, the construction sector comes in third place when it comes to the total CO_2 emissions and can be seen in Appendix B. Looking towards all the activities construction firms carry out within their project portfolio, less is known how this is divided in the Netherlands. It depends on the structure of the firm and its strategy. Because in the United States, 40% of the total projects are carried out in housing construction according to Statista 2022, which is a large amount, a more in-depth look will be given towards housing construction and how sustainable they are built and perform over time. Moreover, in the introduction was said that there are upcoming regulations on the CSRD and that stakeholders attach value to firms who run their business more sustainable. This is also a reason that a look will be given on how to make a sustainable impact within housing construction.

Construction firms are responsible for the construction of residential houses and the main activities that emit CO_2 in the environment come forward within this process. These phases include the products, construction, use phase, and the end-of-life of the building (Nwodo and Anumba 2019). The category that has a high percentage within the CO_2 emission of the construction sector is the use phase. The use phase of a building contains several activities namely: use (operational energy use and operational water use), maintenance, repair, and replacement refurbishment (Abd Rashid and Yusoff 2015). The use phase accounts for a total of more than 69% of the GHG emissions in a building's lifecycle (Bastos, Batterman, and Freire 2014). CO_2 emissions that are emitted during the use phase are called operational CO_2 emissions. CO_2 that arises from other lifecycle phases, i.e. product design, construction, and end-of-life phase, are called embodied CO_2 emissions (Programme and Architecture 2023). Therefore, the use phase can be called the operational phase.

This paper will look into the carbon dioxide equivalent emissions (CO_2e) emissions for construction companies when possible. CO_2e emissions are all the GHG emissions that are recalculated to CO_2 emissions. When other GHG emissions emit during activities these will be recalculated to CO_2e emissions. Because CO_2 emissions are the largest contributor from all the GHG gasses within the construction sector according to Global Emissions (2019), and the construction sector emits a large proportion, 33%, towards the environment from all sectors according to Allwood et al (2010), focusing on the construction sector can be helpful to add new literature to bring down the total CO_2e emissions in the construction sector.

When construction firms want to make a sustainable impact on having less CO_2e emissions in the housing construction there are two important views, the housing construction as a whole of building residential houses or renovation projects which focus on reducing operational usage. Both, renovation projects and building residential houses, are important in the Netherlands. As the population continues to grow, the need for new homes is becoming increasingly pressing (Lalor 2022). This means that careful consideration must be given to the construction of new houses to ensure that they are both functional and sustainable. One of the main concerns when building new homes is the environmental impact. It is important to use eco-friendly materials and building techniques to minimize the carbon footprint of the new buildings. By building sustainably, it can be ensured that communities can continue to thrive in the future. Renovation projects are interesting because the goal is to reduce CO_2e emissions in the operational phase of the building. After renovation, buildings typically do not require the same amount of energy, electricity, and water as before, resulting in lower CO_2e emissions than before the renovation. The Netherlands is committed to reducing its carbon footprint and transitioning towards a more sustainable built environment. Renovating existing houses plays a vital role in achieving these objectives as it allows for retrofitting energy-efficient technologies. This helps to reduce energy usage and dependence on fossil fuels, leading to lower emissions and a more sustainable housing sector (Klunder 2005).

Now that it is clear that the construction industry has a significant proportion on emitting CO_2e emissions into the environment and the Netherlands is committed to making the construction sector more sustainable, a look can be given into these CO_2e emissions. CO_2e emissions are divided into three categories: Scope 1, 2, and 3. Scope 1 emissions are the direct emissions produced by the firm, Scope 2 emissions are indirect emissions, such as from electricity purchased, and Scope 3 emissions are emissions in the value chain, including upstream activities (indirect emissions from suppliers) and downstream activities (indirect emissions to consumers) (Toffel and Van Sice 2011). Research from Huang et al. (2009) shows that Scope 3 emissions account for 70% to 80% of the total emission from Scope 1,2, and 3.

Many studies have attempted to quantify the CO_2e emissions that the construction sector is responsible for in general. There has been a lot of research done on Scope 1 and 2 emissions and how they should be reduced but not on Scope 3 (Toffel and Van Sice 2011). This means that for Scope 3 which is the biggest contributor in the construction industry, there is less known on Scope 3 emissions. Looking more in-depth at why there is less known on Scope 3 emissions, Patchell (2018,) provides reasons why not to report on Scope 3, such as difficulties in costs and responsibility allocation and management of CO_2 emissions throughout the value chain. Also setting the boundaries for measuring Scope 3 emissions is difficult. According to the Callahan et al. (n.d.) several factors cause this difficulty:

1. Complex value chain: Scope 3 emissions cover indirect emissions throughout a company's entire value chain, including suppliers and customers. Firms often lack direct control over these external activities.
2. Multiple categories: There are 15 categories of Scope 3 emissions, each with unique characteristics, such as purchased goods, transportation, and product use.
3. Operational boundaries: Firms must define which activities they control to determine their operational boundaries. While reporting Scope 1 and Scope 2 emissions is mandatory, Scope 3 reporting is optional but encompasses most of the GHG footprint, which is beyond direct control.
4. Data collection challenges: Accurate data collection for Scope 3 emissions is difficult due to the involvement of various stakeholders, requiring collaboration with suppliers, customers, and partners.
5. Consistency and relevance: Companies need to identify the most relevant Scope 3 categories and establish clear boundaries for data collection to ensure consistent reporting. Regular updates and data verification are crucial.

All these difficulties imply why success in management and reporting on Scope 3 emissions has been limited. However, with increased demand for transparency from stakeholders and regulations such as the CSRD, construction firms must incorporate sustainability into their business models. Being ahead of the CSRD regulations and being open to the stakeholders' requirements, firms need to show how they perform on Scope 3 emissions. Keeping in mind that the Netherlands is committed to making the construction industry more sustainable and Scope 3 is the largest contributor towards the total CO_2e emissions, there is need for more research on Scope 3, which can be confirmed by Downie and Stubbs (2013). They mention the need to conduct further research on Scope 3 emissions, especially on the aspect of measuring specific activities for the total Scope 3 emissions. Downie & Stubbs (2013) conducted a study to see which methods and data distinct types of firms use to assess their Scope 3 emissions. At the moment there is a lack of tools to measure these emissions. Measuring Scope 3 emissions is challenging due to their indirect nature, complex supply chains, and data availability issues. Firms need to collaborate with suppliers to minimize the environmental impacts and see how much their total Scope 3 emissions are. With the upcoming CSRD regulations firms are becoming more willing to collaborate which is good for building tools to calculate Scope 3 emissions. Also, Downie & Stubbs (2013) mention in their article that firms require a simple spreadsheet tool that simplifies calculating the Scope 3 emissions which can be used in sustainable reports. As said before, it is at the moment not clear for firms how to calculate Scope 3 emissions, the information is not known or not available and therefore the calculation and reporting on Scope 3 emissions are neglected. When a tool is available or information on how much on average specific activities in Scope 3 emit, firms can use this to measure their emissions themselves. This would help to get a clear calculation of the total emission in Scope 3. The lack of tools to calculate Scope 3 emissions can also be stated by Shrimali (2022), who suggests using methods such as the Greenhouse Gas Protocol which firms can use as a guideline on what activities to measure within Scope 3 emissions, this will also be further discussed in Chapter 2. However, Shrimali (2022) states that there are challenges in getting clear insights into Scope 3 emissions and that there is still much work to be done in developing standardized protocols and approaches for measuring and managing Scope 3 emissions, which could help to increase transparency and consistency in reporting these emissions. Standardized measures will increase information about managing Scope 3 emissions because they can provide a consistent framework (Münstermann, Eckhardt, and Weitzel 2010). Therefore, it is an important addition to the literature to research different relationships within the unknown aspects of Scope 3. Another addition to report on Scope 3 emissions comes from Roca and Searcy (2012). They carried out a study that investigates different indicators on sustainability which firms include in their sustainability reports. The analysis of Roca & Searcy (2012) focuses on how firms convey their commitment to sustainable practices, as well as the specific areas of sustainability on which they choose to report. Within these reports, it came forward that all firms together have reported on a total of 170 sustainable indicators. These indicators can be categorized as Scope 1, 2, or 3 emissions. Based on these 170 indicators, this research provides an analysis to place the indicators in the category of Scope 1, 2, and 3. A detailed table of the total number of times an indicator has been reported can be seen in Appendix C. The figure in Appendix C based on the study of Roca & Searcy (2012) revealed that Scope 3 has the most indicators but it is less reported on by firms. While the indicators are there to report on, they are neglected in sustainability reports. This aligns with the study by Downie & Stubbs (2013), which emphasizes the need for spreadsheet tools to calculate Scope 3 emissions. Although Roca & Searcy (2012) demonstrate that Scope 3 emissions have numerous measurable indicators, these are often overlooked due to the lack of tools and collaboration among firms, as noted by Downie & Stubbs (2013). Having the right tools would enable firms to better prepare for upcoming CSRD regulations by allowing them to analyze, measure, and report on Scope 3 emissions.

As described before, Scope 3 emissions account for the largest contributor of the total emissions within the construction sector, the operational phase accounts for 69% of the GHG emissions of the lifecycle of a building, and the Netherlands is focusing on building houses more sustainable, the objective of this paper has been narrowed down in this area. In addition, the upcoming regulations of the CSRD make it necessary for firms to come up with sustainability reports on these Scope 3 emissions. Within this area, there is a gap in the literature to fill and prepare firms for the upcoming CSRD regulations. At the moment there is an unknown answer on the relationship between renovation projects on sustainability performance and how they perform on operational Scope 3 emissions after the renovation project in the Netherlands. This relationship can show how houses perform after renovation projects compared to before the renovation has been done and how much Scope 3 has been emitted during the renovation project. Research can be done on the total Scope 3 emissions that are emitted during renovation projects, how much is emitted during the lifecycle of a building, compared before the renovation to after the renovation. If the performance of the operational phase of the house is known, meaning how much electricity and gas is consumed after renovation, then it can be determined how much this saves compared to before the renovation. This can be compared with the CO_2e emissions that have been emitted during the renovation project. From this, it can be calculated how much time it takes to regain these savings for the environment. When research has been done on this calculation firms can mention it within their sustainability reports to substantiate they are working on a sustainable environment.

1.2 Practical problem

In a discussion with Kormelink b.v., a construction company from the Netherlands preparing for upcoming CSRD regulations, the emphasis is on meeting increased requests from suppliers for more detailed information on sustainability practices. Kormelink b.v. aims to acquire insights that can be effectively communicated to its stakeholders. Kormelink b.v. is currently engaged in projects for their client, De Woonplaats, focusing primarily on renovating residential properties to improve their sustainability. These projects involve activities related to the bathrooms, kitchens, and toilets of existing houses. However, Kormelink b.v. currently lacks information on how much CO_2e emissions they have emitted during their projects with regards to Scope 3 emissions and what the operational emissions on electricity and gas are for these houses, before and after renovation. They aim to determine the areas in which certain projects outperform others and quantify the overall sustainability improvements achieved in each project. Thus, the development of a tool that calculates Scope 3 emissions for each project would enable the identification of the first step of the relationship between polluting activities of emissions during a project and how it affects the operational phase after the renovation. It will identify the most sustainable choices that can be made for each activity within a renovation project. In addition, the differences in performance can be seen easily within different projects. For the operational phase Kormelink b.v. is dependent on other firms who measure the performance of these houses. Therefore, the operational phase data needs to be collected from the residents where renovation projects have been carried out.

1.3 Research goal

In combination with the literature gap on the relationship between the Scope 3 emissions within renovation projects, the operational phase pre- and post-renovation, and the practical problem Kormelink b.v. is struggling with, a goal has been set for this paper.

The main goal of this paper is to answer the following research question: “What is the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation?”

For this research, the end-of-life phase is excluded due to a lack of data. While Section 1.1 already has said that there is a need for a spreadsheet tool to calculate the Scope 3 emissions, this is also needed to answer a part of this question. The tool should calculate the Scope 3 emissions from the renovation project which can be used to calculate the time to regain the CO_2e emissions in the environment compared to the operational phase of a building. In Section 1.2 it was mentioned that Kormelink b.v. does not have information on the operational emissions. These operational emissions are maintained by De Woonplaats. Due to privacy reasons, they could not share this data on emissions. Although the emissions can not be calculated directly from Kormelink b.v. the data on these emissions have been gathered directly from residents where renovation projects have been carried out. This means that the tool includes the input of data which is available to Kormelink b.v. for Scope 3 activities. These data are categorized into specific Scope 3 activities so a distinction can be made where sustainable practices can be made. As said before, the operational data of a building for the payback period is collected from the residents where renovation projects have been carried out. The total CO_2e emissions from the project can be compared to the difference in the operational phase, pre- and post-renovation, to calculate how much time is needed to regain the CO_2e towards the environment. The insights provided by the tool about the Scope 3 emissions should be included in sustainability reports to fulfill the need for stakeholders to see that firms are being transparent and actively aware of their sustainability performance. Stakeholders can gain insights into the processes and where polluting activities take place, and the sustainability report can be used for decision-making toward sustainable practices.

To answer the research question the following sub-research questions have been made:

1. Which specific activities within Scope 3 emissions are related to renovation projects within the Dutch building sector?
2. Which activities are the most influenceable within Scope 3 emissions related to renovation projects?
3. Which sustainable practices related to Scope 3 activities for renovation projects can be implemented at different phases?
4. What are existing tools or methods for gathering data on Scope 3 emissions?
5. How can Scope 3 project emissions, emitted before the operational phase, be effectively measured to enable meaningful comparison with operational CO_2e in the operational phase of a building's lifecycle?
6. What are the savings on operational CO_2e emissions in the operational phase of a building's lifecycle after the renovation projects Kormelink b.v. has carried out?
7. What is the payback period on Scope 3 emissions that are emitted during renovation projects and the savings in operational CO_2e emissions in the operational phase of a building's lifecycle compared to pre- and post-renovation?

The data of the renovation projects of Kormelink b.v. is used to test and validate the tool. Then the results from the tool are compared to the operational phase of the residential properties and compared to how they performed while not being renovated.

The paper is structured as follows. Chapter 2 describes the relevant literature about the research streams on GHG emissions in general and applies it to the literature for construction activities for Scope 3 and then looks towards renovation projects, it discusses the research streams on tools to calculate the total CO_2e emissions for Scope 3. Chapter 2 begins with an introduction to what Scope 3 activities are. In addition, the housing construction process is mapped. After the construction process is mapped a view is given of renovation projects and the operational phase after these projects. Thirdly it discusses the existing tools to calculate the total emission. In Chapter 3 the methodology of the project is discussed. Chapter 4 discusses the performance of the built tool. Chapter 5 discusses the results. Chapter 6 discusses the implications and limitations of the research. Chapter 7 is the conclusion and gives a summary and possibilities for future research.

2. Literature review

This chapter gives a look into the existing literature about sub-research questions 1, 2, 3, and 4. In Section 2.1 general Scope 3 activities are described and the renovation activities for Scope 3 are discussed. This provided answers to sub-research questions 1, 2, and 3 In Section 2.2 existing tools towards the measurement of Scope 3 emissions are discussed. Section 2.2. provided an answer to sub-research question 4. The 2 sections in Chapter 2 together form the base input for the research design in Chapter 3 which answers 5.

2.1 Scope 3 activities within the research

Before looking at the renovation activities within Scope 3, an understanding of all activities within Scope 3 is necessary before specifying it towards renovation activities. Therefore, Section 2.1.1 discusses the general activities within Scope 3. Section 2.1.2 discusses the Scope 3 activities related to renovation projects. Section 2.1.3 looks in depth at the lifecycle of renovation projects. Lastly, Section 2.1.4 discusses which activities are influenceable by the construction firms and how sustainable practices can be implemented at different phases of a building's lifecycle.

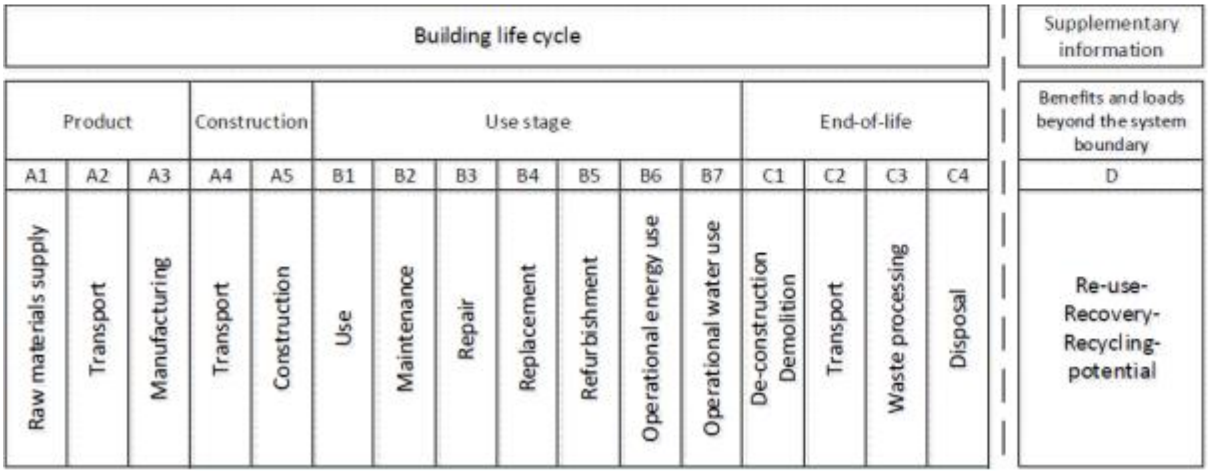
2.1.1 General Scope 3 activities

Looking towards the activities that are within Scope 3, upstream and downstream activities can be distinguished. Upstream activities deal with indirect GHG emissions related to purchased or acquired goods and services; downstream emissions are indirect GHG emissions related to sold goods and services. Looking more in-depth at upstream and downstream activities, they both can be roughly categorized into specific categories (Callahan et al. ,n.d.):

- Upstream activities:
    - Purchased goods
    - Capital goods
    - Fuel- and energy-related activities (if not included in Scope 1 or Scope 2 already)
    - Upstream transportation and distribution
    - Waste generated in operations
    - Business travel
    - Employee commuting
    - Upstream leased assets
- Downstream activities:
    - Downstream transportation and distribution
    - Processing of sold products
    - Use of sold products
    - End-of-life treatment of sold products
    - Downstream leased assets
    - Franchises
    - Investments

2.1.2 Overview of Scope 3 activities within renovation projects

From the Scope 3 activities described in Section 2.1.1, the activities that are relevant for the research question: "What is the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation?" need to be selected. Therefore, a look will be given into the process of a building's lifecycle which can be seen in Figure 1.



Building life cycle																Supplementary information
Product			Construction		Use stage							End-of-life				Benefits and loads beyond the system boundary
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw materials supply	Transport	Manufacturing	Transport	Construction	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction Demolition	Transport	Waste processing	Disposal	Re-use-Recovery-Recycling-potential

Figure 1: A building's life cycle (Source: Nwodo & Anumba, 2019)

While these phases are from a building's lifecycle it can be said that renovation projects have similarities with the lifecycle in Figure 1. The comparison is within:

1. Product phase: In a building's lifecycle, this involves the extraction, manufacturing, and delivery of building materials. In a renovation project, this could involve sourcing new materials or repurposing existing ones. Phase A of the lifecycle encompasses the raw material supply, transportation, and manufacturing. This is the production of the end materials which are being used in the construction phase.

2. Construction phase: In a building´s lifecycle, this is when the building is constructed. In a renovation project, this is when the renovation work is carried out. This encompasses all the activities from the products used when the production of the materials has been finished and used in the renovation project.

3. Use stage: In a building lifecycle, this involves the operation and maintenance of the building. In a renovation project, this could involve the use and maintenance of the renovated space and the related energy usage to the renovated part. This is also called the operational phase.

4. End-of-life: In a building lifecycle, this involves the demolition and disposal of the building. In a renovation project, this could involve the disposal of any waste materials generated during the renovation. As mentioned, the end-of-life phase is not in focus of this research.

However, a key difference is that a renovation project typically focuses on a specific part of a building, rather than the entire building. Also, the scale and impact of a renovation project are usually smaller compared to a building's lifecycle. For example, a renovation project may not have as significant an impact on Scope 3 emissions as constructing a new building would. But like a new building, a renovation project does offer opportunities to implement sustainable practices and reduce environmental impact (Liao, Ren, and Li,2023). Now the activities are clear from a renovation building's lifecycle the link is put towards Scope 3 CO_2e emissions and how important sustainable practices are. This can be seen in the Table below:

Phase	Key Activities	Scope 3 emissions	Importance of sustainable practices
A1	Raw material extraction and processing, processing of secondary material input	Emissions from energy use in extraction and processing, transportation of raw materials	Using renewable resources, minimizing energy consumption, promoting recycling to reduce demand for new raw materials
A2	Transport to the manufacturer	Emissions from transportation, including fuel combustion and vehicle manufacturing	Using low-emission vehicles, optimizing logistics, utilizing renewable energy sources
A3	Manufacturing	Emissions from energy consumption in manufacturing processes	Reducing energy consumption, using environmentally friendly production techniques, minimizing waste generation
A4	Transport to the building site	Emissions from transportation, similar to Phase A2	Minimizing emissions associated with logistics and delivery, optimizing supply chains, and using local suppliers when possible
A5	Installation into the building	Limited emissions directly associated with installation, but indirectly linked to embodied emissions of materials and transportation	Efficient use of materials, reducing waste, employing eco-friendly construction techniques
B1-B6	Use, Maintenance, Repair, Replacement, Refurbishment, Operational energy, and water use	Emissions associated with energy and water consumption, production and transportation of maintenance and replacement materials	Designing for energy and water efficiency, using renewable energy sources, implementing green building standards, promoting circular economy principles
C1-C4	De-construction, Transport to waste processing, Waste processing, Disposal	Emissions from demolition equipment operation, transportation of waste, landfilling, or incineration processes	Minimizing waste generation, maximizing material recovery through recycling and reuse, reducing emissions associated with waste disposal

D	Reuse, recovery, and/or recycling potentials	Emissions associated with the production and transportation of recycled materials and avoided emissions from reduced demand for virgin materials	Promoting material circularity, designing for disassembly, establishing take-back programs, supporting markets for recycled materials

Table 1: Overview of building's lifecycle phases with the key activities, Scope 3 emissions and sustainable practices (Sources: (Farsan et al. 2018; Gregory and Krol 2024; Anon 2011)

From all phases, it is clear what the Scope 3 emissions are and what the importance of sustainable practices are. These sustainable practices can be implemented in organizations to achieve future goals for achieving Zero-Emission buildings in 2050 (Toth et al. 2022). Because all the phases (from product to end-of-life) of a building's lifecycle will take place within renovation projects, Section 2.1.3 will look at the existing lifecycle analysis literature and how this is related to Scope 3.

2.1.3 Lifecycle of renovation projects

As said in Section 2.1.2, all the phases of a building's lifecycle will take place within renovation projects, therefore, different kinds of lifecycle analysis can be approached to measure environmental impacts. There can be distinguished three processes within the whole lifecycle as can be seen in Figure 2:

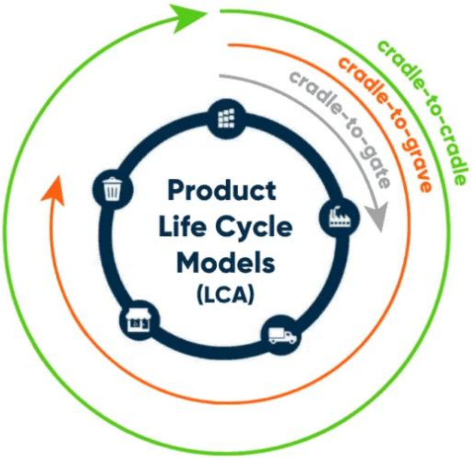


Figure 2: Life cycle models (Source: Ecochain, 2023)

1. Cradle-to-gate emissions focus on the environmental impact of a product with the extraction of raw materials for production. This means that it only assesses the upstream (up to the gate) activities required to make the product.
2. Cradle-to-grave analyzes a product's impact throughout all five stages of the product lifecycle, from sourcing raw materials (cradle) to product disposal (grave), where transportation can occur at any stage.
3. Cradle-to-cradle is the lifecycle model that replaces the waste stage of cradle-to-grave with recycling processes, allowing materials to be reused for other products which makes the lifecycle circular.

These three stages can be linked back to the building's lifecycle as described in Section 2.1.2. The difference is mainly in the distinction between the upstream and downstream activities. Upstream activities refer to the processes that occur before the construction of a building, such as the extraction, manufacturing, and transportation of building materials, as they are responsible for a large portion of the embodied CO_2e emissions. Embodied CO_2e emissions are the emissions that are emitted during the building's lifecycle without the operational phase. In Figure 1 these are phases A and C. Phase A is categorized as cradle-to-site and all phases without recycling processes are cradle-to-grave. Downstream activities refer to the processes that occur after the construction of a building, such as the use, maintenance, and eventual demolition of the building. Within the downstream activities, the operational phase CO_2e emissions are covered (Orr, Gibbons, and Arnold 2020). In Figure 1 this is phase B. These activities also have a large impact on the carbon footprint of a building, it includes the operational carbon emissions of a building's lifecycle. The differences between operational and embodied emissions can be seen in Figure 3:

Figure 3: Differences between embodied and operational emissions for a building's lifecycle (Source: Programme and Architecture 2023)

Section 1.1 mentioned the fact that the operational phase of a building's lifecycle accounts for more than 69% of the CO_2e emissions of a building's lifecycle. Looking towards the distinction within the lifecycle analysis, embodied CO_2e emissions and, operational CO_2e emissions, Zhang & Wang (2015) states that about 82-86% of the total carbon emissions are in the operational phase of a building's lifecycle. This has shifted in recent years more to the distribution of 50 % operational and 50% embodied carbon (Anon 2024c). Therefore, choices made in the embodied carbon phases of the lifecycle are becoming more important than it was before because the distribution has shifted more towards phases A and C. Orr, Gibbons and Arnold (2020) state that from the embodied carbon emissions the most emit within phase A, product and construction. To get the most accurate carbon emissions and eventually the CO_2e emissions from each phase within the lifecycle, Environmental Product Declarations (EPDs) should be used from each used material. Shortly, EPDs provide information about a product's impact on the environment. This will be elaborated on in Section 2.2.

Figure For construction companies, understanding the different phases of the lifecycle and the upstream and downstream activities is important to manage the CO_2e emissions of their construction operations effectively. By understanding all the phases within a building's lifecycle on reducing CO_2e emissions, construction companies can work towards more sustainable building practices. As described, it is clear that most CO_2e emissions emit during phases A and C from Figure 1. Gathering information on downstream CO_2e emissions, in this case, phase C, for Scope 3 in the construction industry can be a challenging task. The downstream activities refer to the indirect emissions that occur outside the boundaries of a company's operations, and these firms need to be transparent in sharing information on the operational phase of the building. In addition, as per the environmental footprint guidelines established by the European Commission, the consideration of upstream emissions is a requirement, whereas the inclusion of downstream emissions is optional (European Commission, 2021). For most of the firms, the focus will therefore be on upstream activities. Sooner or later downstream emissions will be mandatory to report on. Therefore, being prepared as a firm and already taking actions towards both, upstream and downstream, emissions is the most efficient way to prepare for the regulations.

