Construction Process Climate Impacts under Denmark's 2025 Building Regulations

A Case-Based Sensitivity Analysis

Master's thesis in Industrial Ecology

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Cover: Photograph of construction site by Quang Nguyen Vinh.

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Abstract

This thesis investigates climate impacts from construction processes (modules A4 and A5) under Denmark’s 2025 Building Regulations and in accordance to EN 15978 using a detailed case study of a 14,000 m^2 residential development in a Copenhagen suburb. The thesis assesses reported climate impacts using the regulatory methodology and explores how both physical project parameters and methodological variation influence outcomes.
The baseline assessment shows that total A4 and A5 impacts exceed the regulatory threshold by 15 percent with construction waste alone accounting for 80 percent of total emissions. This dominance is not attributed to excessive waste generation but to the regulatory assessment method which applies the highest impact factor to entire mixed waste fractions.
Scenario-based sensitivity analyses reveal that while changes in geographic sourcing and material substitution have limited effects, methodological differences such as assessment approach and an updated waste assessment method can alter reported impacts by up to 1.4 kg CO_2e/m^2year equivalent to 94 percent of the regulatory threshold without altering physical parameters.
These findings highlight a misalignment between the threshold setting dataset and the regulatory assessment method raising concerns about the method’s accuracy in assessing actual climate performance. The thesis recommends that the method applied to construction waste and the calibration of threshold values be reconsidered to better reflect real world conditions. For practitioners it identifies practical strategies for increasing the accuracy of reported impacts and reducing both reported and actual emissions through procurement choices and improved waste handling on site.

Keywords: construction process, LCA, mitigation, regulatory compliance, scenario analysis, transport, construction waste, carbon, sensitivity, buildings.

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David Bro Falbe-Hansen, August 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AP	Acidification Potential
BR	Building Regulations
BR18	Danish Building Regulations
CH	Switzerland
CO2e	Carbon Dioxide equivalents
DK	Denmark
DE	Germany
EF	Emission Factor
EP	Eutrophication Potential
EPD	Environmental Product Declaration
EoL	End of Life
FR	France
FU	Functional Unit
GHG	Greenhouse Gas
GLEC	Global Logistics Emissions Council
GVW	Gross Vehicle Weight
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
IPCC	Intergovernmental Panel on Climate Change
kWh	kiloWatt-hours
L	Liter
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MDO	Marine Diesel Oil
NL	Netherlands
PL	Poland
PMF	Particulate Matter Formation
PVC	Polyvinylchlorid
qty	Quantity
ROPAX	Roll-on/roll-off Passenger
RQ	Reseach Question
RSL	Reference Service Life
TI	Danish Technological Institute
WTW	Well To Wheel
WG	Working Group

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1 Introduction

The global rise in atmospheric temperature, driven by greenhouse gas emissions from human activity, continues to accelerate despite international agreements such as the Paris Agreement[1]. The construction sector is a major contributor to this challenge, accounting for 37% of global GHG emissions and 34% of energy use in 2022[2]. In Denmark, the sector is estimated to account for 30% of national emissions and 35% of total waste[3].

Historically, most emissions from buildings have stemmed from operation. However, as operational efficiency improves, attention is shifting to embodied emissions, including those occurring during construction[4]. These emissions are fixed by the time construction is finished and cannot be mitigated later, making them a critical target for near-term reductions.

In response, in 2023 Denmark introduced an amendment to the building regulations mandating LCAs for all new buildings, and a threshold value of 12 kg CO_2e/m^2/year for the life cycle modules covering manufacturing (A1-A3), Use (B4 & B6), and EoL (C3-C4) [5]. As of July 1st, 2025 this threshold is reduced to a value of 7.1 kg CO_2e/m^2/year, and requirements are expanded to include the construction process, specifically the modules transport (A4), and on-site activities and waste (A5), with a separate threshold of 1.5 kg CO_2e/m^2/year[6]. The regulation is informed by the BUILD report *Ressourceforbrug på byggepladsen* [7], which also proposes assessment methods and standard datasets.

However, the amended regulation incorporates methodological changes and updated emission factors not reflected in the original dataset. Subsequently, key regulatory assumptions are based on evolving or limited data, raising questions about how real-world construction projects will perform under the new requirements and how assessment methodology affects reported climate impacts.

1.1 Aim & Research Questions

The primary aim of this thesis is to contribute to the reduction of climate impacts from building construction processes. The thesis examines how these impacts are assessed within the framework of Denmark's 2025 building regulations, and, through a scenario-based analysis, identifies opportunities for impact reductions both in terms of actual GHG emission mitigation and reported values. In doing so, the project aims to support informed decision-making among practitioners and strengthen the alignment between regulatory compliance and climate performance.

This aim is pursued by addressing the following research questions:

Question 1: *What is the climate impact associated with the construction processes of a new building when assessed using Denmark's 2025 regulatory method?*
Question 2: *How are climate impacts affected by key project-specific parameters?*
Question 3: *How are climate impacts affected by key methodological choices?*

2 Theory & Background

This section includes descriptions of the relevant theory behind methods used throughout the thesis and covers the research and regulatory context in which this thesis is located.

2.1 LCA in Building & construction

Life Cycle Assessment is a systematic method for quantifying the environmental impacts of a product, process, or system across all stages of its life cycle, from raw material extraction through production, use, and end-of-life treatment [8]. The approach is grounded in the concept of *life-cycle thinking*, which encourages consideration of environmental consequences beyond immediate or local effects by accounting for upstream and downstream processes across the value chain[9].