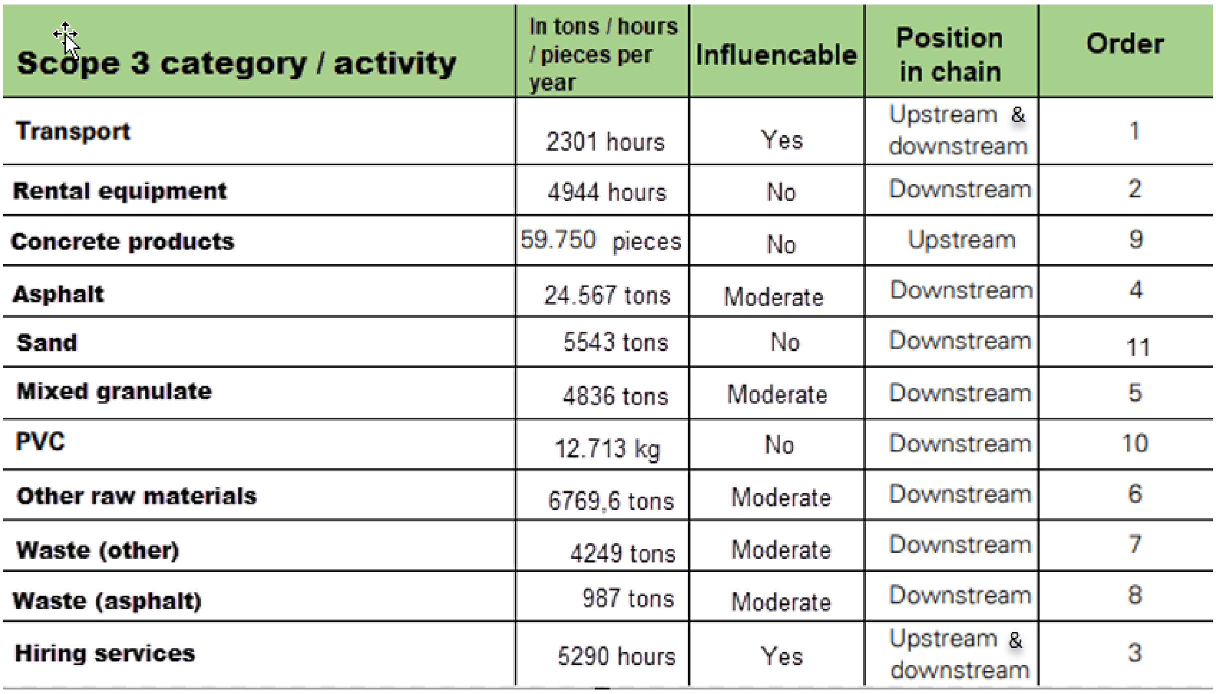
Now that the different lifecycle models are clear and how operational and carbon emissions are distributed within a building's lifecycle, Section 2.1.4 describes what the influenceable activities are within Scope 3.

2.1.4 Influenceable activities and sustainable practices for Scope 3 activities within a building's lifecycle

In the previous sections the activities of Scope 3 in renovation projects, the lifecycle models with differentiation in kinds of emissions are described. This section looks into influenceable activities and sustainable practices for Scope 3 activities within a building's lifecycle to get a deeper understanding of the research question of where organizations should implement sustainable practices first to bring down their Scope 3 emissions. First, the influenceable activities will be discussed and then the link is put towards sustainable practices according to studied literature.

A: Influenceable activities

In 2019 a case study was done for Mouwrik Waardenburg b.v. by an external company about Scope 3 emissions and where the firm can make an impact. The report of Mouwrik Waardenburg b.v. is not fully in line with the Scope of this thesis because its focus is on road construction. However, road construction and housing construction share similar Scope 3 activities. Both use concrete, need to transport materials to the construction site, and often rely on rental services, which can be viewed as subcontractors. Therefore, a look at the report of Mouwrik Waardenburg b.v. can help to rank the most influenceable activities for some Scope 3 activities for a building's lifecycle. The report of Mouwrik Waardenburg b.v. describes the method used to analyze and quantify the Scope 3 emissions. A ranking is established of the most material Scope 3 emissions, and quantitative assessments are made by an external company. The report also emphasizes the importance of involving suppliers, subcontractors, and other chain partners in working together to reduce CO_2e emissions in the projects of Mouwrik Waardenburg. However, the report does not contain specific information about the size of the Scope 3 emissions of Mouwrik Waardenburg b.v. the results can be used to rank the most activities for Scope 3 emissions which Mouwrik Waardenburg b.v. can influence. The results can be seen in Table 2 below.



Scope 3 category / activity	In tons / hours / pieces per year	Influencable	Position in chain	Order
Transport	2301 hours	Yes	Upstream & downstream	1
Rental equipment	4944 hours	No	Downstream	2
Concrete products	59.750 pieces	No	Upstream	9
Asphalt	24.567 tons	Moderate	Downstream	4
Sand	5543 tons	No	Downstream	11
Mixed granulate	4836 tons	Moderate	Downstream	5
PVC	12.713 kg	No	Downstream	10
Other raw materials	6769,6 tons	Moderate	Downstream	6
Waste (other)	4249 tons	Moderate	Downstream	7
Waste (asphalt)	987 tons	Moderate	Downstream	8
Hiring services	5290 hours	Yes	Upstream & downstream	3

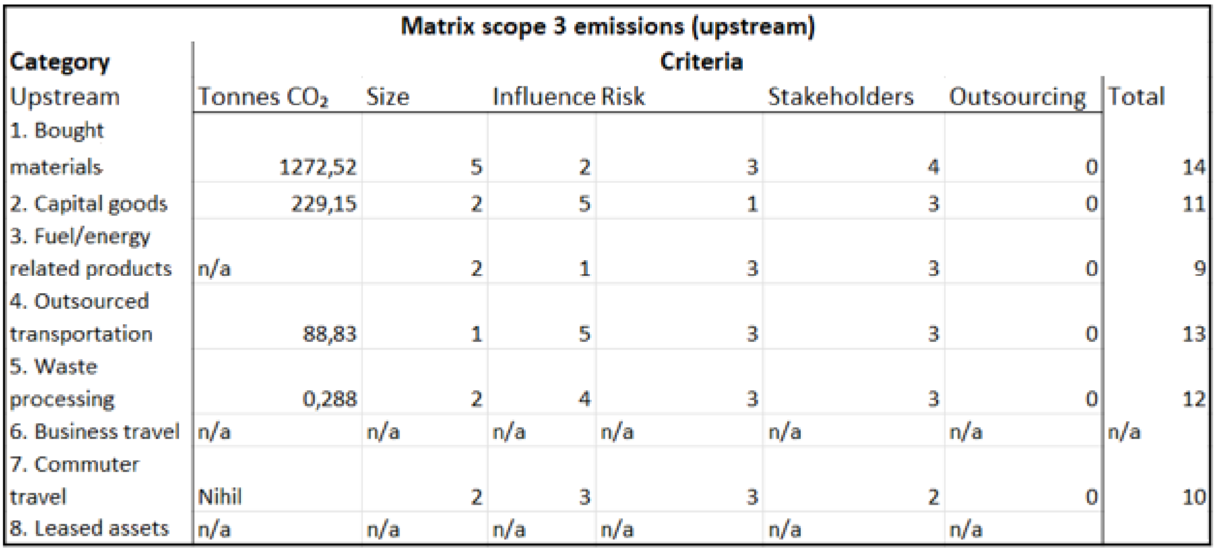
Table 2: Chain analysis for the most material Scope 3 activities (Adapted from: Waardenburg, 2021)

The column, order, can be used to interpret the results. The column order is based on the amount of Scope 3 emissions and if it is influenceable. Although, in Table 2 rental equipment is not directly influenceable by Mouwrik Waardenburg b.v., they have the opportunity to choose other organizations where they can rent them. If these work more sustainably the Scope 3 emissions for Mouwrik Waardenburg b.v. will go down. From this case study comes forward that transport, rental equipment, and hiring services are the most influenceable and within these activities choices can be made to bring down the Scope 3 emissions.

In addition, the company Koen Meijer b.v. had done a case study about their Scope 3 emissions. Koen Meijer b.v. is a construction company and reported on Scope 3 emissions according to the GHG Protocol, which will be described in Section 2.2.2. Looking towards the upstream and downstream activities within Scope 3 they have made a matrix with five different categories to determine their reduction goals for Koen Meijer b.v., which are the following:

1. Size; ratio of the amount of CO_2 of the assessed Scope 3 emission category.
2. Influence; the degree of influence the company can exert to achieve reduction.
3. Risk; The risk related to climate change. For example: financially, through regulation in the supply chain.
4. Stakeholder; Stakeholders find it important that actions are taken for the reduction
5. Outsourcing; Outsourcing of activities that were previously performed by the company itself.

Every category can get a score of zero to five. Where 0 means that there is no influence and five implies a lot of influence can be exerted by Koen Meijer b.v. The outcome of the matrix can be seen in Tables 3 and 4 below and shows the total points that are the most important for the reduction strategy. Table 3 is about the upstream Scope 3 emissions and Table 4 is about the downstream Scope 3 emissions.



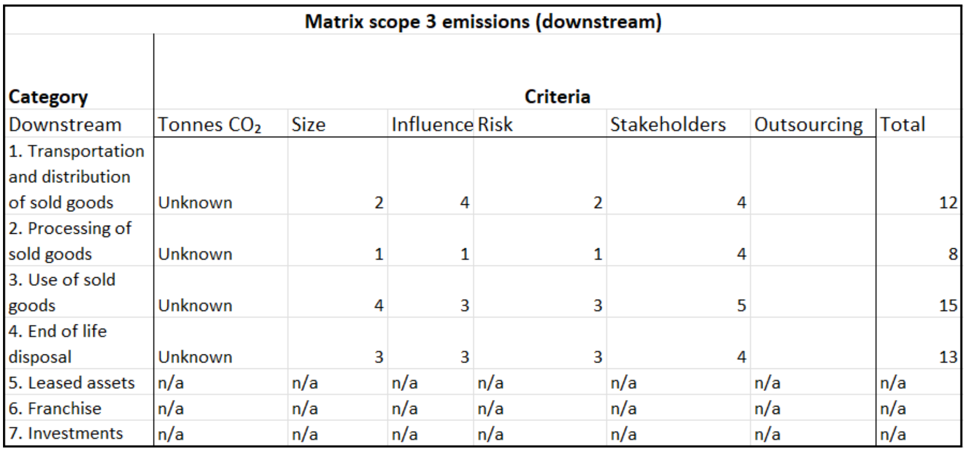
Matrix scope 3 emissions (upstream)							
Category	**Criteria**						
Upstream	Tonnes CO_2	Size	Influence	Risk	Stakeholders	Outsourcing	Total
1. Bought materials	1272,52	5	2	3	4	0	14
2. Capital goods	229,15	2	5	1	3	0	11
3. Fuel/energy related products	n/a	2	1	3	3	0	9
4. Outsourced transportation	88,83	1	5	3	3	0	13
5. Waste processing	0,288	2	4	3	3	0	12
6. Business travel	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7. Commuter travel	Nihil	2	3	3	2	0	10
8. Leased assets	n/a	n/a	n/a	n/a	n/a	n/a	

Table 3: Important Scope 3 upstream activities (Adapted from: Meijer, 2021)

The results of Table 3 can be interpreted as follows according to the total category column on the right:

1. Bought materials
2. Outsourced transportation
3. Waste processing
4. Capital goods
5. Commuter travel
6. Fuel/energy-related projects.

The upstream Scope 3 category of bought materials has the highest priority over all the Scope 3 upstream criteria groups combined with a score of 14. This means that the focus for Koen Meijer b.v. in the first place for the upstream categories in reducing Scope 3 emissions is on the category of bought materials. Looking at the downstream activities Table 4 can be interpreted.



Matrix scope 3 emissions (downstream)							
Category	**Criteria**						
Downstream	Tonnes CO_2	Size	Influence	Risk	Stakeholders	Outsourcing	Total
1. Transportation and distribution of sold goods	Unknown	2	4	2	4		12
2. Processing of sold goods	Unknown	1	1	1	4		8
3. Use of sold goods	Unknown	4	3	3	5		15
4. End of life disposal	Unknown	3	3	3	4		13
5. Leased assets	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6. Franchise	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7. Investments	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 4: Important Scope 3 downstream activities (Adapted from: Meijer, 2021)

The results of Table 4 can be interpreted as follows according to the total category column on the right:

1. Use of sold goods

2. End of life disposal
3. Transportation and distribution of sold goods
4. Processing of sold goods

The categories of leased assets, franchises, and investments are not applicable. For the downstream Scope 3 emissions this means that Koen Meijer b.v. should reduce the use of sold goods category as first, the operational phase in the building's lifecycle. When Koen Meijer b.v. reduces the categories that have scored the highest for the upstream and downstream categories they are focusing on the most important categories. While the operational phase is the most important category for the reduction of CO_2 emission it is unknown in the research of Koen Meijer b.v. how much the operational phase emits.

Comparing Table 2 with Tables 3 and 4 there are differences within rankings and how the different firms map the general Scope 3 activities. Table 2 is composed within each Scope 3 activity while Tables 3 and 4 are more specified. The more specific each activity is, the more useful it can be for decision-making. Therefore, Tables 3 and 4 are more practicable for decision-making towards CO_2 reduction. Based on these two reports, the order of influenceable activities is necessary for the stakeholders to see where the quickest wins can be achieved and where a company needs to put its focus.

B: Sustainable practices

This section describes which sustainable practices can be implemented at the different phases of a building's lifecycle. Phase A described which activities are the most influenceable. Looking towards these activities, the most important ones for stakeholders are those that are influenceable related to the phenomenon of stakeholder management (Stakeholdersanalyse, 2023). Stakeholders are more interested in activities that they can influence and where their actions can have an impact. These are three of the categories described in Tables 3 and 4. In addition to the described activities in phase A, the Network of Construction Companies for Research and Development (ENCORD) has prepared a protocol of measurement for the construction sector (Ger Maas Royal et al. 2012). In this protocol, the most influential indicators have been mentioned for the construction sector. For Scope 3 these contain, vehicle fuel, public transport, sub-contractors, waste, materials, and product (operational phase). These are in line with the case studies in phase A.

In a study conducted by Kedir & Hall (2021), a literature review was carried out which shows a frequency analysis and is shown below in Figure 4, revealing the most frequently mentioned areas in various phases of a building's lifecycle in the literature where resource efficiency could be implemented. It is based on industrialized housing construction (IHC). IHC means that industrialized production methods have been used with the potential to increase energy efficiency and decarbonization. This could be seen as the same goal for renovation projects to decrease operational emissions and apply sustainable practices.

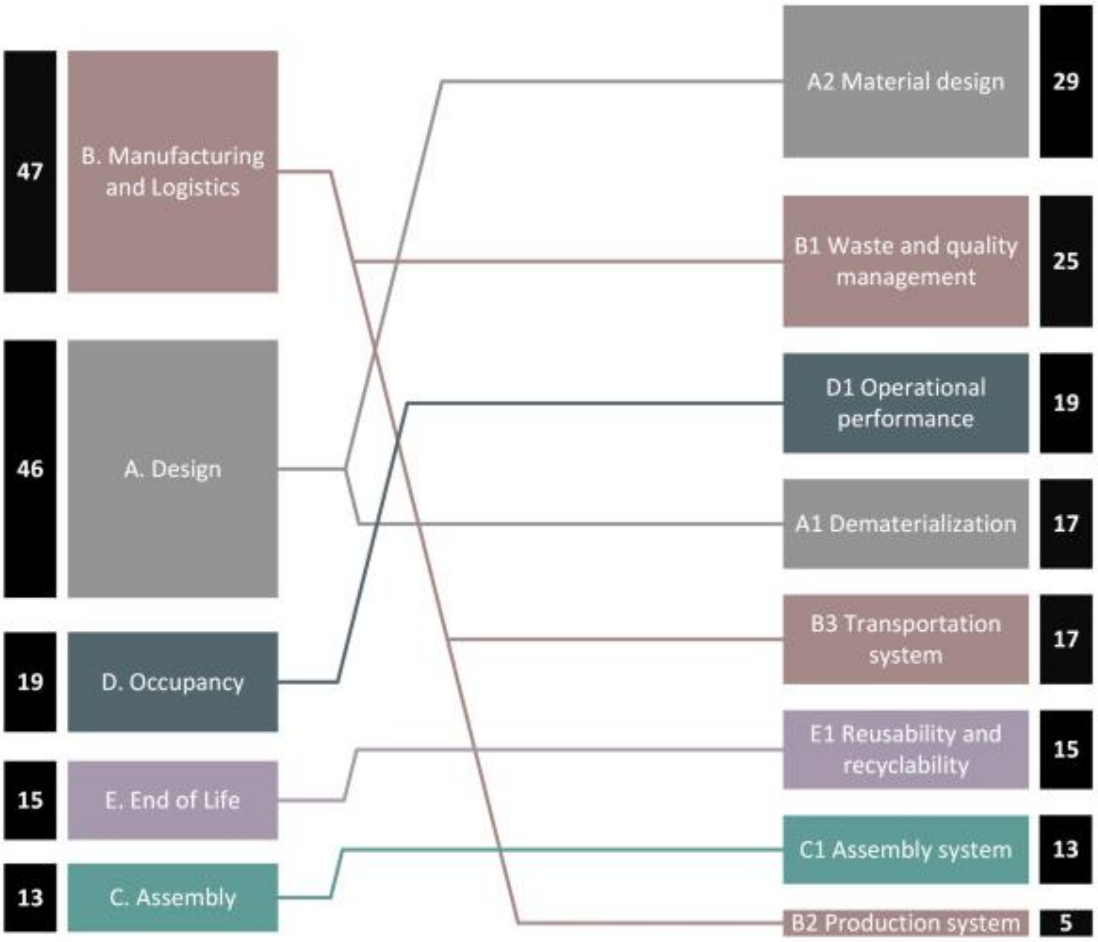


Figure 4: Recurring themes of a building's lifecycle in studied literature (Source: Kedir & Hall, 2021)

The literature review of Kedir & Hall indicates that there are specific phases in the building lifecycle of IHC where interventions can have an impact on resource efficiency. Figure 4 top down on the left side shows where most of the resource efficiency methods could be implemented. From all the 86 papers, there are 47 studies in phase b, manufacturing and logistics, which study resource efficiency. On the right side, these are divided into sub-themes and how much of the 47 are within each theme. For phase b these are in waste and quality management, transportation, and production systems. Most of the studied phases on the left side can be linked to a building's lifecycle phase. It is important to understand these themes to know where sustainable decisions for Scope 3 emissions can be made. The phases where there is room to make an impact on resource efficiency include:

1. Design: Before a project starts decisions can be made in this phase. Firms can decide which materials they use and how processes flow, which subcontractors they hire, and what kind of equipment they use. Dematerialization refers to the reduction of material inputs and waste outputs in the production and consumption of goods and services (Świątek 2013). This can be achieved through various means, such as product design optimization, material substitution, and process efficiency improvements. Product optimization could be achieved through design awareness of advanced manufacturing and/or digital tools for design optimization (Iuorio, Wallace, and Simpson 2019). The goal of dematerialization is to achieve sustainable development by reducing the environmental impact of economic activities while maintaining

or increasing the well-being of society. This can be achieved by looking at the chain analysis and seeing the total outputs for decision-making.

The main goal of the studies about material design is to use efficient resources and shift resources towards low-carbon materials, and move away from energy-intensive and non-renewable resources (Achenbach, Wenker, and Rüter 2018). Cement, lime, and plaster are the materials that cause the largest carbon footprints (Hertwich 2021). Overall, the use of materials in construction accounts for 70% of all sectors. Looking at the materials that the construction sector is using, **Error! Reference source not found.** can be interpreted.

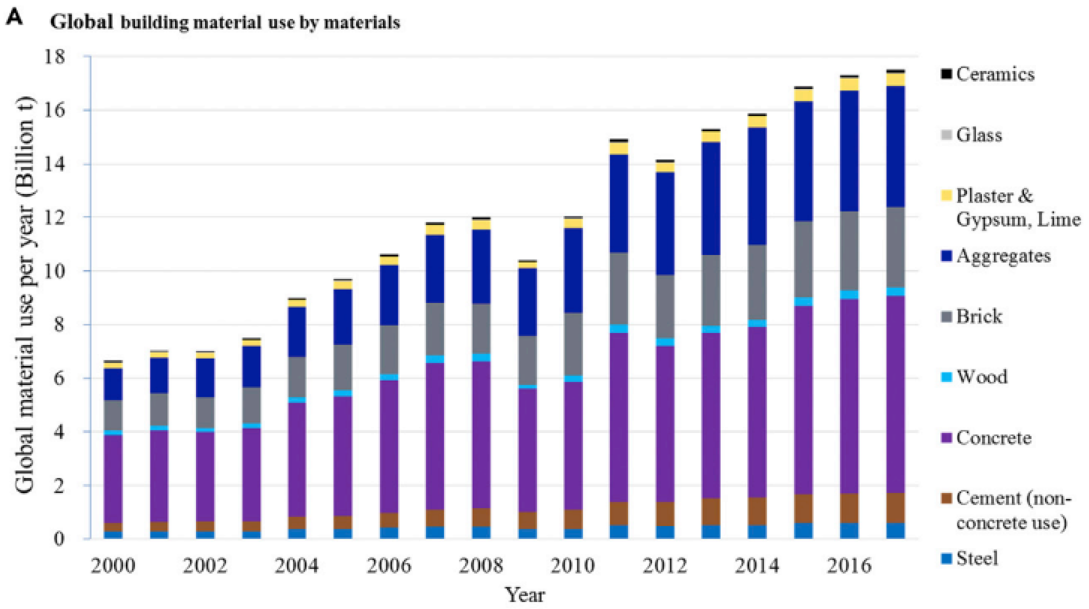


Figure 2: Global usage of building materials (Source: Heeren & Fishman, 2019)

Most of these materials are non-renewable. Non-renewable building materials come from sources that cannot be replaced quickly or are only available in limited amounts. Once we use them up, they are gone for a long time. Renewable building materials come from sources that can be replaced naturally in a short time. Renewable materials often have lower embodied emissions which results in lower CO_2e during their lifecycle. In Figure 5, wood is a renewable building material, the others are non-renewable.

2. Manufacturing and logistics: Implementing resource-efficient manufacturing processes and techniques can minimize waste, optimize material use, and enhance overall resource efficiency. Quality and waste management (B1) are aligned with decisions from within the firm. Quality and waste management can be described as an approach to achieving and sustaining high-quality output where the emphasis is more on management practices (inputs) than quality performance (outputs) (Flynn, Schroeder, and Sakakibara 1994). These inputs of management can be described as methods to reduce waste and improve quality. An important concept in waste and quality management is lean manufacturing (Figueroa et al. 2023). The focus of lean manufacturing is on improving efficiency and quality. Methods how this can be established are using the Just-In-Time (JIT) principle and Kaizen. JIT is about producing only what is needed and when it is needed, this reduces inventory. Kaizen is about continuous improvement of processes and employees. The goal is to use fewer resources to get the same or even better results. Another concept in quality and waste management is circular economy.

The goal of circular economy is to extend a product's lifecycle by designing products that are easier to repair and are more durable (Slaveykova et al. 2019)

Production systems (B2) for housing construction involve the manufacturing processes of building elements. These systems have the potential to enhance resource efficiency by improving material process flow planning and fostering seamless information exchange among stakeholders (Barriga et al. 2005). Making use of these systems will lead to choices for a reduction in emissions because of the efficient use of material.

Looking towards the last activity of phase B, transportation systems refer to the place from manufacturing to the place of the final assembly site. Transportation is a significant contributor to GHG emissions due to the total use of energy and burns most of the world his petroleum. This is a significant contributor through the emission of carbon dioxide and the equivalent of one billion tons of carbon dioxide ($GtCO_2e$) (*Union of Concerned Scientists*, 2008). In Appendix B the overview of total CO_2 in 2019 in The Netherlands can be seen. Existing theory about transportation systems involves strategic planning, efficient resource utilization, and environmental awareness. An existing method is to apply Intelligent Transportation Systems (ITS) management. ITS helps companies optimize traffic flow, minimize delays, and can help choose eco-friendly routes (Verma et al. 2024). When applying ITS, companies can bring down their Scope 3 emissions in the category of transportation and distribution in the upstream category.

3. Assembly: The assembly phase in Figure 4 refers to multiple activities that take place on the construction site. The subtheme is about assembly systems. Assembly systems in the context of industrialized housing construction refer to the on-site processes and activities required to form the entire building system at the construction site. These systems encompass various tasks such as erection, joinery works, and integrating prefabricated building elements to create a complete structure. Assembly systems focus on streamlining and optimizing the assembly process to improve efficiency, reduce waste, and enhance overall resource efficiency. By utilizing prefabricated components and efficient assembly techniques, construction projects can be completed more quickly and with fewer resources than traditional on-site construction methods (Alwisy et al. 2019). Efficient assembly systems play a crucial role in achieving resource efficiency goals in industrialized housing construction by minimizing material waste, reducing energy consumption, and improving the overall sustainability of the building process.
4. Occupancy: Occupancy is about the operational performance. Different sustainable practices can be implemented in the operational phase. The most common ones according to Iyer-Raniga et al (2021) are:

    a. Energy efficiency:
    b. Indoor air quality
    c. Water conservation
    d. Renewable energy

Implementing these practices promotes energy efficiency, occupancy flexibility, and long-term value retention. As a result of sustainable practices, net zero emissions can be achieved (Prasad et al. 2022). A model that enhances efficiency in sustainable building projects by integrating design, construction, and operation information is Building Information Modeling (BIM). BIM is a workflow process. It is based on models used for the planning, design, construction, and management of building and infrastructure projects. When using BIM, sustainable practices for occupancy can be selected in the early design phase of the project.

5. End-of-life: Companies deal with waste in the end-of-life phase of a building's lifecycle. This waste is related to the activities for demolition of the building. Sustainable practices in the end-of-life phase consider resource-efficient strategies, such as recyclability and reusability of materials, which can contribute to overall resource efficiency and sustainability. By demolishing a building, large amounts of waste need to be processed. This waste requires transportation, processing, and/or disposal of some kind. This can lead to a large amount of Scope 3 emissions. Construction firms can influence the amount of waste generated, through more efficient planning, operations, and design. In addition, they can choose how waste is dealt with (through re-use, recycling, recovery, or disposal). Although it is out of the Scope of my paper it is important to mention that achievements can be achieved in this aspect. As mentioned in Section 1.1, the operational phase accounts for 69% of the total GHG emissions in a building's lifecycle and is therefore the most important factor for the Scope 3 emission.

By focusing on implementing sustainable practices within these phases and resource-efficient practices and strategies, stakeholders in industrialized housing construction can maximize resource efficiency and minimize environmental impact throughout the building's lifecycle, leading to lower Scope 3 emissions.

2.1.5 Conclusion activities within Scope 3

All relevant theories have been discussed about Scope 3 emissions for renovation projects. The activities in Scope 3 contain upstream and downstream activities and can be categorized in the different phases of a building's lifecycle. Upstream activities contain the stream of Scope 3 emissions related to the purchase of goods and services, downstream activities contain the Scope 3 emissions that emit after goods or services are sold. The Scope 3 activities that relate to renovation projects in the Dutch building sector can be categorized into the building's lifecycle phases: product, construction, use, and end-of-life. The emissions that emit during the product, construction, and end-of-life phase are the embodied CO_2e emissions The phases of the lifecycle that emit the most emissions for the embodied carbon are in the product and construction phase. The other CO_2e emissions emit during the operational phase. In recent years, the distinction between operational and embodied CO_2e emissions has shifted from predominantly embodied emissions to a more balanced 50-50 split. The building's lifecycle phases which are the most influenceable and have the highest priority to stakeholders are the bought materials in the product phase of a building's lifecycle, outsourced transportation in the product and construction phase of a building's lifecycle, and the operational phase. When reducing Scope 3 emissions priority should lay on these activities. This can be done by implementing sustainable practices. For the product phase in the building's lifecycle, these are about using efficient resources and low-carbon materials and moving away from energy-intensive and non-renewable resources. Sustainable practices in the construction phase can be implemented using management on waste and quality management and by using production and transportation systems. Management on waste and quality can be deployed by using methods such as lean manufacturing and circular economy. The production systems are focused on sustainable manufacturing that enhances energy efficiency. Transportation systems make use of efficient planning and optimize traffic flow so that the emissions are minimized. During the operational phase, sustainable practices focus on improving energy efficiency, enhancing indoor air quality, conserving water, and increasing the use of renewable energy sources. Sustainable practices can enhance the end-of-life phase by emphasizing careful planning and design during demolition. By incorporating sustainable elements into the design phase, more materials can be recycled or reused when a building's lifecycle reaches its end.

In conclusion, Section 2.1 showed which phases of a building's lifecycle Scope 3 emissions emit, which phases are the most influenceable, and which sustainable practices can be implemented at each phase.

2.2 Tools and guidelines to report and calculate emissions

So far, Section 2.1 has discussed the general Scope 3 activities and categorized them for renovation projects. Existing literature has shown at which phase of a building's lifecycle Scope 3 emissions are emitted and which phases are the most influenceable and should be prioritized first when bringing down Scope 3 emissions. In addition, for each lifecycle phase literature has shown which sustainable practices can be implemented. In this section, an overview of existing tools to calculate emissions will be evaluated. In addition, methods will be elaborated in steps of accounting and reporting for Scope 3 emissions for renovation projects. This section will answer the following sub-research question 4: "What are existing tools or methods for gathering data on Scope 3 emissions?". Section 2.2.6 will discuss the payback period which is an introduction to the sub-research question "What is the payback period on Scope 3 emissions that are emitted during renovation projects and the savings in operational CO_2e emissions in the operational phase of a building's lifecycle compared pre-and post-renovation?" to understand the method of the payback period.

2.2.1 CSRD

As said in the introduction, the CSRD makes it obligatory for large companies to report on their sustainability performance. The main concepts are about double materiality and to which standards companies need to report on. Double materiality requires companies to assess and report on sustainability matters from two perspectives (EFRAG 2022):

1. Financial materiality: This perspective looks at how sustainability issues might create financial risks or opportunities for the company. It focuses on the potential impact of ESG factors on the company's financial performance and position over the short, medium, and long term.
2. Impact materiality: This perspective examines the company's actual or potential impacts on people and the environment. It considers both positive and negative effects that the company's operations and value chain might have on society and the environment.

By incorporating both perspectives, double materiality ensures comprehensive transparency and accountability in sustainability reporting. This approach helps stakeholders understand not only how sustainability issues affect the company but also how the company affects the world around it (EFRAG 2022).

The European Sustainability Reporting Standards (ESRS) are a set of guidelines developed to standardize sustainability reporting for the CSRD. For large companies, the ESRS is mandatory to follow. For Scope 3 there are standards within the ESRS E1: Climate change. The key aspects for reporting on ESRS E1 are :

1. Categories: Scope 3 emissions include a wide range of activities both upstream and downstream in the value chain. This can encompass emissions from purchased goods and services, business travel, employee commuting, waste disposal, use of sold products, transportation and distribution (BDO 2023).
2. Disclosure requirement: Companies are required to disclose (EFRAG 2022):

    a. The total Scope 3 GHG emissions from significant categories.
    b. The percentage of emissions calculated using primary data.
    c. The boundaries and calculation methods used for each significant Scope 3 category.
3. Significance: Scope 3 emissions often represent the largest portion of a company's total GHG emissions, making their accurate reporting crucial for understanding the full climate impact of a company's operations. Without this information, it would be difficult to get a complete picture of the company's contribution to climate change and to develop effective strategies for reducing its overall carbon footprint (BDO 2023).
4. Scope 3 emissions can be complex due to the need for data from various parts of the value chain, which may not always be readily available or easy to quantify. Companies are encouraged to describe the methods and tools they use to gather and calculate this data, as well as any limitations or uncertainties involved. By disclosing these challenges companies provide transparency about the difficulties they face and the steps they are taking to improve the accuracy and completeness of their Scope 3 emissions reporting (EFRAG 2022).

The ESRS does not provide specific methods or guidelines on how to measure these Scope 3 emissions. Therefore, Section 2.2.2 describes different methods on how to measure Scope 3 emissions.

2.2.2 European Commission environmental footprint methods

Pelletier et al., (2014) discuss and evaluate existing methods for measuring the environmental impact of organizations and compare them to the reference method for organizational environmental footprint (OEF) developed by the European Commission (EC). The research focuses on the similarities and differences between these various methods and their implications for improving sustainability in production and consumption.

Pelletier et al., (2014) talk about four core criteria that guided the development of the EC organizational environmental footprinting method. These criteria include the need for a multi-criteria, life-cycle-based approach that covers all organizational and related activities in the supply chain, providing reproducibility and comparability over flexibility, and ensuring physically realistic modeling. Pelletier et al., (2014) also discuss the challenges of establishing system boundaries for OEF analyses in a systematic way. This is because organizations are often part of larger systems, and their activities can have indirect or upstream/downstream impacts that are difficult to quantify. Additionally, not all activities or processes within the system boundaries may be environmentally significant, and it may not be possible to acquire the data necessary to include them in the OEF model. For these reasons, cut-off criteria are often established in environmental accountancy models to provide thresholds for inclusion of environmentally significant processes and flows, in the interest of balancing returns on effort and analytical robustness. However, there is no common approach to establishing cut-off criteria among the reviewed methods.

Pelletier et al., (2014) find that following the specific rules of the EC OEF method, especially when it comes to evaluating various environmental impacts and the quality of data, has advantages and disadvantages. It might lead to organizations needing more technical knowledge, which could increase their expenses. However, this detailed approach might also mean that users do not have to be experts in methodology to make informed decisions.

The research in the article of Pelletier et al., (2014) provide a critical evaluation of existing methods for measuring the environmental impact of organizations. It discusses six methods for measuring the environmental impact of organizations:

1. ISO 14064:2006 Greenhouse gases—Part 1 to 3:

This method is focused on quantifying and reporting greenhouse gas emissions and removals at the organizational level. It consists of three parts: Part 1 deals with the specification concerning the inventory and reporting of greenhouse gas emissions and removals, Part 2 deals with the specification concerning the verification and validation of greenhouse gas inventories, and Part 3 deals with the specification concerning the projects for greenhouse gas emission reduction (ISO 14064-3, Greenhouse gases, 2019).

2. The Carbon Trust Standard for Supply Chain: This method is focused on measuring the CO_2 emissions of the supply chain from an organization. It consists of three steps: establishing system boundaries, collecting data and calculating CO_2 emissions, and reporting the results.
3. The GHG Protocol: This method is focused on measuring and reporting greenhouse gas emissions at the organizational level. It consists of three Scopes: Scope 1 covers direct emissions from sources that are owned or controlled by the organization, Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating, and cooling, and Scope 3 covers all other indirect emissions resulting from the activities of the organization (Callahan et al. 2011). The GHG Protocol Serves as a guide, offering detailed calculation methods and operational strategies for emissions management and reporting. It differs from ISO 14064:2006, in a way that it is more of a guide, and ISO 14064:2006 focuses on requirements and specifications.
4. The Bilan Carbone method: This method is focused on measuring the CO_2 emissions of organizations and their activities. It consists of six steps: establishing system boundaries, collecting data, calculating CO_2 emissions, identifying key emission sources, developing an action plan, and monitoring progress (Carbone 2007).
5. The DEFRA Environmental Reporting Guidelines: These guidelines are focused on providing a framework for organizations to report their environmental impacts, including greenhouse gas emissions. They consist of three parts: Part 1 guides the principles of environmental reporting, Part 2 guides the measurement and reporting of greenhouse gas emissions, and Part 3 guides the measurement and reporting of other environmental impacts.
6. The Global Reporting Initiative (GRI) Sustainability Reporting Guidelines: These guidelines are focused on providing a framework for organizations to report on their sustainability performance, including their environmental impacts. They consist of three parts: Part 1 guides the principles of sustainability reporting, Part 2 guides the measurement and reporting of sustainability performance indicators, and Part 3 guides the external assurance of sustainability reports.

These methods differ from each other based on key purposes. ISO 14064:2006 focuses on detailed, validated GHG inventory and reduction projects. When focusing on the supply chain the Carbon Trust Standard is recommended to follow. Focusing on emissions in each Scope the GHG Protocol needs to be followed for a comprehensive approach to measuring and managing emissions across all Scopes. Only focusing on CO_2 emissions, the Bilan Carbone method needs to be used. The key focus of the DEFRA Guidelines is on broad environmental reporting and the GRI guidelines need to be followed for a holistic view of sustainability performance.

Among the methods for measuring CO_2 emissions, the GHG Protocol, the Carbon Trust Standard, and the Bilan Carbone method are the most practical guidelines to follow. The primary distinction is that the GHG Protocol explicitly measures Scope 3 emissions, while the Bilan Carbone method categorizes emissions as either direct or indirect. (Anon n.d.). The Carbon Trust and the GHG Protocol are quite similar in their approaches. The main difference is that the GHG Protocol is the only internationally recognized method, providing it with broader support. Therefore, the GHG Protocol is the preferred method for calculating Scope 3 emissions throughout a building's lifecycle. Section 2.2.3 will discuss the GHG Protocol in more detail.

2.2.3 GHG Protocol

The GHG Protocol is a comprehensive global framework for measuring and managing GHG emissions. It has been developed through a partnership between the World Resources Institute and the World Business Council for Sustainable Development, it provides standardized guidelines for both private and public sectors.

The GHG Protocol is divided into several standards, each serving a specific purpose:

1. Corporate Standard: This is the most widely used standard, helping companies and organizations prepare a GHG emissions inventory. It covers the accounting and reporting of seven GHG emissions: CO_2, CH4, N_2O, Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs), Sulfur hexafluoride (SF_6), and, Nitrogen trifluoride (NF_3). The Corporate Standard aims to provide a true and fair account of emissions, simplify the inventory process, and increase consistency and transparency in GHG accounting (Ranganathan et al. 2004).
2. Scope 2 Guidance: This standard focuses on emissions from purchased electricity, steam, heat, and cooling. It provides methods for companies to measure and report these emissions accurately (Sotos 2015).
3. Corporate Value Chain (Scope 3) Standard: This standard helps businesses account for emissions throughout their entire value chain, including both upstream and downstream activities (Callahan et al. 2011).
4. Project Protocol: This standard is used for quantifying reductions associated with GHG mitigation projects, which can be used as offsets or credits (Greenhalgh et al. 2000).

The GHG Protocol is essential for businesses and governments aiming to track progress toward climate goals. It is compatible with most existing GHG programs and helps organizations develop comprehensive and reliable inventories of their GHG emissions. By providing a standardized approach, the GHG Protocol ensures that emissions data is consistent, transparent, and comparable across different entities and regions.

The Corporate Value Chain (Scope 3) Standard is the most practicable for accounting Scope 3 emissions and consists of the following steps which can be seen in Figure 6 below.

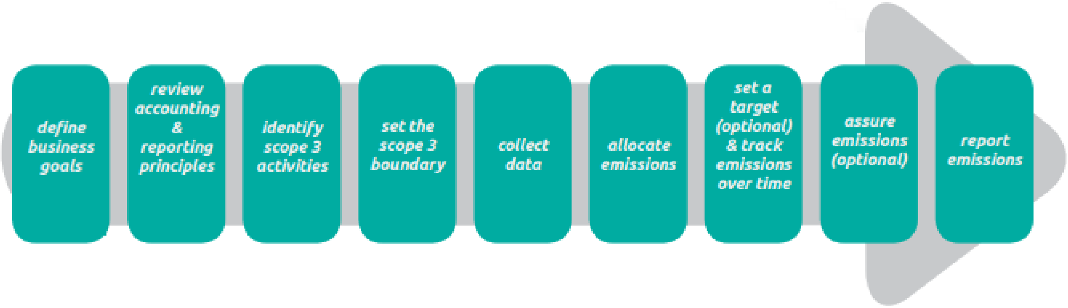


Figure 6: Overview of steps in Scope 3 accounting and reporting (Source: Callahan et al., n.d.)

In short, these steps can be described as:

1. Define business goals: Establish what you aim to achieve with your greenhouse gas emissions accounting and reporting.
2. Review accounting & reporting principles: Ensure you understand the principles and guidelines for accurate emissions reporting.
3. Identify Scope 3 activities: Determine which activities in your value chain contribute to Scope 3 emissions.
4. Set the Scope 3 boundary: Decide the boundaries for your Scope 3 emissions accounting, including which activities and sources to include.
5. Collect data: Gather the necessary data on emissions from the identified activities.
6. Allocate emissions: Distribute the collected emissions data appropriately across different activities and sources.
7. Set a target**:** Establish targets for reducing Scope 3 emissions.
8. Track Emissions over time**:** Optionally, monitor and track emissions over time to measure progress.
9. Report emissions: Compile and report the emissions data according to the established principles and guidelines.

Following these steps can lead to several achievements. The most useful for Scope 3 is that it makes comprehensive emissions tracking available, and it helps to allocate emissions efficiently to related Scope 3 activities. At last, when following the Standard, it prioritizes the categories where sustainable practices can be made for the activities measured (Callahan et al. 2011).

2.2.4 Life cycle assessment

In Section 2.1.3 different lifecycles have been discussed. These lifecycles can be measured by LCAs. LCA is a systematic evaluation method used to assess the environmental impacts associated with a product, process, or service throughout its entire life cycle. It takes into account all stages, from the extraction of raw materials to manufacturing, transportation, use, and final disposal. LCA provides valuable insights into the environmental aspects and potential sustainability improvements of a particular activity (United Nations Environment Programme, 2011). In the context of the construction process and Scope 3 activities, LCA can be applied to analyze and mitigate the environmental impacts arising from the sourcing and production of materials, as well as transportation activities. By conducting an LCA for Scope 3 activities, one can gain a comprehensive understanding of the environmental consequences associated with the materials used in construction projects, including their extraction, processing, and transportation to the construction site. The specific interest of LCA is on the environmental aspect therefore LCA can be adapted to environmental life cycle assessment (ELCA), which estimates the environmental impacts of products and construction phases. ELCA helps in identifying hotspots or areas with significant environmental impacts within the activities of construction. With this information, stakeholders can make informed decisions regarding the selection of materials, suppliers, transportation methods, and renewable energy methods. By considering the life cycle impacts, it becomes possible to choose alternatives that are more environmentally friendly, thus reducing the overall environmental footprint of the construction process.

Furthermore, ELCA can support the identification of opportunities for improvement and the implementation of sustainable practices (United Nations Environment Programme, 2011). It enables the comparison of different materials, designs, and supply chain options to assess their environmental performance. By optimizing material choices and transportation strategies, construction projects can minimize emissions, energy consumption, and resource depletion associated with Scope 3 activities.

Conducting an LCA for Scope 3 activities in the construction process allows for a holistic evaluation of the environmental impacts and helps drive sustainable decision-making. It promotes the adoption of environmentally conscious practices, facilitates the reduction of greenhouse gas emissions, and encourages the use of materials and transportation methods with lower environmental footprints.

ELCA contains of four phases shown in Figure 7:

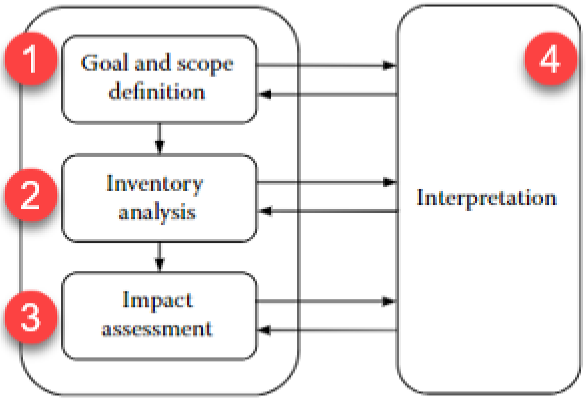


Figure 7: Four phases of life cycle assessment (Source: Jolliet et al., 2015)

1. Goal and Scope definition: Define the purpose of the study, the system boundaries, the functional unit (the unit of the product or service being assessed), data requirements, and the specific environmental impacts to be considered. There are two types of ELCA that can be distinguished in the goal and Scope definition phase, attributional and consequential. Attributional ELCA is defined by its focus to describe the emission and energy flow associated with a product (Finnveden et al. 2009). Consequential ELCA is defined by its aim to describe how environmentally relevant flows will change to possible decisions in forecasting the change of environmental impacts (Curran, Mann, and Norris 2005).
2. Inventory analysis: Collecting data on the inputs (e.g., raw materials, energy) and outputs (e.g., emissions, waste) associated with each life cycle stage. This step often involves life cycle inventory (LCI) databases and various data sources. This could be achieved through field surveys, interviews, literature reviews, etc. Provided in ISO 14040:2006, there are two types: the process and the input-output (I-O) ELCA (British Standards 2006). The process focuses on calculating the emissions, material flows, and energy flows for each unit in the study. I-O on the other hand links environmental data to the economic data. Compared to the process ELCA, I-O ELCA is a fast method that can save time on data collection while process ELCA can lead to more accurate results as the emissions and energy flows are collected for the specific study. The choice between process and I-O ELCA depends on the availability of data and the requirement of accuracy.
3. Impact assessment: This phase assesses the potential environmental impacts based on the inventory data. This step involves using impact assessment methods and models to quantify the effects on categories such as climate change, human health, ecosystem quality, and resource depletion. This could be done with a midpoint or endpoint approach. The midpoint approach assesses the environmental impact by examining the cause-effect chain, from the release of emissions to the eventual damage they cause.(Wegener Sleeswijk, Suh Helias et al. 2001). The endpoint refers to the endpoints such as human health, ecosystem, and resources (Hauschild et al. 2011). In the context of an LCA, the midpoint approach facilitates the

quantification of CO_2 emissions through the calculation of CO_2 equivalents. This methodology entails the conversion of other greenhouse gases, such as CH_4 and N_2O, into their respective CO_2 equivalents, considering their GWP over a predetermined temporal interval.

4. Interpretation: Analyzing and interpreting the results of the assessment, considering the uncertainties, limitations, and sensitivities of the data and methodologies used. This step involves identifying key areas for improvement and making recommendations.

For these steps, there are standards and guidelines. ISO14040:2006 provides the general features of an ELCA and describes the four phases mentioned before. It describes how to carry out an ELCA study and provides guidelines in this context, and how to interpret the results.

The result of an LCA could be an Environmental Product Declaration (EPD). An EPD is a transparent report of the lifecycle assessment of a product in a single, comprehensive document, providing verified information about its environmental impact. This can be split into each lifecycle phase from Scope 3. Therefore, using an EPD to see the environmental impacts of each lifecycle stage for Scope 3 is important when assessing each emission to a lifecycle phase as described in Section 2.1.2.

2.2.5 EMoC

Another model to use for calculating emissions is the tool of Dong & Ng (2015). Dong & Ng (2015) discuss a tool called the Environmental Model of Construction (EMoC) that helps stakeholders make decisions about building projects in Hong Kong and understand how those projects affect the environment. It looks at all the phases from when the materials are first taken from the earth to when the building is used and eventually demolished, the cradle-to-grave lifecycle.

To establish the EMoC model, the researchers conducted a case study of typical high-rise residential properties in Hong Kong. They collected data on the materials used in construction, the energy consumed during construction and use, and the waste generated during construction and demolition. They then used this data to model the environmental impacts of the building's construction and operation, including greenhouse gas emissions, water use, and waste generation.

The EMoC tool allows people to put in information about different parts of building projects, like materials, transportation, construction methods, and waste handling. Then, it tells them how those things impact the environment. It gives a detailed breakdown of the impacts, like how much greenhouse gas emissions there are or how much water is used. This helps people see where they can make changes to make the project better for the environment (Dong and Ng 2015). The tool looks at 18 different environmental impact categories in detail at the midpoint and endpoint levels. By inputting project-specific data to EMoC, it can generate results of over two hundred detailed processes. The tool should help support decision-makers in identifying pragmatic solutions to reduce the environmental impact of a building project at the design, procurement, and construction stages.

Although the EMoC tool was developed specifically to evaluate the environmental impacts of building construction projects in Hong Kong, the general principles and methodology used in the development of EMoC could potentially be adapted for use in other regions. However, the model was designed and calibrated using data from Hong Kong and may not accurately reflect the environmental impacts of building construction in other regions without modification. By inputting data on the materials and energy used in a building project, the tool can generate a comprehensive assessment of the project's environmental impacts. This information can be used to identify areas where improvements can be made to reduce the environmental impact of the building, such as by using more sustainable materials or adopting energy-efficient design strategies.

In the next section, the payback period method will be explained. When all the emissions are calculated and allocated to each phase of a building's lifecycle in the project, the difference in emissions that set free during the operational phase needs to be compared to the emissions that are emitted during the project phase.

2.2.6 Payback period

To answer the main research question: "What is the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation?" the payback period needs to be explained. The payback represents the time it takes to recover the cost of an investment or reach a breakeven point (Gallo 2016).

While a payback period normally focuses on costs, it can also be interpreted with emissions. Three steps need to be taken to calculate the payback period for emissions:

1. Calculate Emissions Savings:
   a. Determine the difference in greenhouse gas (GHG) emissions between the "before" and "after" phases of the project.
   b. Calculate the annual emissions reduction (in CO_2-equivalent units).
2. Payback Period Calculation:
   a. Divide the total project emissions (before implementing sustainable measures) by the annual emissions reduction.
   b. Payback Period = total project emissions / annual emissions reduction
3. Interpretation:
   a. A shorter payback period indicates a more attractive investment, as it means the emissions reduction benefits will be realized sooner.

The payback period gives a quick way to see when the environmental investments in a renovation project will pay off. It shows how long the benefits take to balance out the initial costs towards the environment (Bandyopadhyay 2020).

2.2.5 Conclusion tools to calculate emissions

In conclusion, Chapter 2 has provided existing methods on how to collect information about GHG emissions in the Dutch construction industry with tools and guidelines that are available. The European Commission environmental footprinting method describes a critical evaluation of existing methods for measuring the environmental impact of organizations. The GHG protocol has been explained in detail because it is the most relevant for Scope 3 activities and can be used as a guideline for calculating and allocating Scope 3 emissions. The LCA method is a systematic evaluation method used to assess the environmental impacts associated with a product, process, or service throughout its entire life cycle. Therefore, it can be used to measure all emissions during each Scope 3 activity and see at which phase the most emissions arise. The payback period has been explained and how it can help to measure the amount of years the GHG emissions that have been emitted during the project will be offset for the environment during the operational phase of the building's lifecycle. The EMoC model can be used by stakeholders to make decisions for building projects and how this affects the environment. For now, it only can be applied to similar areas as Hong Kong.

2.3 Conclusion

Overall, the literature review in Chapter 2 provides a comprehensive understanding of the payback period between Scope 3 activities, phases of a building's lifecycle, in the operational phase in relation to environmental emissions in the Dutch building sector. The literature identified Scope 3 activities that have a significant environmental impact, including extraction and transportation of materials and the most significant part, the operational phase. The literature also shows the importance of activities that need to be dealt with first and which sustainable practices should be implemented at each lifecycle phase. Chapter 2 also provided several existing tools and methods for gathering data on Scope 3 emissions and how to report on them, such as (E)LCA, EMoC, and the GHG Protocol.

3. Methodology

This chapter outlines the research design and approach employed to address the research question and achieve the objectives of this study. It provides a detailed description of the steps taken to collect, analyze, and interpret the data necessary to investigate the relationship, and the forthcoming payback period, between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation. The methodology encompasses both the theoretical framework and the empirical study, aiming to provide a comprehensive understanding of the environmental impact of renovation projects and the implications for sustainable practices. This study comes forward with a tool that enables the measurement of the Scope 3 project emissions in the Dutch building sector. This makes the first part of the comparison between the answer to the main research question possible, the Scope 3 project emissions. This chapter will discuss the research design and provides an answer to sub-research question 5: How can Scope 3 project emissions, emitted before the operational phase, be effectively measured to enable meaningful comparison with operational CO_2e in the operational phase of a building's lifecycle?" by explaining the methods used to built the tool. This Chapter also discusses how the operational CO_2e emissions pre- and post-renovation have been collected.

3.1 Research design

In this paper, a literature review was conducted to answer the sub-research questions one to four. To analyze and measure the operational Scope 3 emissions for renovation projects for Kormelink b.v. and to answer sub-research questions 5, 6, and, 7 an empirical study has been done. From the methods described in Section 2.2. the most practicable regarding the research question of this paper a combination of methods have been chosen. The main method used to answer sub-research questions 5,6, and, 7 is the GHG Corporate Value Chain (Scope 3) Standard and the ELCA. The GHG Corporate Value Chain (Scope 3) Standard described in Section 2.2.3 has been used as a guideline to follow the right steps in Scope 3 emissions accounting. The GHG Corporate Value Chain (Scope 3) Standard is a good method to follow because it is aligned with the ESRS to report on the CSRD This alignment also helps companies use established methodologies to meet ESRS requirements, ensuring accuracy and comparability of the reported data (EFRAG 2022).

In addition, the emissions need to be measured and reported on to the right activity within Scope 3. The described ELCA in Section 2.2.3 is used out to come up with the environmental impact within the building phases of the renovation for the Netherlands based on the data of the company Kormelink b.v. In the end, the built tool can be used to calculate Scope 3 emissions for each Scope 3 activity within renovation projects where data was available. Because ELCAs have been used from existing data to calculate the Scope 3 emissions, this process will not be discussed more in detail then Section 2.2.4. All the steps taken, which data has been used data, and how this has been gathered, to get to the built tool will now be described according to the GHG Corporate Value Chain (Scope 3) Standard.

3.1.1 GHG Corporate Value Chain (Scope 3) Standard

In Section 2.2.3 the GHG Corporate Value Chain Standard has been described shortly. This standard was used to follow the journal and track the emissions that emit during renovation projects for Kormelink b.v. In the figure below a recap of the steps are shown.

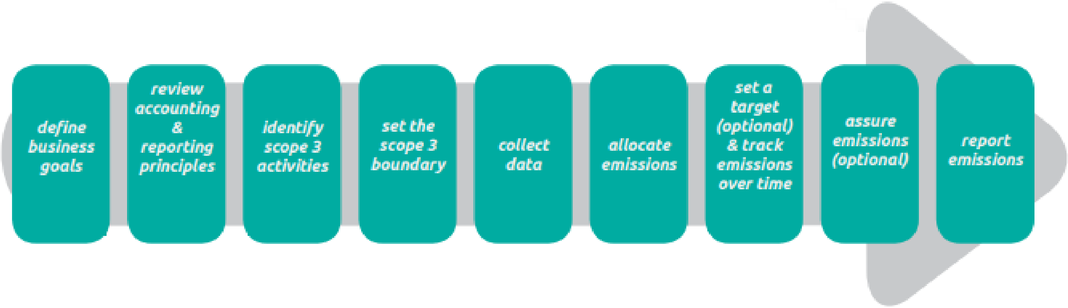


Figure 8: Overview of steps in Scope 3 accounting and reporting (Source: Callahan et al., n.d.)

The steps in Figure 8 have been taken in practice to analyze and measure Scope 3 emissions for Kormelink b.v. An explanation of how this has been done will be given.

Step 1: Define business goals

This phase focuses on getting clear insights into the risks and opportunities associated with Scope 3 emissions. When risks are clear goals can be set to reduce these risks. In the first interview with Kormelink b.v. it became clear that the risks were not known. The primary risk identified is that if Kormelink b.v. fails to report on certain sustainability metrics, it will fall behind to competitors who do. Over time, this could lead to a loss of clients, as sustainability is becoming increasingly important in society. The goal is related to improve stakeholder relations. Kormelink b.v. wanted to know how the renovated houses perform better on their sustainability in the operational phase of the building's lifecycle after the renovation had finished. In addition Kormelink b.v. did not know how much emissions were emitted during their activities within renovation projects. These two questions combined formed the research question to understand the payback period between Scope 3 CO_2e emissions and the operational CO_2e emissions building renovation project, both pre-and post-renovation. For Kormelink b.v. the main is to calculate the payback period by comparing emissions during the project with operational savings before and after renovations.

Step 2: Review accounting & reporting principles

The next phase is to review accounting & reporting principles where financial accounting and reporting are generally accepted. The Scope 3 emissions for this paper should represent a true, and fair amount of the total emissions. This phase is based on the following principles:

1. Relevance: The Scope 3 inventory reflects all the Scope 3 emissions of the company and serves the decision-making needs of users – both internal and external to the company.
2. Completeness: Companies should ensure that the Scope 3 inventory appropriately reflects the emissions of the company, and serves the decision-making needs of users, both internal and external to the company
3. Consistency: Use consistent methodologies to allow for meaningful tracking of the Scope 3 emissions over time. The consistent application of accounting approaches, inventory boundary, and calculation methodologies is essential to producing comparable GHG emissions data over time
4. Transparency: The disclosure of all relevant assumptions and appropriate references to the accounting and calculation methodologies and data sources used.
5. Accuracy: As far as can be judged, make sure that the quantification of the Scope 3 emissions systematically neither is over nor under the actual emissions.

This research has been done with desk research. Data was used from Kormelink b.v. regarding three renovation projects where all data has been gathered and analyzed. This was the first step to make sure all necessary data regarding the principles of relevance and completeness for Scope 3 emissions would be taken into account. For the consistency principle, a tool has been built based on the data of the three project data which enables measurement of all renovation projects. Transparency has been taken into account to mention all data sources for all Scope 3 inventory activities and items that have been included in the tool to measure the amount of Scope 3 emissions. The principle of accuracy of Scope 3 emissions calculations has been ensured by using known project data and appropriate parameters from relevant activities. These are found by suppliers or databases. For data where emissions quantification is unknown, assumptions are made based on existing parameters from other databases or sources with similar activities to those conducted by Kormelink B.V.

Steps 3, 4, and 5: Identifying Scope 3 emissions, set the boundaries, and collect the data

The phase of identifying Scope 3 emissions is about the categorization of activities into the upstream and downstream activities, which is shown in Figure 6, this has been described in Section 2.1.1. In addition to Section 2.1.1, there are boundaries on the upstream activities for reporting. In Section 2.1.3 was mentioned that the upstream activities are mandatory and the downstream activities are optional to report on. To fully meet the GHG Protocol Corporate Standard it is necessary to report on all relevant categories from both upstream and downstream categories (Anon n.d.)

Before something can be said if the boundaries are met, data has been collected and analyzed. The process of collecting data consists of 3 steps:

1. Prioritize data collection efforts: Companies should prioritize data collection efforts on the Scope 3 activities that are expected to have the most emissions, offer the most reduction opportunities, and are most relevant to the company's business goals. Collecting higher quality data for priority activities allows companies to focus resources on the most significant emissions in the value chain, more effectively set reduction targets, and track and demonstrate GHG emissions reductions over time. Companies may use a combination of approaches and criteria to identify priority activities. Within the GHG Protocol Corporate Standard there are 2 quantification methods:

   1. Direct measurement: Quantification of Scope 3 emissions using direct monitoring. This can be measured by emission data multiplied by the global warming potential (GWP). This converts all the GHG emissions into CO_2e. GWP values describe the radiative forcing impact of one unit of a given GHG relative to one unit of CO_2. In a formula, it is Scope 3 emissions = emission data x GWP.

   2. Calculation: Quantification of Scope 3 emissions by multiplying activity data by an emission factor. In a formula, it is Scope 3 emissions = Activity data x emissions factor x GWP.
   The distinction of activity data and emission factors can be seen in Table 5 as an example.

Activity data	**Emissions factors**
Liters of fuel consumed	Kilogram CO_2 emitted per liter of fuel consumed
Kilowatt-hours (kWh) of electricity consumed	Kilogram CO_2 emitted per kWh of electricity consumed
Kilograms of material consumed	Kilogram PFC emitted per kilogram of material consumed
Kilometers of distance traveled	ton CO_2 emitted per kilometer traveled

Table 5: distinction activity data and emissions factors

Within this research, both quantification methods have been used. Direct monitoring was available for the materials used where LCAs has been carried out with an EPD as a result, as described in Section 2.2.4. From these materials, the GWP could be used to determine the CO_2e emissions per material used. The calculation method has been used to calculate transportation from the materials, employees, and for the transportation of sub-contractors. The operational phase pre- and post-renovation has also been calculated based on the calculation method because activity data is used.

2. Select data: After prioritizing Scope 3 activities companies should select data based on the following: The company's business goals, the relative significance of Scope 3 activities, the availability of primary and secondary data, and the quality of available data. Companies should use primary data collected from suppliers and other value chain partners for Scope 3 activities targeted for achieving Scope 3 emission reductions. In some cases, primary data may not be available or may not be of sufficient quality. In such cases, secondary data may be of higher quality than the primary data. If the main goal of a company is to reduce Scope 3 emissions, track performance on specific operations within the value chain, or engage suppliers, primary data should be used. Primary data is supplier-specific data. Secondary data is about industry-average data. When the goal of a company is to understand the relative magnitude of various Scope 3 activities, to identify hotspots, and to prioritize primary data collection secondary data should be used. For primary and secondary data, the following quality indicators should be considered as a guide for getting the highest quality of data for a given emissions activity (Weidema and Wesnæs 1996a).

    a. Technological data: The degree to which the data reflects the actual technology(ies) used
    b. Representative in time: The degree to which the data set reflects the activity's actual time (e.g., year) or age.
    c. Representative in geography: The degree to which the data set reflects the actual geographic location of the activity (e.g., country or site.
    d. Completeness: The degree to which the data statistically represents the relevant activity. Completeness includes the percentage of locations for which data is available and used out of the total number that relates to a specific activity. Completeness also addresses seasonal and other normal fluctuations in the data.
    e. Reliability: The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable.

These quality indicators are put in a table below to show the evaluation of each indicator.

Score	Technology	Time	Geography	Completeness	Reliability
Very good	Data generated using the same technology	Data with less than 3 years of difference	Data from the same area	Data from all relevant sites over an adequate time period to even out normal fluctuations	Verified data based on measurements
Good	Data generated using similar	Data with less than 6 years of difference	Data from a similar area	Data from more than 50 percent of sites over an adequate	Verified data partly based on

	but different technology			time period to even out normal fluctuations	assumptions or non-verified data based on measurements
Fair	Data generated using a different technology	Data with less than 10 years of difference	Data from a different area	Data from less than 50 percent of sites for an adequate time period to even out normal fluctuations or more than 50 percent of sites but for a shorter time period	Non-verified data partly based on assumptions, or a qualified estimate (e.g. by a sector expert)
Poor	Data where technology is unknown	Data with more than 10 years of difference or the age of the data is unknown	Data from an area that is unknown	Data from less than 50 percent of sites for shorter time periods or representativeness is unknown	Non-qualified estimate

Table 6: Evaluation of data quality indicators (Adapted from: Weidema and Wesnæs 1996)

Primary data has been used for all the materials that Kormelink b.v. has used in renovation projects. All the parameters to calculate the emissions could be gathered at the suppliers in the value chain or where known from existing LCAs. For some materials, the use of databases and publications was necessary because the parameters to calculate the emissions were not known. For transportation methods and the operational phase pre- and post-renovation secondary data was used because it is based on average parameters which have been accepted in the Netherlands to calculate with. The quality indicators for each Scope 3 activity can be seen in Table 9 at the end of this section.

3. Collect data and fill data gaps: Primary data can be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, or other methods for obtaining data from specific activities in a company's value chain. Where possible, companies should collect energy or emissions data from suppliers and other value chain partners in order to obtain site-specific data for priority scope 3 categories and activities. To do so, companies should identify relevant suppliers from which to seek Scope 3 emissions data. Suppliers may include contract manufacturers, materials and parts suppliers, capital equipment suppliers, fuel suppliers, third-party logistics providers, waste management companies, and other companies that provide goods and services to the reporting company. The data that needs to be collected from suppliers can come forward through:
   1. Product life cycle Scope 3 emissions data following the GHG Protocol Product Standard
   2. Scope 1 and Scope 2 emissions data for the reporting year from suppliers
   3. The supplier's upstream scope 3 emissions and/or the types of activities that occur upstream of the supplier (if applicable). Also, the methods that are used to allocate these emissions and if the data has been validated should be mentioned.

   When secondary data is used, companies should prioritize databases and publications that are internationally recognized. Data quality indicators should be used to select secondary data sources that represent in terms of technology, time, geography, and that are the most complete and reliable. When data of sufficient quality is not available proxy could be used. Proxy data is data from a similar activity that is used as a comparable activity. Proxy data can also be scaled up or customized to be more representative of the given activity. The data of Kormelink b.v. is of sufficient quality to not use proxy data. In Tables 7 and 8 below there can be seen of what types it has been collected.

The steps for collecting data have been taken and can be summarized in Tables 7 and 8. The calculation method, which kind of data, and how it is collected are shown per Scope 3 category. In these tables, the boundaries for each Scope 3 activity are mentioned and can be seen if the condition is met. Table 7 contains the upstream categories, and Table 8 the downstream categories.

Upstream category	**Minimum boundary**	**Met boundary after collecting data**	**Calculation method used**	**Kind of data**	**Collected through**
Purchased goods and services	All upstream (cradle-to-gate) emissions of purchased goods and services	Yes	Calculation method	Primary and secondary	**Primary:** Invoices from the reporting company and Budgeted amounts of materials for subcontractors **Secondary:** EPD, LCA databases, emission factor databases
Capital goods	All upstream (cradle-to-gate) emissions of purchased capital goods	Not used for renovation projects	N/A	N/A	N/A
Fuel- and energy-related activities which are not included in Scope 1 or Scope 2	a. For upstream emissions of purchased fuels consumed by the reporting company: All upstream (cradle-to-gate) emissions of purchased fuels (from raw material extraction up to the point of, but excluding combustion) b. For upstream emissions of purchased electricity consumed in the generation by the	Not used for renovation projects	N/A	N/A	N/A

	reporting company on electricity, steam, heating and cooling: All upstream (cradle-to-gate) emissions of purchased fuels (from raw material extraction up to the point of, but excluding, combustion by a power generator) c. For transmission and distribution losses that are lost by the reporting company on the generation of electricity, steam, heating and cooling: All upstream (cradle-to-gate) emissions of energy consumed in a transmission and distribution system, including emissions from combustion d. For generation of purchased electricity that is sold to end users: Emissions from the generation of purchased energy				
Upstream transportation and distribution	The Scope 1 and Scope 2 emissions of transportation and distribution providers that occur during use of vehicles and facilities. Optional: The life cycle emissions associated with manufacturing vehicles, facilities, or infrastructure	Yes	Calculation method	Primary and Secondary data	**Primary**: Suppliers location information **Secondary**: Emission factor databases
Waste generated in operations	The Scope 1 and Scope 2 emissions of waste management suppliers that occur during disposal or treatment. Optional: Emissions from transportation of waste	Out of scope for this thesis	N/A	N/A	N/A

Business travel	The Scope 1 and Scope 2 emissions of transportation carriers that occur during the use of vehicles. Optional: The life cycle emissions associated with manufacturing vehicles or infrastructure	Not used for renovation projects	N/A	N/A	N/A
Employee commuting	The Scope 1 and Scope 2 emissions of employees and transportation providers that occur during the use of vehicles	Yes	Calculation method	Secondary data	Databases and enterprise resource planning (ERP)
Upstream leased assets	The Scope 1 and Scope 2 emissions of lessors that occur during the reporting company's operation of leased assets. Optional: The life cycle emissions associated with manufacturing or constructing leased assets.	Not used for renovation projects	N/A	N/A	N/A

Table 7: Summary of collected and analyzed data to report on for the boundaries for Kormelink b.v. of upstream Scope 3 emissions

Downstream category	**Minimum boundary**	**Met boundary after collecting data**	**Calculation method used**	**Kind of data**	**Collected through**
Downstream transportation and distribution	The Scope 1 and Scope 2 emissions of transportation providers, distributors, and retailers that occur during use of vehicles and facilities Optional: The life cycle emissions associated with manufacturing vehicles, facilities, or infrastructure	Not used for renovation projects	N/A	N/A	N/A
Processing of sold products	The Scope 1 and Scope 2 emissions of downstream companies	Not used for renovation projects	N/A	N/A	N/A

	that occur during processing				
Use of sold products	The direct operational phase emissions of sold products over their expected lifetime (i.e., the Scope 1 and Scope 2 emissions of end users that occur from the use of products that directly consume energy (fuels or electricity) during use Optional: The indirect use-phase emissions of sold products over their expected lifetime (i.e., emissions from the use of products that indirectly consume energy (fuels or electricity) during use)	Yes	Calculation method	Secondary data	Emission factor databases and invoice data from residents
End-of-life treatment of sold products	Scope 1 and Scope 2 emissions of waste management companies that occur during disposal or treatment of sold products.	Out of scope for this thesis	N/A	N/A	N/A
Downstream leased assets	The Scope 1 and Scope 2 emissions of lessees that occur during the operation of leased assets Optional: The life cycle emissions associated with manufacturing or constructing leased assets	Not used for renovation projects	N/A	N/A	N/A
Franchises	The Scope 1 and Scope 2 emissions of franchisees that occur during the operation of franchises Optional: The life cycle emissions associated with manufacturing or constructing franchises	Not used for renovation projects	N/A	N/A	N/A
Investments	Scope 3 emissions associated with the reporting company's	Not used for renovation projects	N/A	N/A	N/A

	investments in the reporting year, not already included in Scope 1 or Scope 2. The investments need to take place in one of the following categories to make it a relevant category: equity investment, debt investment, project finance and managed investments and client services				

Table 8: Summary of collected and analyzed data to report on for the boundaries for Kormelink b.v. on the downstream Scope 3 emissions

After the Scope 3 activities that are within the research have been analyzed, the activity data and emission factors need to be mentioned. The emission factors need to be related to the main research question to understand the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre- and post-renovation. For the purchased goods and services this relates to emission regarding the lifecycle phases that are before the operational phase. From Figure 1, these are lifecycle phases A1, A2, A3, and, A5. Phase A4, transportation will be determined through the Scope 3 activity of upstream transportation and distribution. Emission factors for transportation are based on well-to-wheel (WTW) emissions. WTW is a combination of emissions from upstream activities, such as extraction and production of fuels, and direct emissions from the use of fuel in a vehicle. activity data has been multiplied by the relevant emission factor and the GWP. The summary per Scope 3 activity can be seen in Table 9.

Scope 3 activity	**Activity data**	**Emission factor unit**
Purchased goods and services	- Units of material used - Kilogram of material used - M^1 of material used - M^2 of material used - M^3 of material used	Kilogram CO_2e emitted
Upstream transportation and distribution	Kilometers distance to project location from suppliers warehouse	Kilogram CO_2e emitted
Employee commuting	Kilometers distance to project location from residential house	Kilogram CO_2e emitted
Use of sold goods	- Kilowatt-hours of electricity consumed pre- and post-renovation - Gas per m^3 consumed pre- and post-renovation	Kilogram CO_2e emitted

Table 9: Activity data and emission factor units for Kormelink b.v. for Scope 3 activities

For Kormelink B.V., the Scope 3 activities related to renovation projects have been identified, and the boundaries have been established. The collected data has been analyzed to ensure that the minimum boundaries are met, and research on the emission factors for activity data has been conducted. Finally, the data quality indicators for each activity are presented in the table below to ensure high quality.

Scope 3 activity	**Technology**	**Time**	**Geography**	**Completeness**	**Reliability**
Purchased goods and services	Good, data was generated using a similar but different technology	Very good, they represent less than 3 years of difference	Very good, data is from the same area	Good, it represents all the activities regarding Scope 3. It does not address seasonal fluctuations	Good, primarily grounded with verified data with some assumptions
Upstream transportation and distribution	Very good, data generated using the same technology	Very good, they represent less than 3 years of difference	Very good, data is from the same area	Good, it represents all the activities regarding Scope 3. It does not address seasonal fluctuations	Good, primarily grounded with verified data with some assumptions
Employee commuting	Very good, data generated using the same technology	Very good, they represent less than 3 years of difference	Very good, data is from the same area	Good, it represents all the activities regarding Scope 3. It does not address seasonal fluctuations	Good, primarily grounded with verified data with some assumptions
Use of sold products	Very good, data generated using the same technology	Very good, they represent less than 3 years of difference	Very good, data is from the same area	Fair, data has been used of specific time moments. It does not consider external factors which can cause fluctuations	Very good, only verified data is used

Table 10: Data quality indicators for Scope 3 activities for Kormelink b.v.

Step 6: Allocate emissions

The next phase after the data is collected is to allocate the emissions. Allocation is the process of partitioning Scope 3 emissions from a single facility or system among its various outputs. Allocation is not needed if a facility or other system produces only one output or emissions from producing each output are separately quantified. Allocation is also not necessary if secondary data is used to calculate Scope 3 emissions. These emission factors refer to a single product. Allocation should be avoided or minimized whenever possible, as it introduces uncertainty into emissions estimates and may be inaccurate when a facility produces a wide variety of products with differing contributions to Scope 3 emissions. The primary data that has been analyzed for Kormelink b.v. is supplier-specific information and relates to one activity. This means that allocating emissions is not necessary because it is already made specific for the Scope 3 activity. The secondary data that has been used is already in reference to the activity, which means allocation is not necessary. The Scope 3 emissions are based on an emission factor multiplied by activity data. Allocation only is applied when suppliers deliver materials for multiple projects at once for the activity of upstream transportation and distribution. The total CO_2e emissions will then be divided over all the projects to which the supplier has brought materials.

Step 7: Set a target & track emissions over time

When emissions have been allocated the next phase of the protocol takes place, setting a GHG (Scope 3) reduction target and tracking the emissions over time. A meaningful and consistent comparison of emissions over time requires a base year against which to track performance. When companies choose to track Scope 3 performance or set a Scope 3 reduction target, companies shall choose a Scope 3 base year and specify their reasons for choosing that particular year. Companies should consider several questions when setting a Scope 3 emission reduction target. These are about:

1. Target type: Companies can set either absolute targets, intensity targets, or a combination of absolute and intensity targets. An absolute target is expressed as a reduction in Scope 3 emissions to the atmosphere over time in units of metric tons of CO_2e. An intensity target is expressed as a reduction in the ratio of Scope 3 emissions relative to a business metric, such as output, production, sales, or revenue.
2. Target completion date: The target completion date determines whether the target is relatively short- or long-term. In general, companies should set long-term targets, since they facilitate long-term planning and large capital investments with significant Scope 3 benefits. Companies may also set shorter-term targets to measure progress more frequently.
3. Target level: The target level represents the level of ambition of the reduction target. To inform the numerical value of the target, companies should examine potential Scope 3 reduction opportunities and estimate their effects on total Scope 3 emissions.
4. Use of offsets or credits: A Scope 3 target can be met entirely from internal reductions at sources included in the target boundary, or can be met through additionally using offsets that are generated from Scope 3 reduction projects that reduce emissions at sources external to the target boundary. Companies should strive to achieve reduction targets entirely from internal reductions from within the target boundary. Companies that are unable to meet Scope 3 targets through internal reductions may use offsets generated from sources external to the target boundary.

The reduction target regarding all Scope 3 emissions is not covered in this paper. The goal is to calculate the Scope 3 emissions for renovation projects for Kormelink b.v. and offset them over time during the pre- and post-renovation operational phases to calculate the payback period. When Kormelink b.v. focuses on the whole Scope 3 inventory reduction goals can be set. Kormelink b.v. should mention if the target is absolute or intensity, or a combination of both. Next, Kormelink b.v. should have a completion date of the target. The value of the target level needs to be mentioned and if internal or external reductions have been achieved.

To consistently track Scope 3 emissions over time, companies must recalculate base year emissions when significant changes occur in company structure or inventory methodology. This recalculation is essential for maintaining consistency and enabling meaningful comparisons of the inventory over time. Recalculations are required when the following changes significantly impact the inventory:

1. Structural changes in the reporting organization, such as mergers, acquisitions, divestments, outsourcing, and insourcing.
2. Changes in calculation methodologies, improvements in data accuracy, or discovery of significant errors.
3. Changes in the categories or activities included in the Scope 3 inventory.

There are two basic approaches to account for Scope 3 reductions, the inventory or the project method. The inventory method accounts for Scope 3 reductions by comparing changes in the company's actual emissions inventory over time relative to a base year. This leads to the following formula. Change in emissions from a Scope 3 category = Current year emissions from the Scope 3 category - Base year emissions from the Scope 3 category. This method is the most commonly used. The project method accounts for Scope 3 reductions by quantifying impacts from individual Scope 3 mitigation projects relative to a baseline.

Currently, Kormelink b.v. cannot track emissions over time as this is the first year that Scope 3 emissions for renovation projects are being measured. The first full year when Scope 3 emissions are being measured will be the base year for future years to calculate Scope 3 reductions. When the Scope 3 inventory significantly changes on the described points a new base year must be calculated.

Step 8: Assure emissions

The next phase in the protocol is assurance. Assurance is the level of confidence that the Scope 3 inventory is complete, accurate, consistent, transparent, relevant, and without material misstatements. While assurance is not a requirement, obtaining assurance over the Scope 3 inventory is valuable for reporting companies and other stakeholders when making decisions using the Scope 3 results. For assurance, there are two types, first-party assurance, and third-party assurance. First-party assurance is from within the reporting company but independent of the Scope 3 inventory process conducts internal assurance. And third party assurance is from an organization independent of the Scope 3 inventory process conduct third party assurance. For external stakeholders, third-party assurance is likely to increase the credibility of the GHG inventory. However, first-party assurance can also provide confidence in the reliability of the inventory report, and it can be a worthwhile learning experience for a company prior to commissioning third-party assurance. The level of assurance refers to the degree of confidence that stakeholders can have over the information in the inventory report. There are two levels of assurance: limited and reasonable. The level of assurance requested by the reporting company will determine the rigor of the assurance process and the amount of evidence required. The highest level of assurance that can be provided is a reasonable level of assurance. Absolute assurance is never provided since 100 percent of the inputs to the GHG inventory cannot be tested due to practical limitations.

For Kormelink b.v., beginning with first-party assurance is an effective way to build confidence in the reliability of the Scope 3 inventory. Once the inventory his reliability is established, third-party assurance can provide statements that offer a reasonable level of assurance, which is highly valuable to external stakeholders.

Step 9: Report emissions

The last phase of the protocol is reporting on the emissions. A credible Scope 3 emissions report presents information based on the principles of relevance, accuracy, completeness, consistency, and transparency. It should be based on the best data available and be transparent about its limitations. To fully meet the GHG Protocol Corporate Standard there is information that is required to mention in the report for Scope 3 emissions. These requirements are about:

1. Total Scope 3 emissions reported separately by Scope 3 category
2. For each Scope 3 category, total emissions of GHGs reported in metric tons of CO_2 equivalent, excluding biogenic CO_2 emissions and independent of any GHG trades, such as purchases, sales, or transfers of offsets or allowances.
3. A list of Scope 3 categories and activities included in the inventory.
4. A list of Scope 3 categories or activities excluded from the inventory with justification of their exclusion.
5. After establishing a base year, document the following: the selected base year for Scope 3 emissions, the reasoning behind this choice, the policy for recalculating base year emissions, the Scope 3 emissions categorized by type for the base year in line with the recalculation policy, and the relevant context for any significant changes in emissions that necessitated recalculations of the base year data. For each Scope 3 category, any biogenic CO_2 emissions are reported separately.
6. For each Scope 3 category, a description of the types and sources of data, including activity data, emission factors, and GWP values, used to calculate emissions, and a description of the data quality of reported emissions data.
7. For each Scope 3 category, a description of the methodologies, allocation methods, and assumptions used to calculate Scope 3 emissions.
8. For each Scope 3 category, the percentage of emissions is calculated using data obtained from suppliers or other value chain partners.

Throughout the research, from gathering data to calculating CO_2e emissions, these points were taken into account for Kormelink b.v. In Chapter 4 the performance of the tool will be discussed. It is based on the standards from the GHG Corporate Value Chain (Scope 3) Standard. It will also discuss which assumptions have been made. The results, after filling in the tool where the emissions per Scope 3 activity come forward will be discussed in Chapter 5, where sub-research question 7 and the main research question will be answered. At that point, all the emissions are measured for each Scope 3 activity and the payback period can be calculated on the operational phase, pre- and post-renovation.

3.2 Conclusion

In this section, the research design has been discussed. The method followed is the GHG Corporate Value Chain (Scope 3) Standard. It began with the classification of the business goal for Kormelink b.v., which is to calculate the payback period by comparing emissions during the project with operational savings before and after renovations. The gathered data is based on the principles of relevance, completeness, consistency, transparency, and accuracy. This makes the data useful to calculate the Scope 3 emissions and that it represents a true and fair amount of the total emissions. The built tool makes tracking emissions consistent by using it for all the project data. With desk research, all project data has been gathered to calculate the emissions. The calculation method has been used for all the data. The information from primary data came from invoices from the reporting company, budgeted materials from subcontractors, and location information about suppliers. Secondary data comes from external sources from LCA databases, EPD, ERP system regarding employee data, invoices from residents regarding energy and gas usage, and, emission factor databases for materials. These data sources form the input for the activity data to calculate the eventual emissions. Research about the emission factors has been done for the activity data. Allocation of the emissions was not necessary because the primary and secondary data that is used is already made specific for each material or Scope 3 activity. When a full year of emissions has been tracked, a base year for Kormelink b.v. could be established and emissions could be tracked over time. The same accounts for assurance. When a full year of emissions has been tracked Kormelink b.v. could start with first-party assurance to make sure Scope 3 inventory is of a reliable level. After first-party assurance has established reliability, third-party assurance can provide statements that offer a reasonable level of assurance, which is highly valuable to external stakeholders. The last phase to report on the emissions with all the requirements that need to be in the report will be discussed in Chapter 5 where the results come together, sub-research question 7, and the main research question will be answered. In the next chapter, the performance of the built tool will be discussed.

4. Performance of the tool

In the previous chapter, the research design has been explained. Following the GHG Corporate Value Chain (Scope 3) Standard the analyzed data has been put in an Excel file. In this section, a guideline of the tool which has been built will be discussed. It will discuss step by step how the tool is been made and what sections it consists of according to the Scope 3 activities. To follow the GHG Corporate Value Chain (Scope 3) Standard, it will also discuss what assumptions are made for each section of the tool. At last, it will answer sub-research question 6: “What are the savings on operational CO_2e emissions in the operational phase of a building’s lifecycle after the renovation projects Kormelink has carried out?” in Section 4.4.

4.1 Setting up tables for purchased goods and activities

According to Tables 7 and 8 from Chapter 3 and Section 2.1.1 the tool contains the upstream activities from the purchased goods and activities. This means phases A1, A2, A3, and A5 of a building’s lifecycle. Where phase A4 is classified as upstream transportation and distribution. These are the cradle-to-site activities that are relevant towards the research questions for purchased goods and activities. The main tables that contribute to calculating the emission from purchased goods and activities are:

- Emission list of materials
- Usage table in total Scope 3 emissions

The setup of the emission list of materials is described in the next section and the usage table will be discussed at the end of this chapter. It will discuss how the emissions per material are created and which assumptions have been taken into account.

4.1.1 Emission list of materials

Chapter 3 mentioned that primary and secondary data were used for the category of purchased goods and activities. From the primary data, all the invoices and budgeted amounts from subcontractors regarding the materials that have been used in renovation projects have been written down in a table. This made the activity data used for each material clear. The activity data has been analyzed towards emission factors through secondary data. LCAs with results as EPDs are used for materials to come up with the GWP it has during its lifecycle. The GWP his CO_2e emissions are used to calculate the total CO_2e emissions per material per project. For some materials, an LCA cannot be found. In that case, other secondary data was used or assumptions were made. If the composition of raw materials from the specific material was known and LCAs with EPDs were available these were used to calculate the CO_2e emissions. For example, sealants, are based on silicone-based products and there are lots of substances that can be purchased by several suppliers. But the main raw materials to produce sealants are more or less the same. Therefore, an EPD of silicone-based products is used as an assumption to calculate the CO_2e emissions of sealants. Additionally, group averages for material categories have been provided. This ensures that for future materials where LCAs are not available, the category’s group average can be used to calculate CO_2e emissions. For all the materials in the list, the LCA is mostly based on cradle-to-gate emissions. These are all the steps from A1 to A5. Phase A4 of the known LCAs will be ignored and calculated based on suppliers' information to get the most precise CO_2e emissions. This will be mentioned in the section on upstream transportation and distribution.

In some cases, a cradle-to-gate LCA or phase A5 for construction was not available in the existing EPD for the materials. In those cases, assumptions were made based on the article of (Kumanayke and Luo 2018). When only full LCAs were available, the emission factor was recalculated to get to the CO_2e cradle-to-gate emissions according to the theory for a specific category of materials. According to

Kumanayke & Luo (2018), phase A5 is responsible for 93,173.91 kilograms CO_2e and phases A1-A3 for 3,026,376.31 kilograms CO_2e. This means that 2.99% of the total A phase is responsible for A5 where phase A4 is excluded. This means that for every kilogram/CO_2e produced in the phase of A1-A3, A5 will produce 0,0307 kilogram/CO_2e in relation. This can be used to calculate the unknown construction phase for the materials. The same applies to the materials where only the full LCA is known. All the LCA phases account for 9,580,566.58 kilograms CO_2e, so 32.56 % is accounted for phases A1-A3 plus phase A5. The following columns have been made for all the materials analyzed and can be seen in Figure 9. The full materials table can be found in Appendix E.

A	B	C	D	E	F	G	H	I	J	K
Material	Category	LCA	CO2E (A1-A3 + partial A5)	LCA	A5 emissions	CO2e (A1-A3 +A5)	Unit for co2e	per	LCA	source

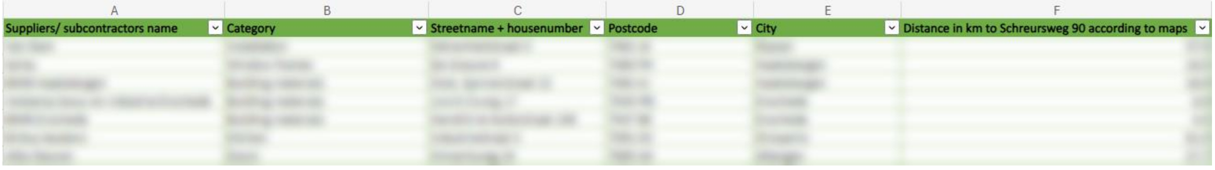
Figure 9: Columns used of the studied LCAs materials table

This means that from the found CO_2e emissions in the EPDs the total is represented in Column D. In Column E is represented which phases it includes from the EPD. This could be A1-A3, A1-A3+A5, and Full LCA. Column F calculates phase A5 based on the found 2.99% from Kumanayke & Luo (2018) when in column E the phases are only A1-A3. Or it is recalculated when it contains the full LCA. This means that Column G contains all the cradle-to-gate emissions where phase A4 is excluded. The use of Column H will be explained in Section 4.3. Column I is the activity data. After all the materials have been analyzed the CO_2e emissions now only consist of phases A1-A3 and A5.

4.2 Setting up tables for upstream transportation and distribution and employee commuting

So far, Scope 3 activity of purchased goods and services with lifecycle phases A1- A3 and A5 have been put into the tool for all the materials. This does not fully cover the cradle-to-site emissions because the transportation, phase A4, is missing. To get from the cradle-to-gate emissions to cradle-to-site emissions there is a need for emission factors to calculate the emissions for the travel distance based on different transportation methods. This is the Scope 3 activity of upstream transportation and distribution. To get the cradle-to-site information of the LCAs it is important to calculate the travel distance between the project location and the supplier's location. In addition, the Scope 3 activity of employee commuting also needs to be calculated. Therefore, help tables have been established to calculate emissions for the Scope 3 activities of upstream transportation and distribution (phase A4 of the lifecycle) and employee commuting. There are several tables generated that all come together in the working sheet, which will be explained in the next section, to calculate the CO_2e emissions per project :

1. Suppliers/ subcontractors table: From all the analyzed primary data, the suppliers have been put into a table. While Kormelink b.v. has a general renovation project location the distance between the suppliers and this general location is filled in in a table with the Google Maps route distance. Table 11 has been created in the tool:



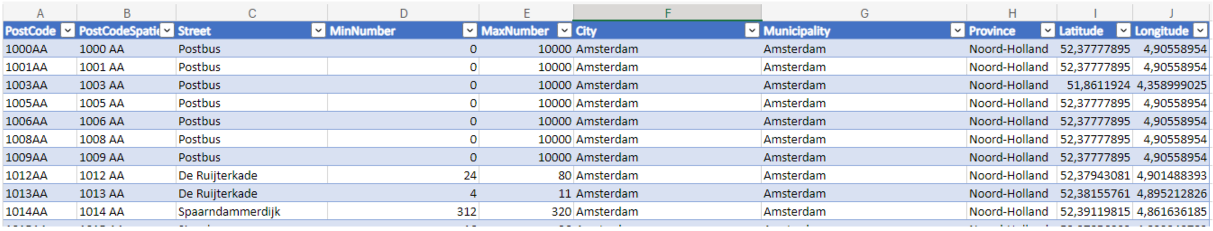
A	B	C	D	E	F
Suppliers/ subcontractors name	Category	Streetname + housenumber	Postcode	City	Distance in km to Schreursweg 90 according to maps

Table 11: Suppliers/subcontractors table from analyzed data

In the working sheet table, there is a dropdown tile that shows all the filled-in suppliers/subcontractors from the table, which is column A in the suppliers/

subcontractors table. In the working sheet, when a supplier/subcontractor is selected it fills in the travel distance from column F from the help table. In the working sheet, the user of the tool then can fill in different facts that are known from the supplier/subcontractor such as travel times, working hours, number of employees, and if the employees travel together. This makes it more user-friendly to calculate an accurate number of the total CO_2e emissions.

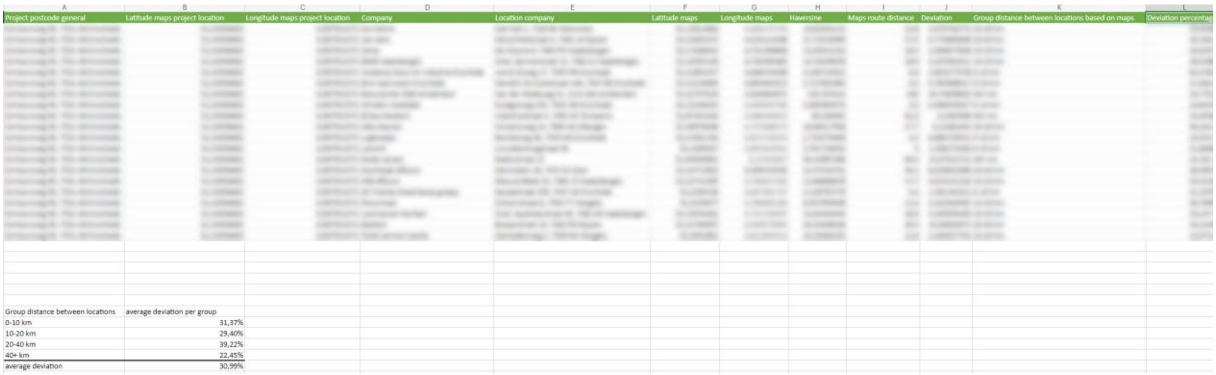
2. Postcode table: This table serves as a reference when new suppliers or subcontractors are added without complete information in the suppliers/subcontractors table. The postcode can be utilized to compute travel distances using a specified formula. For both the project location and the supplier or subcontractor location in the Netherlands, the longitude and latitude will be derived from the postcode. This table collaborates with the Distance groups reference table, which will be described now, along with an explanation of the functionality of the postcode table. The table looks as follows:



A	B	C	D	E	F	G	H	I	J
PostCode	PostCodeSpatie	Street	MinNumber	MaxNumber	City	Municipality	Province	Latitude	Longitude
1000AA	1000 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	52,37777895	4,90558954
1001AA	1001 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	52,37777895	4,90558954
1003AA	1003 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	51,8611924	4,358999025
1005AA	1005 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	52,37777895	4,90558954
1006AA	1006 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	52,37777895	4,90558954
1008AA	1008 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	52,37777895	4,90558954
1009AA	1009 AA	Postbus	0	10000	Amsterdam	Amsterdam	Noord-Holland	52,37777895	4,90558954
1012AA	1012 AA	De Ruijterkade	24	80	Amsterdam	Amsterdam	Noord-Holland	52,37943081	4,901488393
1013AA	1013 AA	De Ruijterkade	4	11	Amsterdam	Amsterdam	Noord-Holland	52,38155761	4,895212826
1014AA	1014 AA	Spaarndammerdijk	312	320	Amsterdam	Amsterdam	Noord-Holland	52,39119815	4,861636185

Table 12: Postcode table

3. Distance groups: Occasionally, Kormelink b.v. engages new suppliers or subcontractors. There is an opportunity to input the Google Maps route distance based on the location and add the supplier or subcontractor details to the suppliers/ subcontractors table. The other option is to calculate the driving distance based on a formula. This formula, known as the haversine formula, calculates the straight-line distance, often referred to as the "as-the-crow-flies" distance, between two locations based on their respective longitude and latitude. These longitude and latitude values are filled in based on the postcode table. When a postcode is filled in, a VLOOKUP function in Excel gets the longitude and latitude from the postcode table. Because the as-the-crow-flies distance is not as accurate as the actual driving distance the distance groups table is made. The distance groups table contains all the known suppliers and subcontractors with the actual driving distance. In this table, the as-the-crow-flies distance is compared to the actual driving distance. Based on the actual driving distance, distance groups for travel distance have been made. These are; 0-10 kilometers, 10-20 kilometers, 20-40 kilometers, and 40+ kilometers. All these groups get a standard deviation based on the actual driving distance and as-the-crow-flies distance. Table 13 is created as a help table for the working sheet in the tool:



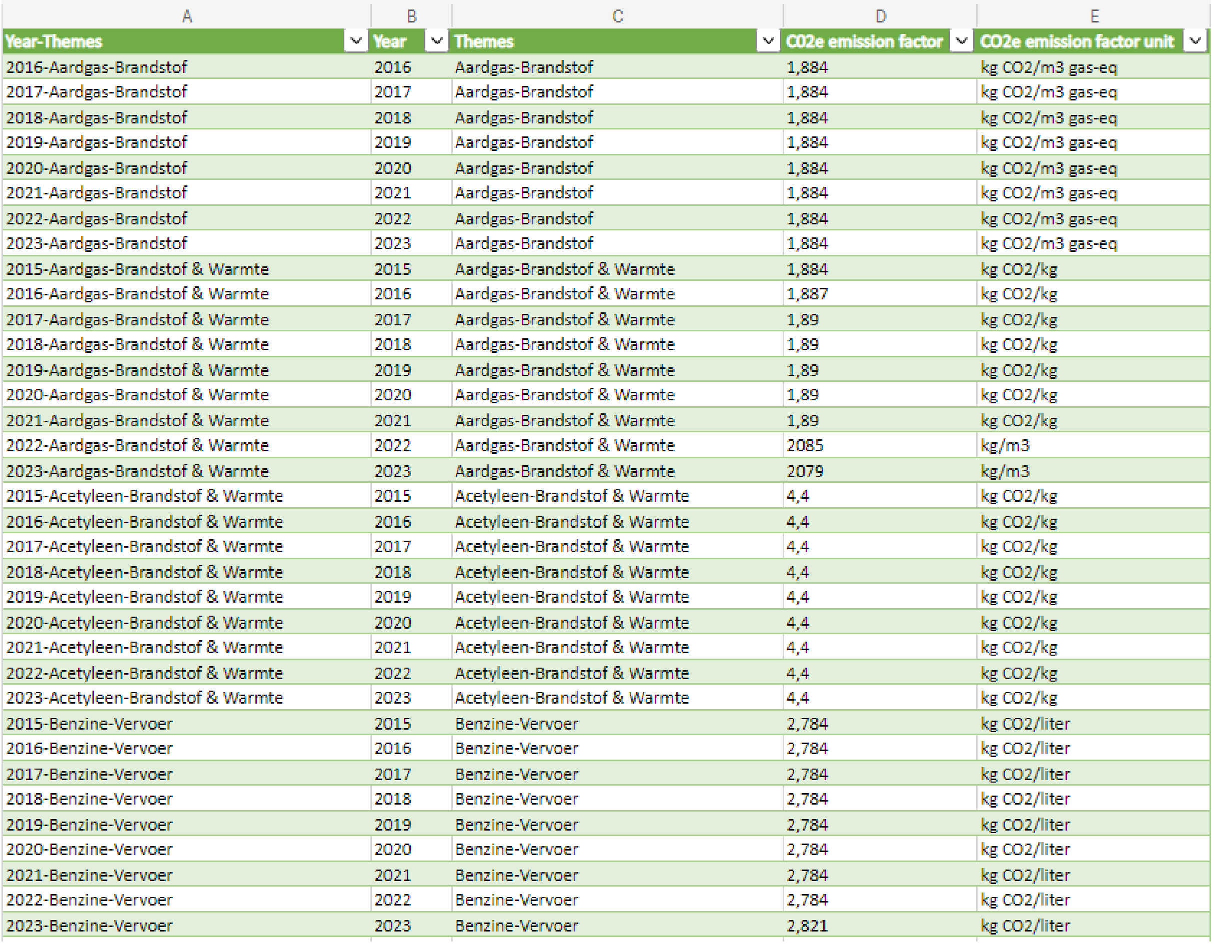
Project postcode general	Latitude maps project location	Longitude maps project location	Company	Location company	Latitude maps	Longitude maps	Haversine	Maps route distance	Deviation	Group distance between locations based on maps	Deviation percentag

Group distance between locations	average deviation per group
0-10 km	31,37%
10-20 km	29,40%
20-40 km	39,22%
40+ km	22,45%
average deviation	30,99%

Table 13: Distance groups table

In the working sheet when an unknown supplier or subcontractor respectively is filled in with the postcode of the location, the driving distance is calculated based on the as-the-crow-flies distance plus the deviation of the distance group it is in. This makes it more accurate towards the real driving distance.

4. Employees table: With the previously described Tables 11, 12, and, 13 it is possible to calculate the travel distance based on two options; the actual driving distance based on the Google Maps route, or based on the haversine formula keeping in mind the deviation from the distance groups. This data has some confidential data and is therefore not shown in this paper. The employees table contains the postcode, longitude, and latitude data for all the employees. The table is used to calculate the distance between the home location of the employee and the project location based on the haversine formula keeping in mind the distance groups. The Google Maps route option is available, but it has not been entered into the table due to time issues.
5. CO_2e emission factors table: Now that all the suppliers, subcontractors, and employees with their driving distance have been filled in, it needs to be converted to actual CO_2e emissions. Therefore, the CO_2e emission factors table has been set up. It is also a help table to calculate the CO_2e emissions for the operational phase which will be described in Section 4.4. This table has been created through the help of Power Query to create a connection with a database on the internet (Anon 2024a). Power Query is an add-in in Excel to create connections with external data sources and transform this data. This connection retrieves all the actual emission factors for the years of CO_2e emission-related activities.



Year-Themes	Year	Themes	C02e emission factor	CO2e emission factor unit
2016-Aardgas-Brandstof	2016	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2017-Aardgas-Brandstof	2017	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2018-Aardgas-Brandstof	2018	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2019-Aardgas-Brandstof	2019	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2020-Aardgas-Brandstof	2020	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2021-Aardgas-Brandstof	2021	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2022-Aardgas-Brandstof	2022	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2023-Aardgas-Brandstof	2023	Aardgas-Brandstof	1,884	kg CO2/m3 gas-eq
2015-Aardgas-Brandstof & Warmte	2015	Aardgas-Brandstof & Warmte	1,884	kg CO2/kg
2016-Aardgas-Brandstof & Warmte	2016	Aardgas-Brandstof & Warmte	1,887	kg CO2/kg
2017-Aardgas-Brandstof & Warmte	2017	Aardgas-Brandstof & Warmte	1,89	kg CO2/kg
2018-Aardgas-Brandstof & Warmte	2018	Aardgas-Brandstof & Warmte	1,89	kg CO2/kg
2019-Aardgas-Brandstof & Warmte	2019	Aardgas-Brandstof & Warmte	1,89	kg CO2/kg
2020-Aardgas-Brandstof & Warmte	2020	Aardgas-Brandstof & Warmte	1,89	kg CO2/kg
2021-Aardgas-Brandstof & Warmte	2021	Aardgas-Brandstof & Warmte	1,89	kg CO2/kg
2022-Aardgas-Brandstof & Warmte	2022	Aardgas-Brandstof & Warmte	2085	kg/m3
2023-Aardgas-Brandstof & Warmte	2023	Aardgas-Brandstof & Warmte	2079	kg/m3
2015-Acetyleen-Brandstof & Warmte	2015	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2016-Acetyleen-Brandstof & Warmte	2016	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2017-Acetyleen-Brandstof & Warmte	2017	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2018-Acetyleen-Brandstof & Warmte	2018	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2019-Acetyleen-Brandstof & Warmte	2019	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2020-Acetyleen-Brandstof & Warmte	2020	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2021-Acetyleen-Brandstof & Warmte	2021	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2022-Acetyleen-Brandstof & Warmte	2022	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2023-Acetyleen-Brandstof & Warmte	2023	Acetyleen-Brandstof & Warmte	4,4	kg CO2/kg
2015-Benzine-Vervoer	2015	Benzine-Vervoer	2,784	kg CO2/liter
2016-Benzine-Vervoer	2016	Benzine-Vervoer	2,784	kg CO2/liter
2017-Benzine-Vervoer	2017	Benzine-Vervoer	2,784	kg CO2/liter
2018-Benzine-Vervoer	2018	Benzine-Vervoer	2,784	kg CO2/liter
2019-Benzine-Vervoer	2019	Benzine-Vervoer	2,784	kg CO2/liter
2020-Benzine-Vervoer	2020	Benzine-Vervoer	2,784	kg CO2/liter
2021-Benzine-Vervoer	2021	Benzine-Vervoer	2,784	kg CO2/liter
2022-Benzine-Vervoer	2022	Benzine-Vervoer	2,784	kg CO2/liter
2023-Benzine-Vervoer	2023	Benzine-Vervoer	2,821	kg CO2/liter

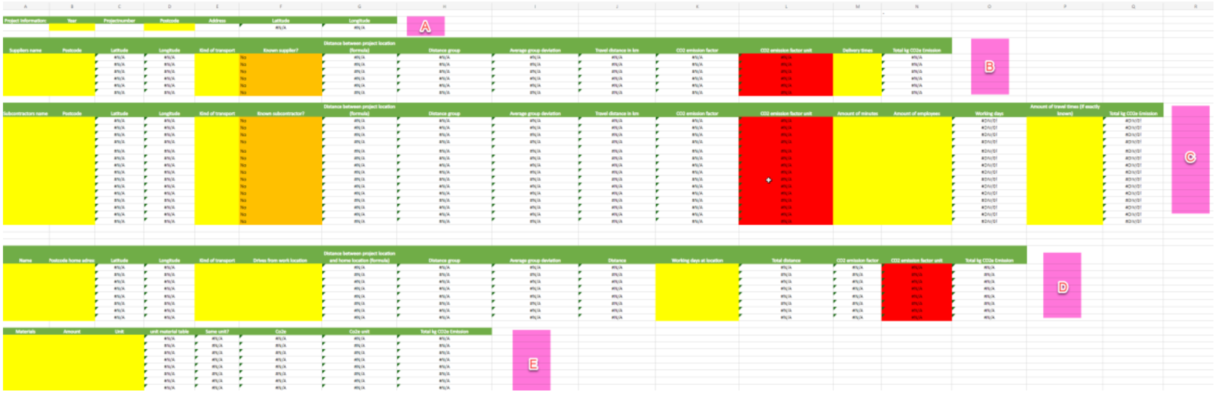
Table 14: Partial list of CO_2e emission factors table

Table 14 contains information per year because over the years the CO_2e emission factors can change. The CO_2e emission factors can change for various reasons, including shifts in practical conditions and new insights into calculation methods. For instance, if power plants increase their use of coal, the CO_2e factor of the resulting electricity will rise. These adjustments are necessary to maintain the most accurate representation of actual emissions and to provide policymakers, businesses, and consumers with current information on the carbon footprint of various activities and products (Anon 2023).

The emission factors from this source were selected because they align with the requirements of the GHG protocol. In the working sheet when all suppliers, subcontractors, and employees have been filled in, there is a dropdown list with all the themes in the CO_2e emission factors table. These themes cover various sources, including electricity, different fuels, and water usage. It's important to mention that you can use them to calculate the corresponding CO_2e emissions. This helps in understanding the environmental impact across different aspects like energy, fuel, and water consumption.

4.3 Working sheet

The previously mentioned tables in Sections 4.1 and 4.2 come together in the working sheet. The working sheet is the main sheet where all the project information based on the upstream Scope 3 emissions within the research is filled in. Below the working sheet is displayed and an explanation of how the sheet works will be given.



Project information:	Year	Projectnumber	Postcode	Address	Latitude	Longitude
					#N/A	#N/A

Suppliers name	Postcode	Latitude	Longitude	Kind of transport	Known supplier?	Distance between project location (formula)	Distance group	Average group deviation	Travel distance in km	CO2 emission factor	CO2 emission factor unit	Delivery times	Total kg CO2e Emission
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A

Subcontractors name	Postcode	Latitude	Longitude	Kind of transport	Known subcontractor?	Distance between project location (formula)	Distance group	Average group deviation	Travel distance in km	CO2 emission factor	CO2 emission factor unit	Amount of minutes	Amount of employees	Working days	Amount of travel times (if exactly known)	Total kg CO2e Emission
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A			#DIV/0!		#DIV/0!

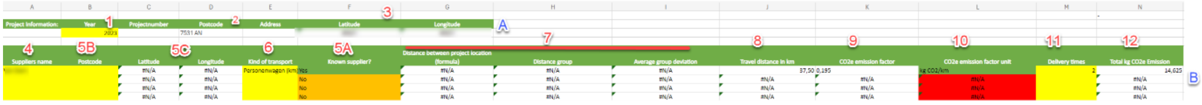
Name	Postcode home adres	Latitude	Longitude	Kind of transport	Drives from work location	Distance between project location and home location (formula)	Distance group	Average group deviation	Distance	Working days at location	Total distance	CO2 emission factor	CO2 emission factor unit	Total kg CO2e Emission
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A
		#N/A	#N/A			#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A

Materials	Amount	Unit	unit material table	Same unit?	Co2e	Co2e unit	Total kg CO2e Emission
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A
			#N/A	#N/A	#N/A	#N/A	#N/A

Table 15: Working sheet of the tool

In Table 15 the yellow-shaded cells are the only cells that need to be filled in, the rest of the model will calculate the CO₂e emissions based on formulas in combination with the filled-in information. The purple sections with letters in them contain the sections that will be described now. The sheet starts with the general project information in purple section A, where the year and postcode need to be filled in of the project. The year should correspond to the period during which the project was conducted. In cases where the project spans multiple years, the year can be updated once all the information for a specific year has been entered. The filled-in working sheet needs then be duplicated and cleared. Then the data for the new year needs to be filled in. When all the data for both years are filled in the sheets need to be merged statically. The sheet needs to be cleared because the correct CO₂e emission factors need to correspond to the right timeframe, this is needed because emission factors change over years as stated before in Section 4.2. The filled-in postcode retrieves the longitude and latitude respectively from the postcode table with a VLOOKUP function discussed in Section 4.2. The year needs to be filled in to retrieve the CO₂e emission factors from the CO₂e emission factors table for the emissions that are set free during the phase of A4, transportation, in the LCA, and the employees commuting.

In the next section of Table 15, B, the suppliers will have to be filled in. Based on the suppliers and subcontractors table, Table 11, a dropdown tile will be shown where a supplier can be selected if it is available in Table 11 based on the company name. When a supplier is selected from the tile the column of known supplier will be highlighted green with "Yes". This means that the driving distance is known on the Google Maps route and this will be used to calculate the total emissions for this supplier. The other option is that the supplier is not known. Then, the postcode also needs to be filled in. This creates the driving distance based on the formula as described in Section 4.2 keeping in mind the deviation from the distance group. This by hand filled in supplier then needs to be added to the suppliers/subcontractors table. At the moment it is not possible to automatically add the supplier to the suppliers/subcontractors table because there is no connection to retrieve the Google Maps driving distance. This should be added manually. If needed, the new supplier can also be added to the distance groups table to make the deviation for the distance group more accurate. When more suppliers or subcontractors are added to the table the calculation of the distance groups is more reliable because there is more data in the table. In the next column of section B, column E in Table 15, the kind of transport needs to be selected, also with a dropdown tile. The linked table here is Table 14, the CO₂e emission factors table. When the method of transport is selected, the CO₂e emission factor will pop up because of the filled-in information of year and method of transport. With a VLOOKUP function, the value is retrieved out of column D, from Table 14. When it is retrieved, column L in Table 15, the CO₂e emission factor unit which is from standard highlighted red, will turn green or red. It will turn green when the unit of the value for the kind of transport is in kilometers. When this is not the case the cell will highlight red. This means that another kind of transport needs to be selected because the travel distance is calculated based on kilometers and therefore the CO₂e emission factor unit also needs to calculate the CO₂e emissions based on kilometers. In this way, a protective measure is built into the tool to warn the user of the tool that he has filled in the wrong cell which he needs to adapt. The last column that needs to be filled in is the delivery times column, column M. When the delivery times are filled in, the total kilograms CO₂e emissions are calculated. Column M will be multiplied by column L. Now follows an example of the working of the combined sections A and B from Table 15 to understand the working of the table.



A	B	C	D	E	F	G
Project Information:	Year	Projectnumber	Postcode	Address	Latitude	Longitude
	2023		7531 AN		[redacted]	[redacted]

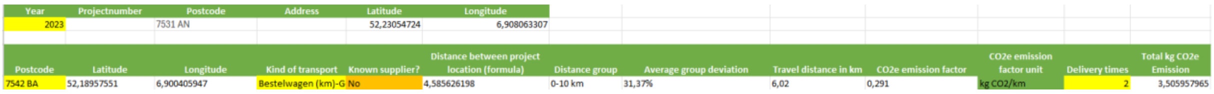
Suppliers name	Postcode	Latitude	Longitude	Kind of transport	Known supplier?	Distance between project location (formula)	Distance group	Average group deviation	Travel distance in km	CO2e emission factor	CO2e emission factor unit	Delivery times	Total kg CO2e Emission
[redacted]		#N/A	#N/A	Personenwagen (km)	Yes	#N/A	#N/A	#N/A	37,50	0,195	kg CO2/km	2	14,625
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A
		#N/A	#N/A		No	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A

Table 16: Working sheet table, sections A and B

In Table 16 above there are numbers from 1 to 12 which are the chronological steps to get to the outcome of the total kilograms CO₂e emissions in step 12. Note that in this example real project data has been used. Therefore project locations and suppliers/subcontractors/employees will not be mentioned or explained. These steps will now be described:

1. In this step in section A of the table the year of the project is filled in.
2. The project location postcode is filled in.
3. Based on the postcode of the project location the latitude and longitude are retrieved from Table 12.
4. A supplier from the dropdown tile is selected which is linked with Table 11. If the supplier is not shown in the tile the supplier is not known in Table 11.
5. A: When the supplier is known from the previous step the cell will turn green and show “Yes”. If it is not known it will turn red and show “No”. Then steps 5B and 5C come in place. If it shows “Yes” steps 5B, 5C, and 7 are skipped as shown in Table 16.
   B: From the unknown supplier the postcode needs to be filled in from the supplier's location. Because in this example the supplier is known, this is not the case.
   C: If this postcode is filled in it retrieves the latitude and longitude from Table 12.
6. Select a transportation method from the dropdown tile or search for a transportation method and select it.
7. This step comes into account when the supplier is not known. When step 5B is filled, the HAVERSINE formula calculates the as-the-crow-flies distance based on the respectively project latitude and longitude and the supplier's latitude and longitude. This retrieves the distance in column G. As said before, Table 13 contains the distance groups and this is linked in the cells in columns H and I from the working sheet. It shows in column H the distance group and in I the deviation percentage of the distance group.
8. Here the travel distance is calculated. When the supplier is known it takes the Google Maps route distance from Table 11. When the supplier is not known the as-the-crow-flies distance will be taken plus the average deviation percentage from the group distance. The distance groups in Table 11 contain all the information from the known suppliers at the moment the data was analyzed. When new suppliers are known within the company these should be added to the table. In this case, the distance groups will be more reliable because the calculation of

the deviation is based on more data. An example will be given of how it looks when an unknown supplier is filled in. The example that now follows is based on a dummy company:



Year	Projectnumber	Postcode	Address	Latitude	Longitude
2023		7531 AN		52,23054724	6,908063307

Postcode	Latitude	Longitude	Kind of transport	Known supplier?	Distance between project location (formula)	Distance group	Average group deviation	Travel distance in km	CO2e emission factor	CO2e emission factor unit	Delivery times	Total kg CO2e Emission
7542 BA	52,18957551	6,900405947	Bestelwagen (km)-G	No	4,585626198	0-10 km	31,37%	6,02	0,291	kg CO2/km	2	3,505957965

Table 17: Example of unknown supplier for calculation of CO_2e emissions in kilograms per km

In Table 17 can be seen how an unknown supplier is filled-in. The as-the-crow-flies distance is 4,58 kilometers. The distance group then is 0-10 kilometers. This has an average group deviation of 31,37%. So the 4,58 kilometers is multiplied by 1,3137 to get to the travel distance of 6,02 kilometers. When the travel distance in kilometers is known step 9 comes in place.

9. Column K from section B retrieves the CO_2e emission factor unit from the transportation method in combination with the year.
10. Column L from section B is a controlling cell. It shows if the filled-in transportation method is based on kilometers because all the calculations are based on kilometers. Therefore when this cell turns red, another transportation method needs to be selected.
11. The number of delivery times needs to be filled in. On the invoice from the suppliers, there is shown a delivery date. When a supplier comes multiple times at the project location for the project this needs to be taken into account. From the analyzed data it is also possible that a supplier delivers materials for multiple projects at the same time. In this case, the delivery times need to be divided by the number of projects it delivers materials for. In this way, the CO_2e emissions are allocated to each project it is related to for the same percentage. For example, if a supplier delivers materials for three projects at the same time, each project is allocated 33% of the total emissions which is set free by the transportation.
12. The total amount of kilograms of CO_2e emissions is calculated. It multiplies the travel distance in km (column J) with the CO_2e emission factor (column K) and the delivery times (column L).

The setup for the next section in Table 15, C, the subcontractor's section is almost the same as the supplier's section but differs on the part from delivery times. While subcontractors are coming to the project location and work on an hourly basis or on full working days instance, the delivery times column is changed to the amount of minutes and amount of employees that are working for the subcontractor to calculate the travel distance and the related CO_2e emissions. Based on the invoice amount and the created budget for the project per subcontractor by Kormelink b.v. it is possible to calculate the total amount back to working days. These days are then multiplied by the CO_2e emission factor and the travel distance. The total amount of employees that the subcontractor is using is optional so it is not necessary to fill it in, in the working sheet.

The next section in Table 15, D, the employees, is also similar to the supplier's section. The link is with the employees help table which is not shown due to confidential information. Like said in Section 3.2.3 it contains information on the living addresses of the employees and also respectively the longitude and latitude. When a new employee is getting to work for Kormelink b.v. they can update the employee help table to get the new information to retrieve the postcodes for the living address. If the employee table is not updated they have to fill in the postcode of the home address manually in column B of Table 15. If the employee is in the help table the longitude and latitude will be retrieved from it. The user of the tool also needs to select if the employee is driving from the office, if this is the case the Google Maps route will be taken for commuting to the project location. At last, in column K the amount of working days at the project location needs to be filled in to calculate the total kilograms of CO_2e emissions.

The last section in Table 15, E, is about the materials. The link is with Table 21 in Appendix E. In the first column materials can be selected that have existing LCAs or EPDs in the materials table. Because the materials are based on a unit in the LCA or EPD the same unit must be chosen to get to the correct CO_2e emissions. Therefore, the unit of the material needs to correspond with the unit in the materials table otherwise it is not calculating the CO_2e emission for the material.

In the working sheet, it is now possible to distinguish the total kilograms between the upstream categories for Scope 3. This makes it also possible to compare suppliers who deliver the same materials or subcontractors who are doing the same work. After coordination with Kormelink b.v. the working sheet, Table 15 can be filled in with three possible options to calculate the total CO_2e emissions:

1. Based on the received invoices from the project.
2. Based on the budget for the project set up by Kormelink b.v.
3. Based on the budget corrected with the received invoices for the project

After coordination, the choice has been made to go for option 3. Option 3 gets the closest to reality. Option 1 based on the received invoices only includes the totals of subcontractors and does not have insights into the materials they are using. Option 1 is good to use when Kormelink b.v. is not using subcontractors and only uses the materials that it buys. In this way, the invoices give the reality of the materials used and which suppliers have come to the project location. Option 2 is not the best option to use because the budget is estimated to be larger than reality. In this budget, they also mention the materials they estimate to use. When the budgeted materials are used, the estimated CO_2e emissions will always be expected to be higher than the reality. The advantage it has is that all the materials that are being used for the renovation are filled in. This also includes the materials used by the subcontractor. Therefore, option 3 is the best to come to the reality. The budgeted materials are being corrected by the received invoices and all the materials which are not on the invoice are coming into the working sheet through the budget.

4.4 Operational phase

To answer sub-research question 6: ”What are the savings on operational CO_2e emissions in the use phase of a building’s lifecycle after the renovation projects Kormelink b.v. has carried out?”, data from residents have been gathered on the operational phase according to the literature and Figure 1, which is described in Section 2.1.2 on operational energy use (gas and electricity). These data contain the usage of the residents before and after the renovation. It shows the relationship and improvement in usage before and after the renovation. For three residents the usage has been gathered where the renovation projects also have been finished so the data can be compared to each other. On average for three residents the total savings every year for gas is 14% and for electricity is 12%. To answer the main research question, the total savings on electricity and gas need to be calculated with the related CO_2e emission factors so the payback period can be calculated. Because the data is project-specific, sub-research question 7 where the payback period will be calculated, will be answered with the data where the impact is the lowest in percentage. In this case, a margin of error will be accounted for. This will be discussed in Chapter 5.

4.5 Conclusion

In conclusion, Chapter 4 has detailed the sections of the built tool and its practical application. The tool’s setup aligns with the GHG Corporate Value Chain (Scope 3) Standard. For each Scope 3 activity, the tool specifies the activity data, the emission factors used, the GWP values of materials, and the assumptions made. It addresses sub-research question 6: ”What are the savings on operational CO_2e emissions in the operational phase of a building’s lifecycle after the renovation projects Kormelink b.v.

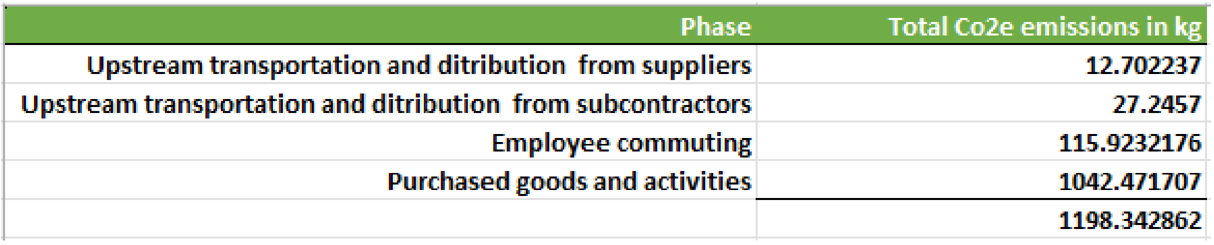
have carried out?” On average, for three residents, the annual savings are 14% for gas and 12% for electricity. Detailed information on the savings for the projects with the lowest and highest impact will be discussed in the next chapter. All the data has been gathered, analyzed, and processed in the tool. The next chapter will look into the results and answer the last sub-research question and main research question.

5. Results

This section highlights the key findings from the analysis conducted using the developed tool, specifically focusing on the calculation of Scope 3 CO_2e emissions associated with renovation projects in the Dutch building sector. It addresses sub-research question 7: ” What is the payback period on Scope 3 emissions that are emitted during renovation projects and the savings in operational CO_2e emissions in the operational phase of a building’s lifecycle compared to pre-and post-renovation?” and the main research question: “What is the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation?”. Additionally, the results on Scope 3 emissions will be applied to emphasize the importance of sustainable practices for stakeholders.

The built tool includes all information related to Scope 3 activities for purchased goods and activities, upstream transportation and distribution, and, employee commuting. The sources that were used to calculate the CO_2e emissions materials come from LCA databases with EPDs as a result. For the upstream transportation and distribution and employee commuting the sources include emission factor databases, the ERP system Kormelink b.v. uses for employee information, budgeted materials that subcontractors use during the project, and, suppliers location information.

From all the project data that is used, 54 materials are used that can be categorized into 24 categories. In total, ten different subcontractors have worked on renovation projects, and from eight different suppliers materials have been bought. For the project data that answers sub-research question 7, the project with the lowest impact on the operational phase after the renovation, as discussed in Section 4.4 to take a margin of error into account, was used for the calculation. After analyzing the data, 16 different materials were used, three subcontractors were hired, and, from two suppliers materials were bought. After the working sheet has been filled in with the data from the project with the lowest impact before and after the renovation, the total CO_2e emissions of the project are estimated at 1,198 kilograms as can be seen in Table 18.



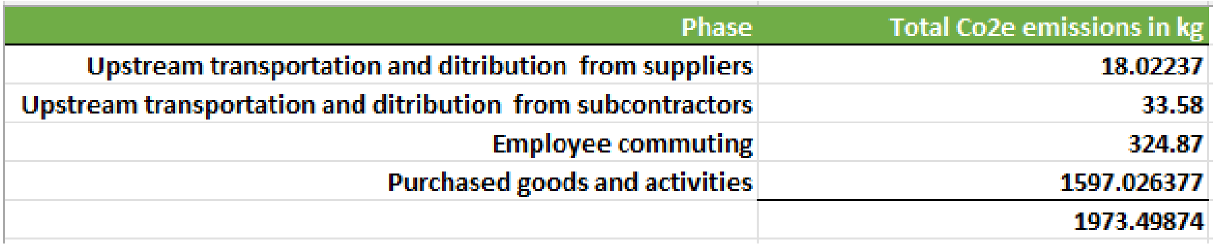
Phase	Total Co2e emissions in kg
Upstream transportation and ditribution from suppliers	12.702237
Upstream transportation and ditribution from subcontractors	27.2457
Employee commuting	115.9232176
Purchased goods and activities	1042.471707
	1198.342862

Table 18: Total CO_2e emissions from project data with the lowest impact in the operational phase after the renovation

Based on the filled-in worksheet and the gathered information on the operational phase, sub-research question 7 can be answered. The saving percentage on the operational phase per year is respectively for electricity 4.99% and for gas 7.49% for the residents on this project location. For the electricity the kWh used before the renovation was 2,996. After the renovation 2,863 kWh was used. This means a savings of 133 kWh was saved. For gas, the usage before the renovation was 1442 m^3. After the renovation 1334 m^3 was used. For gas, a saving of 108 m^3 has been established. When converting the 133 kWh to kilograms CO_2e, a saving of 60.648 kilograms was saved. For gas, this is 225.18 kilograms. For the operational phase, this is a total savings of 285.83 kilograms every year. All the details of the savings can be found in Appendix F. While the total CO_2e emissions that have set free during the project is 1,198 kilograms and the savings on a yearly basis are 285.83 kilograms this means that the payback period on the measured Scope 3 emissions that emit during renovation projects and the savings in operational CO_2e emissions in the operational phase of a building’s lifecycle is 4.5 years. In the

Netherlands, there is an energy-saving obligation. This obligation makes it obligatory for firms to carry out projects when energy savings on CO_2e emissions have a payback period of less than five years (Rijksdienst voor Ondernemend Nederland 2023). With this information, it can be said that from the analyzed data the payback period with the lowest impact has a positive result towards the environment, is relatively short, and has to be carried out.

The main research question can be answered in conjunction with sub-research questions 6 and 7. To understand the relationship, the total emissions for the project with the highest impact on the operational phase was calculated. The total usage of CO_2e emissions in the project and the payback period for this project will be compared to the project where the impact is the lowest. For the project with the highest impact, 2,696 kWh of electricity was consumed, which decreased to 2,370 kWh post-renovation, resulting in a savings of 329 kWh, which is 12.09%. For gas, the consumption was 1,238 m^3 before the renovation and 1,011 m^3 after, leading to a savings of 227 m^3, which is 18.34%. This results with the right CO_2e parameters for electricity and gas usage to a savings of 623.25 kilograms per year. After every activity of Scope 3 is filled in, the total CO_2e emissions for the project are 1973.49874 kilograms. This can be seen in Table 19 below.

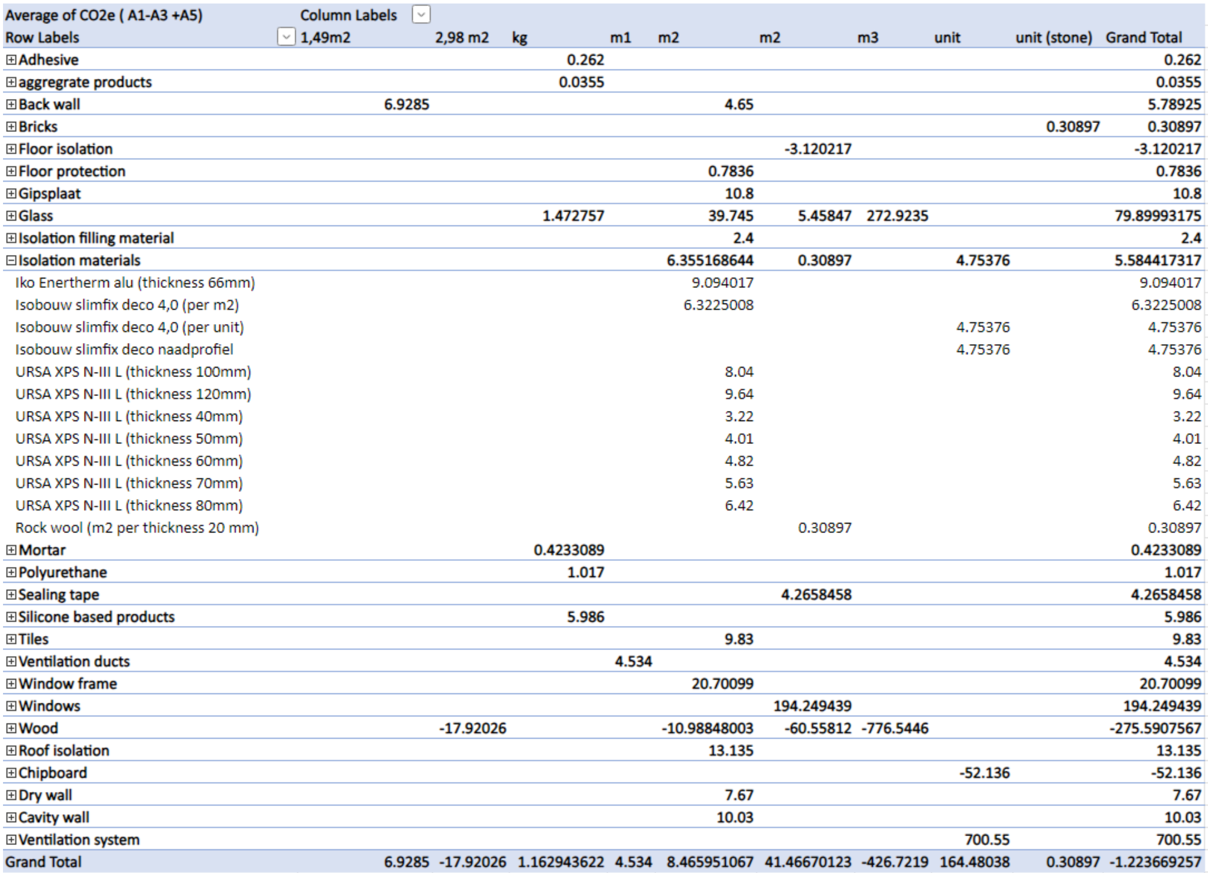


Phase	Total Co2e emissions in kg
Upstream transportation and ditribution from suppliers	18.02237
Upstream transportation and ditribution from subcontractors	33.58
Employee commuting	324.87
Purchased goods and activities	1597.026377
	1973.49874

Table 19: CO_2e emissions for the project with the highest impact in the operational phase after the renovation

The payback period for the project where the impact in the operational phase is the highest is calculated by 1,973 divided by 623.25 which is 3.2 years. The difference between the two projects in savings in the operational phase is 623.25 minus 285.83 which is 337.42 CO_2e kilograms per year. In total, the difference in Scope 3 project emissions is 1973 minus 1198 which is 775 kilograms CO_2e. Based on this information, it means that for every CO_2e kilogram extra used in the project, the operational phase will be saving 0.435 CO_2e kilogram per year. This relationship shows that higher Scope 3 emissions during renovation can lead to greater CO_2e savings during the operational phase, resulting in shorter payback periods. In this research, the savings of 0.435 CO_2e kilogram per year are established from a point when the Scope 3 project emissions are going to be larger than 1198 kilograms.

In addition to the relationship that has been established, the results of the tool identifies hotspots for all the materials and suppliers where emissions are set free during the project. Based on this, stakeholders can make decisions on sustainable practices. The analysis revealed that the category of bought materials is the most polluting, constituting 87% of total CO_2e emissions based on the filled-in project data. This means that organizations can make the most environmental impact on the bought materials. The choice of which materials are being used in a renovation project has a significant impact on the CO_2e emissions during the lifecycle. This can be seen in Table 20.



Average of CO2e (A1-A3 +A5)	Column Labels									
Row Labels	1,49m2	2,98 m2	kg	m1	m2	m2	m3	unit	unit (stone)	Grand Total
⊞Adhesive			0.262							0.262
⊞aggregrate products			0.0355							0.0355
⊞Back wall	6.9285				4.65					5.78925
⊞Bricks									0.30897	0.30897
⊞Floor isolation						-3.120217				-3.120217
⊞Floor protection					0.7836					0.7836
⊞Gipsplaat					10.8					10.8
⊞Glass			1.472757		39.745	5.45847	272.9235			79.89993175
⊞Isolation filling material					2.4					2.4
⊟Isolation materials					6.355168644	0.30897		4.75376		5.584417317
Iko Enertherm alu (thickness 66mm)					9.094017					9.094017
Isobouw slimfix deco 4,0 (per m2)					6.3225008					6.3225008
Isobouw slimfix deco 4,0 (per unit)								4.75376		4.75376
Isobouw slimfix deco naadprofiel								4.75376		4.75376
URSA XPS N-III L (thickness 100mm)					8.04					8.04
URSA XPS N-III L (thickness 120mm)					9.64					9.64
URSA XPS N-III L (thickness 40mm)					3.22					3.22
URSA XPS N-III L (thickness 50mm)					4.01					4.01
URSA XPS N-III L (thickness 60mm)					4.82					4.82
URSA XPS N-III L (thickness 70mm)					5.63					5.63
URSA XPS N-III L (thickness 80mm)					6.42					6.42
Rock wool (m2 per thickness 20 mm)						0.30897				0.30897
⊞Mortar			0.4233089							0.4233089
⊞Polyurethane			1.017							1.017
⊞Sealing tape						4.2658458				4.2658458
⊞Silicone based products			5.986							5.986
⊞Tiles					9.83					9.83
⊞Ventilation ducts				4.534						4.534
⊞Window frame					20.70099					20.70099
⊞Windows						194.249439				194.249439
⊞Wood		-17.92026			-10.98848003	-60.55812	-776.5446			-275.5907567
⊞Roof isolation					13.135					13.135
⊞Chipboard								-52.136		-52.136
⊞Dry wall					7.67					7.67
⊞Cavity wall					10.03					10.03
⊞Ventilation system								700.55		700.55
Grand Total	6.9285	-17.92026	1.162943622	4.534	8.465951067	41.46670123	-426.7219	164.48038	0.30897	-1.223669257

Table 20: Average CO₂e emissions per material category per unit for lifecycle phases A1-A3 +A5

In Table 20 the differences between the materials for the category of isolation materials can be interpreted. Using specific materials can result in lower CO₂e emissions over the lifecycle of the material. This can be linked back to the literature in Section 2.1.4 regarding sustainable practices. Organizations need to shift towards materials that have lower embodied emissions which results in lower CO₂e during their lifecycle. With the built tool Kormelink b.v. can calculate what the results during the lifecycle will be for the materials. The tool enables comparison between the analyzed materials within a specific category. Therefore, Kormelink b.v. has choices to determine the outcome of their own Scope 3 emissions by choosing more sustainable materials. In addition, the Scope 3 CO₂e emissions on upstream transportation and distribution can be improved by choosing more local suppliers and subcontractors to the project location. By choosing more local suppliers and subcontractors the less CO₂e the activity of transportation and distribution will be. The same accounts for choosing employees who are living more local to the project location.

Overall, the relationship between Scope 3 and operational CO₂e emissions in Dutch building renovation projects is quantifiable and significant. Higher Scope 3 emissions during renovation can lead to greater CO₂e savings during the operational phase, resulting in shorter payback periods. Within this research, the savings of 0.435 CO₂e kilogram per year are established from a point when the Scope 3 project emissions are going to be larger than 1198 kilograms. This relationship highlights the importance of considering both the initial CO₂e footprint of renovation activities and the long-term environmental benefits when planning and executing renovation projects. Kormelink b.v. can measure and report on their Scope 3 CO₂e emissions from renovation projects. By using the tool, it assures that it is in line with the GHG Corporate Value Chain (Scope 3) Standard. The tool enables Kormelink b.v. to make sustainable decisions on the Scope 3 categories of purchased goods and activities, upstream transportation and distribution, and, employee commuting. External companies that have similar activities and are using similar products can use the tool for an indication of Scope 3 emissions. When they want to calculate accurate Scope 3 emissions they should adapt the supplier and subcontractor tab, the employee tab, and, the materials tab to their specific needs and business information. When reporting Scope 3 emissions based on CO_2e emission averages for materials from this tool, companies should disclose this to comply with the GHG Corporate Value Chain (Scope 3) Standard, noting that this may reduce the assurance of the Scope 3 inventory's reliability.

6. Discussion

Now all research questions are answered, a look will be given into the contributions and the validity of the research. Also, the limitations of this research will be discussed.

This study makes significant contributions, both theoretically and practically, to the understanding of the environmental impact of renovation projects in the Dutch building sector. Before this study, there was less known about renovation projects and how Scope 3 project emissions relate to the operational phase of the building. The theoretical contribution lies in understanding the relationship and the resulting payback period between Scope 3 and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre- and post-renovation. It contributes to the field of environmental and sustainable practices. The relationship showed that higher Scope 3 emissions during renovation can lead to greater CO_2e savings during the operational phase, resulting in shorter payback periods, and the payback period was calculated at 4.5 years for the project where the positive impact in the operational phase pre- and post-renovation was the lowest. In this research, the savings of 0.435 CO_2e kilogram per year are established from a point when the Scope 3 project emissions are going to be larger than 1198 kilograms. This research aligns with existing Scope 3 research to understand that considering the entire lifecycle of a project is essential for sustainable outcomes.

The outcome of the research can also be used within long-term sustainability on practical implications. Based on the existing literature in Chapter 2 which showed that it is important to distinguish each Scope 3 activity to identify the hotspots where sustainable practices could be implemented. According to the existing literature, it is important for policymakers and decision-makers that each Scope 3 activity is reported on as detailed as possible. They can make better decisions when information is more detailed. Knowing that the outcome of this paper also showed that 87% of the emissions take place in the purchased goods and materials, sustainable practices should be implemented at this phase first to get the biggest wins. Following the literature, decisions need to be made for materials to shift to more renewable materials. Therefore, building companies can use the results of this paper for their benefit to shift towards renewable or sustainable materials. Following the literature this should be done at the design phase of a project. When building companies use the results of this paper for their sustainable practices they can start by examining their materials before conducting full research on the Scope 3 activities, as it is already examined and has the highest impact on the operational phase.

By looking into all the different models that can be used to report on Scope 3 emissions, the choice to follow the GHG Corporate Value Chain (Scope 3) Standard came forward through the objective of this study and the examined literature in Chapter 2. The GHG Corporate Value Chain (Scope 3) Standard is in line with the CSRD. This means that when following the Standard you report following the obligatory regulations of the CSRD. This prepares Kormelink b.v. for the future when they have to report on Scope 3 emissions. In addition, the CSRD mentions that the CO_2e emissions need to be measured and the Standard mentions that it is obligatory to convert all emissions into an equivalent. This could be done with the LCA databases where EPD results were mentioned with the GWP for each material. For the other phases, the LCA databases could be used to calculate the emission factors of transportation and employee commuting. When following other methods this could have led to other emission equivalents which is not in line with the CSRD. Furthermore, when following the Standard the hotspots for each Scope 3 activity will come forward which makes it useful for policy- and decision-makers to implement sustainable practices. The built tool can be used by external companies to measure their own Scope 3 emissions. Building companies can use the material CO_2e emissions averages of the tool or research its material inventory and replace it in the tool. The tool can also be used for further research which will be explained in Section 7.2.

The validity of the research lies in Chapters 2, 3, and 4. Looking towards the Scope of research it was necessary to come up with all the CO_2e emissions which set free during the project, and the difference in the operational phase on the pre-and post-renovation. Therefore, the theory gives a solid answer to gather the required input on these emissions by following the GHG Corporate Value Chain (Scope 3) Standard and the LCA method where the GWP values can be used to calculate the CO_2e emissions. In Chapters 4 and 5, an explanation has been given for which information the tool requires for the Scope 3 emissions. The setup of these tables has been described so that all necessary data is reported on regarding the research. From all analyzed data information regarding the Scope 3 activities Kormelink b.v. has carried out CO_2e emissions could be found. This ensures that the content validity is good. By following the GHG Corporate Value Chain (Scope 3) Standard and not deviating from it the face validity is very good. While the operational phase can vary a lot within residentials, they were asked some questions to residents to rule out big differences in the operational phase which could give problems with the validity. Data was only collected from the residents who did not have a family expansion, such as getting an extra child, have not taken other sustainable practices towards their house which could give a better performance on the operational phase separate from the renovation project, and were the residents were at home the year after the renovation. In addition, in the Netherlands there was a period where gas prices were highly above average, this can be seen in Appendix G. This data varies between November 2021 and November 2022. Therefore, renovation projects where the operational phase after the renovation would fall between this period were also excluded. In the end, this came to data from three residentials that meet the criteria for the operational phase.

However, it is important to note that the research has limitations, such as that the tool is partially static due to the need to input data from suppliers and LCAs of materials, requiring manual input of data from suppliers and LCAs of materials, which may be time-consuming and prone to errors. In addition, subcontractors may not provide complete data on the materials used, leading to potential inaccuracies in the emissions calculations. Yearly parameters need to be updated yearly, to measure emissions with the right parameters. Limitations can also arise in circumstances from the operational phase. In this paper, there are some measures taken to overcome this and only include operational data that is similar to each other across different projects. The interpretation of these limitations is that while the tool provides valuable insights into emissions calculations, the manual input requirements and potential data inaccuracies may hinder its efficiency and accuracy. The last limitation is in the part that only three projects were examined to examine the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation. Although data was only used from projects that assured the validity was good, it is relatively a small sample size. These limitations highlight the need for future research which will discussed in Chapter 7.

7. Conclusion

In this section, a summary of my paper will be given in Section 7.1, and based on the discussion it will lay the foundation for future research in Section 7.2

7.1 Summary

This thesis explored the relationship and the resulting payback period between Scope 3 and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre- and post-renovation. The research follows a two-part approach, including a literature review and an empirical study, addressing key questions like identifying the most environmentally impactful activities for Scope 3, exploring existing data collection tools, studying effective reporting methods, and calculating the Scope 3 emissions for renovation projects and calculating the payback period. By answering these questions it answered the following research question What is the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation?"

The research reveals a relationship between the Scope 3 CO_2e emissions generated during renovation projects and the subsequent CO_2e savings during the operational phase. Specifically, for every additional kilogram of CO_2e emitted during the renovation, there is a saving of approximately 0.435 kilograms of CO_2e annually in the operational phase post-renovation when project emissions exceed the total of 1198 kilograms of CO_2e. The research shows that the payback periods for the two analyzed projects, one with lower Scope 3 emissions and one with higher Scope 3 emissions, are 4.5 years and 3.2 years, respectively. Both payback periods are below the five-year threshold set by Dutch regulations, meaning the energy savings justify the initial CO_2e investment. In addition, The results demonstrate a trade-off between the CO_2e emissions during renovation and the subsequent operational savings. Even when Scope 3 emissions are higher, the operational savings can be substantial enough to achieve a relatively short payback period, thus offering environmental benefits over the building's lifecycle.

The findings highlight the role of considering Scope 3 emissions in renovation projects and emphasize the importance of sustainable decision-making. By identifying the most polluting materials, subcontractors, and suppliers that are commonly used in renovations for the company Kormelink b.v., the study offers insights for stakeholders to make informed decisions for sustainable practices. The developed tool makes it possible to quantify the CO_2e emissions for renovation projects, allowing stakeholders to compare detailed sustainability improvements across both different and within Scope 3 categories effectively.

In conclusion, the relationship between Scope 3 and operational CO_2e emissions in Dutch building renovation projects is quantifiable and significant. Higher Scope 3 emissions during renovation can lead to greater CO_2e savings during the operational phase, resulting in shorter payback periods. This relationship highlights the importance of considering both the initial carbon footprint of renovation activities and the long-term environmental benefits when planning and executing renovation projects.

7.2 Future research

While discussed in Chapter 6 that the tool is partially static, research can be done in the way for improvement including the use of a general database with materials or the use of averages for categories of materials when specific materials are unknown. This can be achieved through further research, which should focus on addressing the limitations of the tool by exploring automated data collection methods and improving the accuracy and reliability of emissions calculations. When data about Scope 3 activities are known and available in a database, firms are more likely to use it more easily. When they have to figure all the LCA and EPD out on their own it is time-consuming and can be a threshold to look into it.

Future research could explore extending the relationship with additional variables. This paper focused on a renovation project as a whole, where measures have been taken into account when project data could be used to assure the validity of the research. future studies could adapt the tool to examine relationships based on specific details, such as the surface area of the buildings. The research could investigate how renovation projects with varying surface areas compare in terms of the operational phase performance, despite having the same Scope 3 activities or renovation activities. In this way, a new relationship can be established that states the influence of surface area on the efficiency in the operation phase of renovation projects also taking the Scope 3 project emissions into account.

Another research could be done to look into the relationship between Scope 3 CO_2e emissions and the operational CO_2e emissions of a building in Dutch building renovation projects, both pre-and post-renovation, where only renewable materials have been used. While literature showed that companies should shift towards more renewable materials this could be investigated. Those results can be compared with the results of this paper to conclude something about the difference in the usage of materials and what the differences in the relationships are when only renewable materials are used. Also, research on circular economy can be done. By focusing on incorporating circular economy principles, such as material reuse and recycling, into renovation projects, the environmental and economic impacts of these practices at scale can be researched. This will extend the relationship with the building's lifecycle phases of end-of-life and recycling.

At last, this study is based on data from only three renovation projects, which restricts the generalizability of the findings. Expanding the research to include a broader range of projects and exploring different building types or renovation scenarios could provide more comprehensive insights into the sustainability literature.

In conclusion, there is space for refining the accuracy, expanding its applicability, and improving the efficiency of the relationship in future studies.

Bibliography

Abd Rashid, Ahmad Faiz, and Sumiani Yusoff. 2015. “A Review of Life Cycle Assessment Method for Building Industry.” *Renewable and Sustainable Energy Reviews* 45:244–48. doi: 10.1016/J.RSER.2015.01.043.

Achenbach, Hermann, Jan L. Wenker, and Sebastian Rüter. 2018. “Life Cycle Assessment of Product- and Construction Stage of Prefabricated Timber Houses.” *European Journal of Wood and Wood Products* 76(2):711–29. doi: 10.1007/s00107-017-1236-1.

Ali, Khozema Ahmed, Mardiana Idayu Ahmad, and Yusri Yusup. 2020. “Issues, Impacts, and Mitigations of Carbon Dioxide Emissions in the Building Sector.” *Sustainability (Switzerland)* 12(18):7427. doi: 10.3390/SU12187427.

Allwood, Julian M., Jonathan M. Cullen, and Rachel L. Milford. 2010. “Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050.” *Environmental Science and Technology* 44(6):1888–94. doi: 10.1021/ES902909K/SUPPL_FILE/ES902909K_SI_001.PDF.

Alwisy, Aladdin, Samer Bu Hamdan, Beda Barkokebas, Ahmed Bouferguene, and Mohamed Al-Hussein. 2019. “A BIM-Based Automation of Design and Drafting for Manufacturing of Wood Panels for Modular Residential Buildings.” *International Journal of Construction Management* 19(3):187–205. doi: 10.1080/15623599.2017.1411458.

Anon. 2011. “Guidance for Calculating Scope 3 Emissions Calculation Guidance for Implementing the GHG Protocol Corporate Value Chain (Scope 3) World Business Council for Sustainable Development.”

Anon. 2019. “Global Emissions - Center for Climate and Energy Solutions Center for Climate and Energy Solutions.” Retrieved March 11, 2024 (https://www.c2es.org/content/international-emissions/).

Anon. 2023a. “Stakeholdersanalyse – Projectmanagementsite.” Retrieved June 8, 2023 (https://projectmanagementsite.nl/stakeholdersanalyse/).

Anon. 2023b. “Tips Gewijzigde CO2-Factoren - Milieubarometer - Stimular.” Retrieved January 21, 2024 (https://www.milieubarometer.nl/voor-gebruikers/tips-gewijzigde-co2-factoren/).

Anon. 2024. “What Is Embodied Carbon? - CarbonCure.” Retrieved May 11, 2024 (https://www.carboncure.com/concrete-corner/what-is-embodied-carbon/).

Anon. n.d. “GHG Protocol vs. Bilan Carbone: What’s the Difference? - Tapio.” Retrieved June 30, 2024a (https://www.tapio.eco/blog/the-differences-between-ghg-protocol-bilan-carbone/).

Anon. n.d. “Scope 3 Inventory Guidance | US EPA.” Retrieved June 27, 2024b (https://www.epa.gov/climateleadership/scope-3-inventory-guidance).

Bandyopadhyay, Santanu. 2020. “Pinch Analysis for Economic Appraisal of Sustainable Projects.” *Process Integration and Optimization for Sustainability* 4(2):171–82. doi: 10.1007/S41660-020-00106-X/METRICS.

Barriga, Edgar M., Jae G. Jeong, Makarand Hastak, and Matt Syal. 2005. “Material Control System for the Manufactured Housing Industry.” *Journal of Management in Engineering* 21(2):91–98.

doi: 10.1061/(ASCE)0742-597X(2005)21:2(91).

Bastos, Joana, Stuart A. Batterman, and Fausto Freire. 2014. “Life-Cycle Energy and Greenhouse Gas Analysis of Three Building Types in a Residential Area in Lisbon.” *Energy and Buildings* 69:344–53. doi: 10.1016/J.ENBUILD.2013.11.010.

BDO. 2023. “Sustainability at a Glance (ESRS) E1-Climate Change.”

Begg, Katie, Frans van der Woerd, and David Levy. 2018. *The Business of Climate Change: Corporate Responses to Kyoto*.

BIS. 2010. *Estimating the Amount of CO2 Emissions That the Construction Industry Can Influence*.

British Standards. 2006. “Environmental Management-Life Cycle Assessment-Principles and Framework.”

Callahan, Wanda, Shell A. James Fava, Susan Wickwire, John Sottong, James Stanway, and Miranda Ballentine. 2011. “Corporate Value Chain (Scope 3) Accounting and Reporting Standard Supplement to the GHG Protocol Corporate Accounting and Reporting Standard GHG Protocol Team.”

Carbone, Bilan. 2007. *Methodological Guidelines Accounting Principles and Objectives*.

Curran, Mary Ann, Margaret Mann, and Gregory Norris. 2005. “The International Workshop on Electricity Data for Life Cycle Inventories.” *Journal of Cleaner Production* 13(8):853–62. doi: 10.1016/J.JCLEPRO.2002.03.001.

Directorate-General for Environment. 2021. “Recommendation on the Use of Environmental Footprint Methods.” Retrieved June 21, 2023 (https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en).

Dong, Ya Hong, and S. Thomas Ng. 2015. “A Life Cycle Assessment Model for Evaluating the Environmental Impacts of Building Construction in Hong Kong.” *Building and Environment* 89:183–91. doi: 10.1016/J.BUILDENV.2015.02.020.

Downie, John, and Wendy Stubbs. 2013. “Evaluation of Australian Companies’ Scope 3 Greenhouse Gas Emissions Assessments.” *Journal of Cleaner Production* 56:156–63. doi: 10.1016/J.JCLEPRO.2011.09.010.

EFRAG. 2022. “European Sustainability Reporting Guidelines 1 Double Materiality Conceptual Guidelines for Standard-Setting.” Retrieved June 30, 2024 (https://www.efrag.org/sites/default/files/sites/webpublishing/SiteAssets/Appendix 2.6 - WP on draft ESRG 1.pdf).

Energievergelijk. 2024. “Energiecijfers Nederland – Energievergelijk.Nl.” Retrieved February 5, 2024 (https://www.energievergelijk.nl/onderwerpen/energiecijfers).

Farsan, Alexander, Andres Chang, Annemarie Kerkhof, Bence Cserna, Chendan Yan, Fernando Rangel Villasana, Nicole Labutong, Bauke Ketelaar, David Van Petersen, Fleur De Haan, Jippe Beltman, Joyce Swanenberg, and Max Uyttewaal. 2018. “Best Practices in Scope 3 Greenhosue Gas Management.”

Figueroa, Luis Javier Márquez, Jorge Luis García-Alcaraz, Ahmed I. Osman, Alfonso Jesús Gil López, Yashar Aryanfar, Mika Sillanpää, and Mamdouh El Haj Assad. 2023. “Measuring Impact of Lean Manufacturing Tools for Continuous Improvement on Economic Sustainability.” *Journal of Systems Science and Systems Engineering*. doi: 10.1007/S11518-023-5588-2.

Finnveden, Göran, Michael Z. Hauschild, Tomas Ekvall, Jeroen Guinée, Reinout Heijungs, Stefanie Hellweg, Annette Koehler, David Pennington, and Sangwon Suh. 2009. “Recent Developments in Life Cycle Assessment.” *Journal of Environmental Management* 91(1):1–21. doi: 10.1016/J.JENVMAN.2009.06.018.

Flynn, Barbara B., Roger G. Schroeder, and Sadao Sakakibara. 1994. “A Framework for Quality Management Research and an Associated Measurement Instrument.” *Journal of Operations Management* 11(4):339–66. doi: 10.1016/S0272-6963(97)90004-8.

Gallo, Amy. 2016. “A Refresher on Payback Method.” Retrieved June 30, 2024 (https://hbr.org/2016/04/a-refresher-on-payback-method).

Ger Maas Royal, ir, Juan Elizaga Corrales, Ferrovial Agroman, Jesse Putzel, Royal BAM Group Johanna Wikander, Skanska Edith Guedella Bustamante, Acciona Shaun Nesbitt, Balfour Beatty Ron van Wijk, Ballast Nedam Maurits Dekker, Bam Infraconsult John Hutton, Bam Nuttall Harry Lakeman, CCC Luc Lakeman, CCC Naim Abu Laila, CCC Pierre Fulconis, Consolis Lucia Monforte Guillot, FCC Valentin Alfaya, Ferrovial Michael Schreurs, Hochtief Goran Gerth, NCC Noel Morrin, Skanska Jennifer Clark, Skanska Rune Stene, Skanska David Harget, Uponor Geraldine Thomas, Vinci Kris Karslake, Vinci Jens-Peter Grunau, Züblin Norbert Pralle, Züblin Gia Kroeff, Bovis Lend Lease Peter Johnson, Kier Paul Cockaday, Rourke Vicki Walsh, and Sir Robert McAlpine. 2012. “A Guide to Reporting against the Green House Gas Protocol for Construction Companies.”

Gregory, Jeremy, and Aaron Krol. 2024. “Scope 1, 2 and 3 Emissions | MIT Climate Portal.” Retrieved May 24, 2024 (https://climate.mit.edu/explainers/scope-1-2-and-3-emissions).

Haleem, Fazli, Sami Farooq, Yang Cheng, and Brian Vejrum Waehrens. 2022. “Sustainable Management Practices and Stakeholder Pressure: A Systematic Literature Review.” *Sustainability 2022, Vol. 14, Page 1967* 14(4):1967. doi: 10.3390/SU14041967.

Hauschild, Michael, Mark Goedkoop, Jerome Guinee, Reinout Heijungs, Mark Huijbregts, Olivier Jolliet, Manuele Margni, and Schryver An De. 2011. “Recommendations for Life Cycle Impact Assessment in the European Context - Based on Existing Environmental Impact Assessment Models and Factors (International Reference Life Cycle Data System - ILCD Handbook)” edited by E. Union. doi: 10.2788/33030.

Heeren, Niko, and Tomer Fishman. 2019. “A Database Seed for a Community-Driven Material Intensity Research Platform.” *Scientific Data* 6(1). doi: 10.1038/S41597-019-0021-X.

Hertwich, Edgar G. 2021. “Increased Carbon Footprint of Materials Production Driven by Rise in Investments.” *Nature Geoscience 2021 14:3* 14(3):151–55. doi: 10.1038/s41561-021-00690-8.

Huang, Y. Anny, Christopher L. Weber, and H. Scott Matthews. 2009. “Categorization of Scope 3 Emissions for Streamlined Enterprise Carbon Footprinting.” *Environmental Science and Technology* 43(22):8509–15. doi: 10.1021/ES901643A/SUPPL_FILE/ES901643A_SI_001.PDF.

Hur, Won Moo, Hanna Kim, and Jeong Woo. 2014. “How CSR Leads to Corporate Brand Equity: Mediating Mechanisms of Corporate Brand Credibility and Reputation.” *Journal of Business Ethics* 125(1):75–86. doi: 10.1007/S10551-013-1910-0/TABLES/4.

ISO 14064-3:2019. 2019. “ISO 14064-3: 2019, Greenhouse Gases — Part 3: Specification with Guidance for the Verification and Validation of Greenhouse Gas Statements.”

Iuorio, Ornella, Andrew Wallace, and Kate Simpson. 2019. “Prefabs in the North of England: Technological, Environmental and Social Innovations.” *Sustainability 2019, Vol. 11, Page 3884* 11(14):3884. doi: 10.3390/SU11143884.

Iyer-Raniga, Usha, Pekka Huovila, and Priyanka Erasmus. 2021. “Sustainable Buildings and Construction: Responding to the SDGs.” 1–15. doi: 10.1007/978-3-319-71061-7_61-1.

Jolliet, Olivier, Myriam Saadé-Sbeih, Shanna Shaked, Alexandre Jolliet, and Pierre Crettaz. 2015. “Environmental Life Cycle Assessment.” *Environmental Life Cycle Assessment* 1–298. doi: 10.1201/B19138.

Kedir, Firehiwot, and Daniel M. Hall. 2021. “Resource Efficiency in Industrialized Housing Construction – A Systematic Review of Current Performance and Future Opportunities.” *Journal of Cleaner Production* 286:125443. doi: 10.1016/j.jclepro.2020.125443.

Klunder, G. 2005. “Sustainable Solutions for Dutch Housing. Reducing the Environmental Impacts of New and Existing Houses.”

Kumanayke, Ramya, and Hanbin Luo. 2018. “Life Cycle Carbon Emission Assessment of a Multi-Purpose University Building: A Case Study of Sri Lanka.” *Frontiers of Engineering Management* 0(0):0. doi: 10.15302/J-FEM-2018055.

Lalor, Ailish. 2022. “Why Is There a Housing Shortage in the Netherlands? The Dutch Housing Crisis Explained | DutchReview.” *Https://Dutchreview.Com/.*

Liao, Haolan, Rong Ren, and Lu Li. 2023. “Existing Building Renovation: A Review of Barriers to Economic and Environmental Benefits.” *International Journal of Environmental Research and Public Health 2023, Vol. 20, Page 4058* 20(5):4058. doi: 10.3390/IJERPH20054058.

Means, Tiffany, and Marc Lallanilla. 2021. “Greenhouse Gases: Causes, Sources and Environmental Effects.” Retrieved July 19, 2023 (https://www.livescience.com/37821-greenhouse-gases.html).

Meijer, Koen. 2021. “Scope 3 Emissies.” Retrieved August 21, 2023 (https://koenmeijer.nl/wp-content/uploads/2021/01/inzicht-scope-3-emissies-2020-v1.pdf).

Münstermann, Björn, Andreas Eckhardt, and Tim Weitzel. 2010. “The Performance Impact of Business Process Standardization: An Empirical Evaluation of the Recruitment Process.” *Business Process Management Journal* 16(1):29–56. doi: 10.1108/14637151011017930.

Nwodo, Martin N., and Chimay J. Anumba. 2019. “A Review of Life Cycle Assessment of Buildings Using a Systematic Approach.” *Building and Environment* 162. doi: 10.1016/J.BUILDENV.2019.106290.

Orr, John, Orlando Gibbons, and Will Arnold. 2020. “A Brief Guide to Calculating Embodied Carbon.” *Structural Engineer* 98(7):22–27. doi: 10.56330/JZNX5709.

Our world in data. n.d. “CO₂ Emissions by Sector, Netherlands.” Retrieved June 26, 2023 (https://ourworldindata.org/grapher/co-emissions-by-sector?country=~NLD).

Park, So Ra, and Jae Young Jang. 2021. “The Impact of ESG Management on Investment Decision: Institutional Investors’ Perceptions of Country-Specific ESG Criteria.” *International Journal of Financial Studies 2021, Vol. 9, Page 48* 9(3):48. doi: 10.3390/IJFS9030048.

Patchell, Jerry. 2018. “Can the Implications of the GHG Protocol’s Scope 3 Standard Be Realized?” *Journal of Cleaner Production* 185:941–58. doi: 10.1016/J.JCLEPRO.2018.03.003.

Pelletier, Nathan, Karen Allacker, Rana Pant, and Simone Manfredi. 2014. “The European Commission Organisation Environmental Footprint Method: Comparison with Other Methods, and Rationales for Key Requirements.” *International Journal of Life Cycle Assessment* 19(2):387–404. doi: 10.1007/S11367-013-0609-X/FIGURES/2.

Prasad, Deo, Aysu Kuru, Philip Oldfield, Lan Ding, Malay Dave, Caroline Noller, and Baojie He. 2022. “Operational Carbon in the Built Environment: Measurements, Benchmarks and Pathways to Net Zero.” *Delivering on the Climate Emergency* 29–78. doi: 10.1007/978-981-19-6371-1_2.

Programme, United Nations Environment. 2011. “Towards a Life Cycle Sustainability Assessment: Making Informed Choices on Products” edited by S. Valdiva, C. M. L. Ugaya, G. Sonnemann, and J. Hildenbrand.

Programme, United Nations Environment, and Yale Center for Ecosystems +. Architecture. 2023. “Building Materials and the Climate: Constructing a New Future.”

Quist, Zazala. 2023. “Ecochain| Life Cycle Assessment (LCA) - Complete Beginner’s Guide.” Retrieved June 20, 2023 (https://ecochain.com/knowledge/life-cycle-assessment-lca-guide/).

Ranganathan, Janet, Laurent Corbier, Simon Schmitz, Kjell Oren, Brian Dawson, Matt Spannagle, Mike Mcmahon Bp, Pierre Boileau, Environment Canada, Rob Frederick, Bruno Vanderborght, Holcim Fraser Thomson, Koichi Kitamura, Chi Mun Woo, &. Naseem, Pankhida Kpmg, Reid Miner, Laurent Segalen Pricewaterhousecoopers, Jasper Koch, Somnath Bhattacharjee, Cynthia Cummis, Rebecca Eaton, Michael Gillenwater, Marie Marache Pricewaterhousecoopers, Roberto Acosta, and Vincent Camobreco. 2004. “GHG Protocol Initiative Team World Business Council for Sustainable Development Pankaj Bhatia World Resources Institute World Business Council for Sustainable Development Peter Gage World Resources Institute Revision Working Group Core Advisors.”

Rijksdienst voor Ondernemend Nederland. 2023. “Terugverdientijdmethodiek - Energiebesparingsplicht.” Retrieved February 2, 2024 (https://www.rvo.nl/onderwerpen/energiebesparingsplicht/onderzoeksplicht/terugverdientijdmethodiek).

Roca, Laurence Clément, and Cory Searcy. 2012. “An Analysis of Indicators Disclosed in Corporate Sustainability Reports.” *Journal of Cleaner Production* 20(1):103–18. doi: 10.1016/J.JCLEPRO.2011.08.002.

RSM. 2023. “RSM|Corporate Sustainability Reporting Directive.” Retrieved March 14, 2023 (https://www.rsm.global/netherlands/en/services/sustainability-consulting/csrd).

Scientists, Union of concerned. 2008. “Cars, Trucks, Buses and Air Pollution | Union of Concerned Scientists.” Retrieved June 26, 2023 (https://www.ucsusa.org/resources/cars-trucks-buses-and-air-pollution).

Shrimali, Gireesh. 2022. “Scope 3 Emissions: Measurement and Management.” *The Journal of Impact and ESG Investing* 3(1):31–54. doi: 10.3905/JESG.2022.1.051.

Slaveykova, Vera I., Patrice Couture, Sabine Duquesne, Patrick D’Hugues, and Wilfried Sánchez. 2019. “Recycling, Reuse, and Circular Economy: A Challenge for Ecotoxicological Research.” *Environmental Science and Pollution Research* 26(21):22097–100. doi: 10.1007/S11356-019-04626-Z/METRICS.

Sotos, Mary. 2015. “GHG Protocol Corporate Standard GHG Protocol Scope 2 Guidance.”

Statista. 2022. “Residential Construction in the U.S. - Statistics & Facts | Statista.” *Statista Research Department*. Retrieved April 11, 2023 (https://www.statista.com/topics/3249/us-residential-construction/#topicOverview).

Świątek, L. 2013. “Dematerialization in Architecture as an Imperative of Sustainable Building.”

Toffel, Michael W., and Stephanie Van Sice. 2011. “Carbon Footprints: Methods and Calculations.” *Harvard Business School Technology & Operations Mgt. Unit Case, 611-075* 16. Retrieved March 14, 2023 (https://www.hbs.edu/faculty/Pages/item.aspx?num=40588).

Toth, Zsolt, Jonathan Volt, Sibyl Steuwer Reviewed, Barney Jeffries, Caroline Milne, Hélène Sibileau, Maria Stambler, Oliver Rapf, and Mariangiola Fabbri. 2022. “ROADMAP TO CLIMATE-PROOF BUILDINGS AND CONSTRUCTION HOW TO EMBED WHOLE-LIFE CARBON IN THE EPBD.”

United Nations. 2023. “United Nations |The 17 Goals| Sustainable Development.” Retrieved March 14, 2023 (https://sdgs.un.org/goals).

Verma, Subhash Kumar, Richa Verma, Bipin Kumar Singh, and Ravi Shankar Sinha. 2024. “Management of Intelligent Transportation Systems and Advanced Technology.” *Energy, Environment, and Sustainability* Part F2419:159–75. doi: 10.1007/978-981-97-0515-3_8.

Waardenburg, Mouwrik. 2021. “Keten-Analyse Scope 3 Emissies En Reductiedoelstellingen.”

Wegener Sleeswijk, Anneke Sangwon, Suh Helias, Udo de Haes, Hans de Bruijn, Mark AJ Huijbregts, Erwin Lindeijer, Aksel AH Roorda, -Bernhard L van der Ven, Bo P. Weidema, and Lca Consultants. 2001. “Life Cycle Assessment -An Operational Guide to the ISO Standards.”

Weidema, Bo Pedersen, and Marianne Suhr Wesnæs. 1996. “Data Quality Management for Life Cycle Inventories—an Example of Using Data Quality Indicators.” *Journal of Cleaner Production* 4(3–4):167–74. doi: 10.1016/S0959-6526(96)00043-1.

Welford, Richard. 2016. *Corporate Environmental Management 3: Towards Sustainable Development*. Vol. 3. Taylor and Francis.

Zhang, Xiaocun, and Fenglai Wang. 2015. “Life-Cycle Assessment and Control Measures for Carbon Emissions of Typical Buildings in China.” *Building and Environment* 86:89–97. doi: 10.1016/J.BUILDENV.2015.01.003.

Appendices

Appendix A: Global CO_2 emissions by sector in 2019

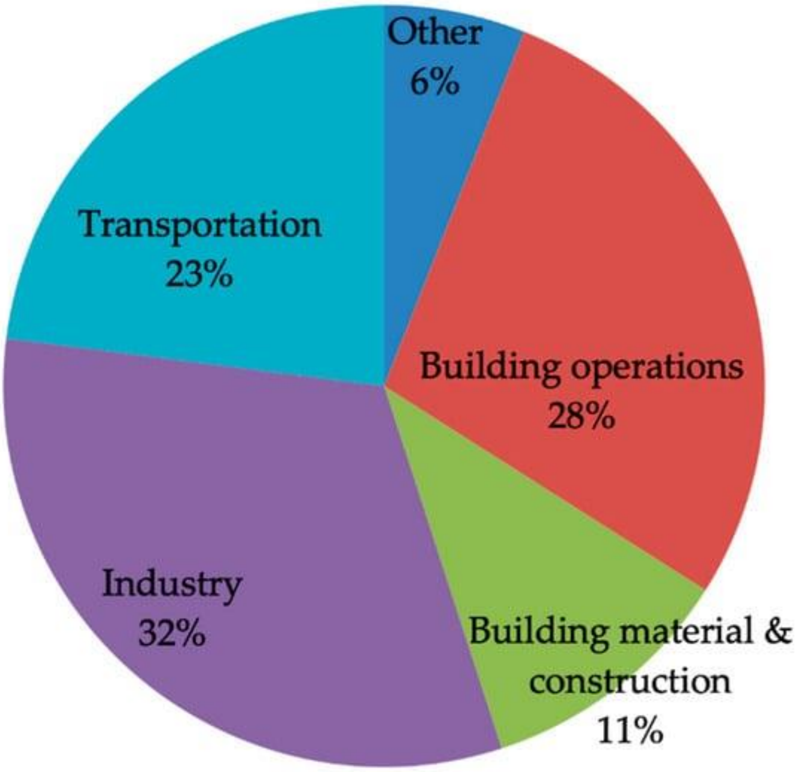


Figure 10: Global CO_2 emission by sectors (Source: Ali et al., 2020).

Appendix B: CO$_2$ emission by sector in the Netherlands

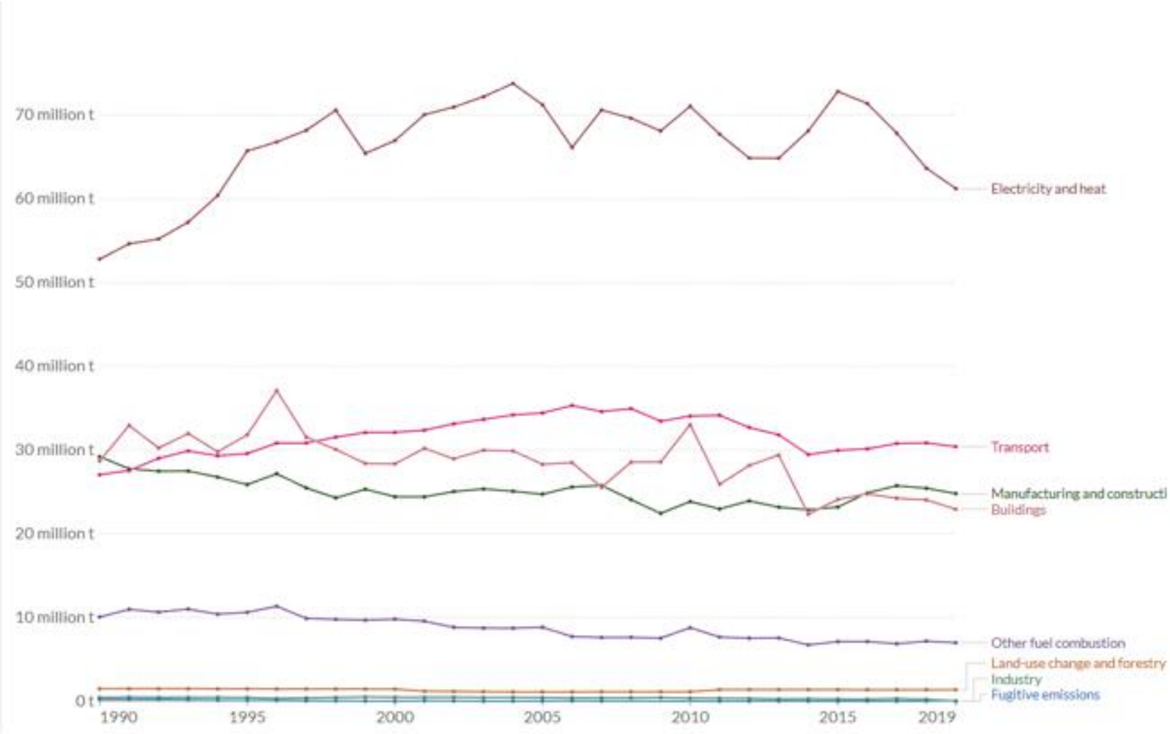
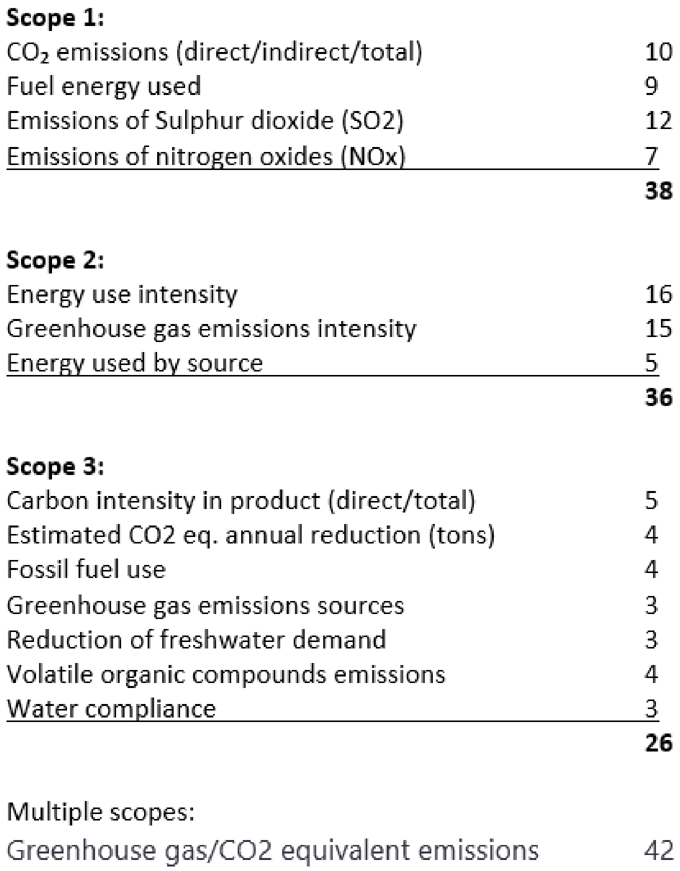


Figure 11: CO$_2$ emissions in tons by sector in the Netherlands (Source: Open world data, n.d.)

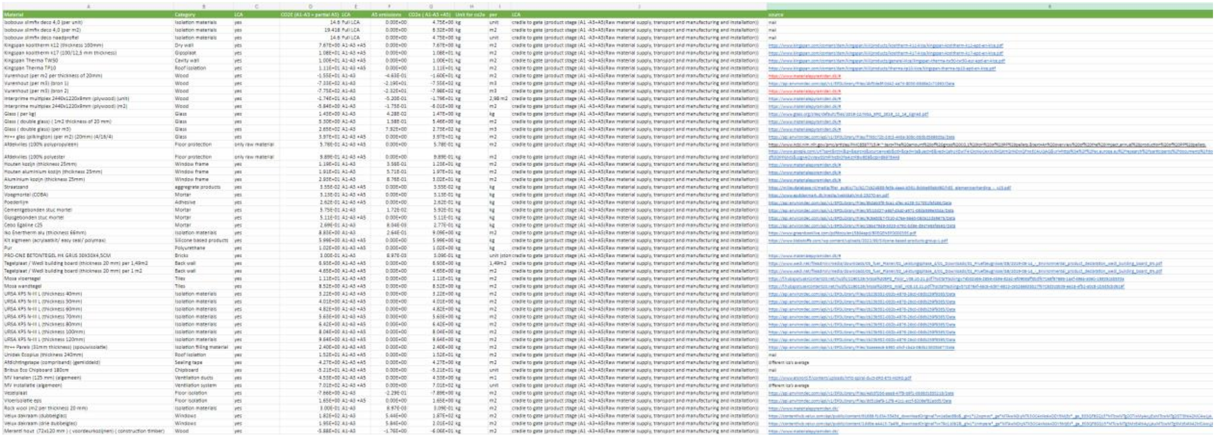
Appendix C: Most indicators mentioned in corporate sustainability reports



Scope 1:	
CO_2 emissions (direct/indirect/total)	10
Fuel energy used	9
Emissions of Sulphur dioxide (SO2)	12
Emissions of nitrogen oxides (NOx)	7
	38
Scope 2:	
Energy use intensity	16
Greenhouse gas emissions intensity	15
Energy used by source	5
	36
Scope 3:	
Carbon intensity in product (direct/total)	5
Estimated CO2 eq. annual reduction (tons)	4
Fossil fuel use	4
Greenhouse gas emissions sources	3
Reduction of freshwater demand	3
Volatile organic compounds emissions	4
Water compliance	3
	26
Multiple scopes:	
Greenhouse gas/CO2 equivalent emissions	42

Figure 12: An overview of the indicator for Scope 1, 2, and 3 and the times they have been reported on (Roca and Searcy 2012).

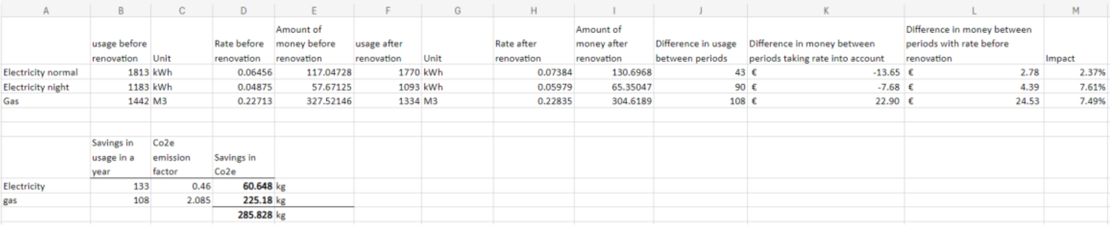
Appendix E: Materials list of the built tool



Material	Category	LCA	CO2E (A1-A3 + partial A5)	LCA	A5 emissions	CO2e (A1-A3 +A5)	Unit for co2e	per	LCA	source
Isobouw slimfix deco 4,0 (per unit)	Isolation materials	yes	14.6	Full LCA	0.00E+00	4.75E+00	kg	unit	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	mail
Isobouw slimfix deco 4,0 (per m2)	Isolation materials	yes	19.418	Full LCA	0.00E+00	6.32E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	mail
Isobouw slimfix deco naadprofiel	Isolation materials	yes	14.6	Full LCA	0.00E+00	4.75E+00	kg	unit	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	mail
Kingspan kooltherm k12 (thickness 100mm)	Dry wall	yes	7.67E+00	A1-A3 +A5	0.00E+00	7.67E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Kingspan kooltherm k17 (100/12,5 mm thickness)	Gipsplaat	yes	1.08E+01	A1-A3 +A5	0.00E+00	1.08E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Kingspan Therma TW50	Cavity wall	yes	1.00E+01	A1-A3 +A5	0.00E+00	1.00E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Kingspan Therma TP10	Roof isolation	yes	1.11E+01	A1-A3 +A5	0.00E+00	1.11E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Vurenhout (per m2 per thickness of 20mm)	Wood	yes	-1.55E+01	A1-A3	-4.63E-01	-1.60E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Vurenhout (per m3) (bron 1)	Wood	yes	-7.33E+02	A1-A3	-2.19E+01	-7.55E+02	kg	m3	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Vurenhout (per m3) (bron 2)	Wood	yes	-7.75E+02	A1-A3	-2.32E+01	-7.98E+02	kg	m3	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Interprime multiplex 2440x1220x8mm (plywood) (unit)	Wood	yes	-1.74E+01	A1-A3	-5.20E-01	-1.79E+01	kg	2,98 m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Interprime multiplex 2440x1220x8mm (plywood) (m2)	Wood	yes	-5.84E+00	A1-A3	-1.75E-01	-6.01E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Glass (per kg)	Glass	yes	1.43E+00	A1-A3	4.28E-02	1.47E+00	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Glass (double glass) (1m2 thickness of 20 mm)	Glass	yes	5.30E+00	A1-A3	1.58E-01	5.46E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Glass (double glass) (per m3)	Glass	yes	2.65E+02	A1-A3	7.92E+00	2.73E+02	kg	m3	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Hr++ glas (pilkington) (per m2) (20mm) (4/16/4)	Glass	yes	3.97E+01	A1-A3 +A5	0.00E+00	3.97E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Afdekvlies (100% polypropyleen)	Floor protection	only raw material	5.78E-01	A1-A3 +A5	0.00E+00	5.78E-01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Afdekvlies (100% polyester	Floor protection	only raw material	9.89E-01	A1-A3 +A5	0.00E+00	9.89E-01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Houten kozijn (thickness 25mm)	Window frame	yes	1.19E+01	A1-A3	3.56E-01	1.23E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Houten aluminium kozijn (thickness 25mm)	Window frame	yes	1.91E+01	A1-A3	5.71E-01	1.97E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Aluminium kozijn (thickness 25mm)	Window frame	yes	2.93E+01	A1-A3	8.76E-01	3.02E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Straatzand	aggregrate products	yes	3.55E-02	A1-A3 +A5	0.00E+00	3.55E-02	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Voegmortel (COBA)	Mortar	yes	3.13E-01	A1-A3 +A5	0.00E+00	3.13E-01	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Poederlijm	Adhesive	yes	2.62E-01	A1-A3 +A5	0.00E+00	2.62E-01	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Cementgebonden stuc mortel	Mortar	yes	5.75E-01	A1-A3	1.72E-02	5.92E-01	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Gipsgebonden stuc mortel	Mortar	yes	5.11E-01	A1-A3 +A5	0.00E+00	5.11E-01	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Cebo Egaline c25	Mortar	yes	2.69E-01	A1-A3	8.04E-03	2.77E-01	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Iso Enertherm alu (thickness 66mm)	Isolation materials	yes	8.83E+00	A1-A3	2.64E-01	9.09E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Kit algmeen (acrylaatkit/ easy seal/ polymax)	Silicone based products	yes	5.99E+00	A1-A3 +A5	0.00E+00	5.99E+00	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Pur	Polyurethane	yes	1.02E+00	A1-A3 +A5	0.00E+00	1.02E+00	kg	kg	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	
PRO-ONE BETONTEGEL HK GRIJS 30X30X4,5CM	Bricks	yes	3.00E-01	A1-A3	8.97E-03	3.09E-01	kg	unit (ston	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/#
Tegelplaat / Wedi building board (thickness 20 mm) per 1,49m2	Back wall	yes	6.93E+00	A1-A3 +A5	0.00E+00	6.93E+00	kg	1,49m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Tegelplaat / Wedi building board (thickness 20 mm) per 1 m2	Back wall	yes	4.65E+00	A1-A3 +A5	0.00E+00	4.65E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Mosa vloertegel	Tiles	yes	1.11E+01	A1-A3 +A5	0.00E+00	1.11E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Mosa wandtegel	Tiles	yes	8.52E+00	A1-A3 +A5	0.00E+00	8.52E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 40mm)	Isolation materials	yes	3.22E+00	A1-A3 +A5	0.00E+00	3.22E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 50mm)	Isolation materials	yes	4.01E+00	A1-A3 +A5	0.00E+00	4.01E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 60mm)	Isolation materials	yes	4.82E+00	A1-A3 +A5	0.00E+00	4.82E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 70mm)	Isolation materials	yes	5.63E+00	A1-A3 +A5	0.00E+00	5.63E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 80mm)	Isolation materials	yes	6.42E+00	A1-A3 +A5	0.00E+00	6.42E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 100mm)	Isolation materials	yes	8.04E+00	A1-A3 +A5	0.00E+00	8.04E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
URSA XPS N-III L (thickness 120mm)	Isolation materials	yes	9.64E+00	A1-A3 +A5	0.00E+00	9.64E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Hr++ Parels (31mm thickness) (spouwisolatie)	Isolation filling material	yes	2.40E+00	A1-A3 +A5	0.00E+00	2.40E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Unidek Ecoplus (thickness 240mm)	Roof isolation	yes	1.52E+01	A1-A3 +A5	0.00E+00	1.52E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	mail
Afdichtingstape (compriband) (gemiddeld)	Sealing tape	yes	4.27E+00	A1-A3 +A5	0.00E+00	4.27E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	different lca's average
Bribus Eco Chipboard 180cm	Chipboard	yes	-5.21E+01	A1-A3 +A5	0.00E+00	-5.21E+01	kg	unit	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	mail
MV kanalen (125 mm) (algemeen)	Ventilation ducts	yes	4.53E+00	A1-A3 +A5	0.00E+00	4.53E+00	kg	m1	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
MV installatie (algemeen)	Ventilation system	yes	7.01E+02	A1-A3 +A5	0.00E+00	7.01E+02	kg	unit	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	different lca's average
Vezelplaat	Floor isolation	yes	-7.66E+00	A1-A3	-2.29E-01	-7.89E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Vloerisolatie eps	Floor isolation	yes	1.65E+00	A1-A3 +A5	0.00E+00	1.65E+00	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Rock wool (m2 per thickness 20 mm)	Isolation materials	yes	3.00E-01	A1-A3	8.97E-03	3.09E-01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/
Velux dakraam (dubbelglas)	Windows	yes	1.82E+02	A1-A3	5.44E+00	1.87E+02	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Velux dakraam (drie dubbelglas)	Windows	yes	1.96E+02	A1-A3	5.84E+00	2.01E+02	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	[illegible]
Meranti hout (72x120 mm) (voordeurkozijnen) (construction timber)	Wood	yes	-5.88E+01	A1-A3	-1.76E+00	-6.06E+01	kg	m2	cradle to gate (product stage (A1 -A3+A5(Raw material supply, transport and manufacturing and installation))	https://www.materialepyramiden.dk/

Table 21: Materials list in the built tool

Appendix F: Residential data on the operational phase before and after the renovation



A	B	C	D	E	F	G	H	I	J	K	L	M
	usage before renovation	Unit	Rate before renovation	Amount of money before renovation	usage after renovation	Unit	Rate after renovation	Amount of money after renovation	Difference in usage between periods	Difference in money between periods taking rate into account	Difference in money between periods with rate before renovation	Impact
Electricity normal	1813	kWh	0.06456	117.04728	1770	kWh	0.07384	130.6968	43	€ -13.65	€ 2.78	2.37%
Electricity night	1183	kWh	0.04875	57.67125	1093	kWh	0.05979	65.35047	90	€ -7.68	€ 4.39	7.61%
Gas	1442	M3	0.22713	327.52146	1334	M3	0.22835	304.6189	108	€ 22.90	€ 24.53	7.49%

	Savings in usage in a year	Co2e emission factor	Savings in Co2e	
Electricity	133	0.46	**60.648**	kg
gas	108	2.085	**225.18**	kg
			285.828	kg

Table 22: Savings in CO₂e emissions for the project data with the lowest impact

Appendix G: Fluctuation of gas prices in the Netherlands

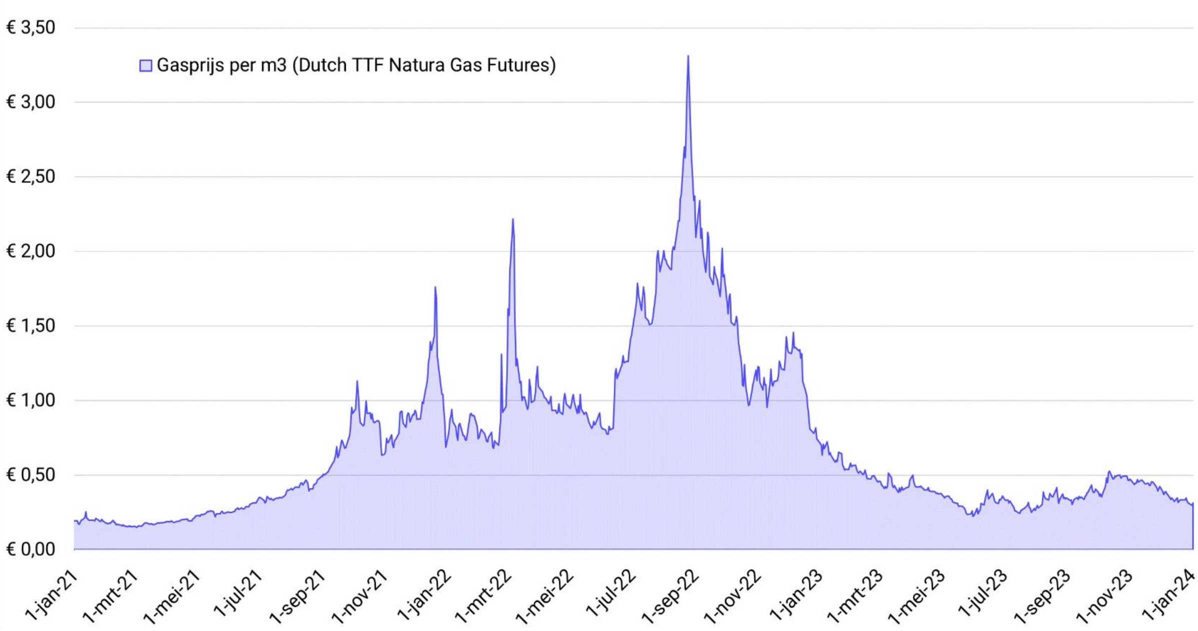


Figure 13: Fluctuation of gas prices through the years in the Netherlands in euros (Source: Energievergelijk, 2024)