In the context of climate mitigation, LCA has become a central tool for identifying emission hotspots, comparing design alternatives, and informing decisions that reduce environmental impacts. Its primary strength lies in its comprehensive scope across the entire life cycle, which makes LCA particularly well-suited to evaluating trade-offs between different design or process options, where a focus on only one life cycle stage or impact category might lead to suboptimal outcomes[10].

Despite these strengths, LCA has notable limitations. Results are often sensitive to data availability and methodological choices such as system boundaries, allocation procedures, and impact assessment methods [11]. In practice, full data coverage is rarely achievable, and the reliance on generic data or assumptions can lead to considerable uncertainty. Moreover, LCA does not inherently prioritise which emissions are most critical to address, which requires the relative importance of impacts to be weighted[10].

Within the building and construction sector, climate mitigation attempts have historically been focused on reducing the energy consumption of thermal regulation through increasing building performance, however this approach includes only operational impacts. Buildings are long-lived, material-intensive systems, and their environmental footprint is distributed across several contributors[4]. LCA in building and construction ideally includes all phases including manufacturing (A1–A3), transport (A4), construction (A5), use (B), and end-of-life phases (C and D), as defined by the European standard EN 15978 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method [12].

2.1.1 LCA Methodology

The methodological foundation for life cycle assessment is defined by the international standards ISO 14040 and ISO 14044 [8], [13], which provide a general framework applicable to all products and systems. In the context of buildings, this framework is specified and operationalised through the European standard EN 15978 [12], which defines rules, system boundaries, and reporting requirements specific to the environmental assessment of buildings.

EN 15978 adopts a modular structure, dividing the building life cycle into stages and modules representing standardised groupings and contents of a product life cycle. The stages are:

- **Product stage (A1–A3):** Raw material extraction, transport, and manufacturing.

- **Construction stage (A4–A5):** Transport of products to the site and the construction process itself.
- **Use stage (B1–B7):** Operation, maintenance, repair, replacement, and energy use.
- **End-of-life stage (C1–C4):** Deconstruction, transport, waste processing, and disposal.
- **Beyond the system boundary (Module D):** Benefits or burdens from reuse, recycling, or energy recovery.

LCAs conducted using the EN 15978 structure are usually aligned with the principles of *attributional LCA* [14]. Attributional LCA models the actual material and energy flows associated with the assessed building as it is constructed and operated, based on project-specific data or representative averages. This approach is commonly applied in the building sector due to the complexity and volume of actors, products, material and energy flows which create challenges for defining consistent system boundaries for *consequential* LCA. *Consequential* LCA is change-oriented and prospective, and includes modelling which intends to capture system-wide effects, and requires higher data fidelity and quality, and modelling complexities that are impractical or unfeasible in many building assessment contexts [11].

The LCA process, as defined by ISO 14040/14044 is an iterative process consisting of four interconnected phases:

2.1.1.1 Goal and Scope Definition

This first phase is defined to unambiguously state the intended application, target audience, and reason for carrying out the study[13]. In doing so, it establishes the *system boundary*, which include natural systems, geographical, temporal and technical boundaries, and determines which life cycle processes and stages are included in the assessment, whether only product and construction stages are considered (cradle-to-gate), or if use and end-of-life stages are also covered(cradle-to-grave). This is essential for ensuring transparency and comparability between assessments.

Another key element is the *functional unit*, which provides a reference against which all inputs and outputs are normalised. For comparative studies, the functional unit provides the basis for comparison within the study. In Danish building LCA regulations, this is defined as 1 m^2 of net floor area over a 50-year reference study period [15]. This ensures that environmental impacts are reported relative to a standardised building function, allowing comparisons across different designs and scales.

Assumptions and methodological choices, such as data sources, cut-off criteria, allocation procedures, and the type of LCA (e.g., attributional), are also specified in this phase. These choices significantly influence the interpretation of the results and must be transparently documented. Relevant for this thesis is *Allocation*, in which life cycles elements of products in the assessment that have input or output flows are linked to other systems [10]. The ISO standard orders the preference of methods for cases that this applies to, where system expansion and increased modelling detail are preferred, but in cases where this is not an option, partitioning should be based on physical parameters [13].

2.1.1.2 Life Cycle Inventory Analysis

This phase involves the systematic collection and quantification of all relevant energy, material, and emission flows into and out of the system as defined in the goal and scope. In the building context, this includes inputs such as raw materials, fuels, electricity, and water, and outputs such as solid waste, wastewater, and air emissions [10].

For construction projects, data must be collected for each relevant life cycle stage, covering sources such as:

- Construction products and materials used (mass, composition, supplier, origin)
- Transport logistics (mode, distance, frequency)
- On-site energy consumption (electricity, heating, fuel)
- Waste generation, sorting, and disposal methods
- Operational energy and maintenance, if applicable

Data is often collected and quantified relative to the functional functional unit demand. Data quality is a defining part of assessment quality, and may include both project-specific measurements and sourcing from generic databases, depending on availability and the required level of detail.

2.1.1.3 Life Cycle Impact Assessment

In this phase, the inventory flows from the LCI are translated into potential environmental impacts using characterisation models. The emissions and resource use identified in the LCI phase are grouped into environmental impact categories, where each pollutant and substance crossing the system boundary is classified by the impacts it contributes to. The flows of pollutant and substance corresponding to an impacts category are then added up using equivalency factors correcting each impact contributing flow by magnitude to a common unit, thereby achieving an expression of the total contribution of flows with varying quantities and impact intensities [10].

In building LCAs, the most commonly applied category is *global warming potential* (GWP) using the IPCC GWP100 characterisation method, which aggregates greenhouse gas emissions into units of kg CO_2-equivalents [16]. Other categories may include acidification, eutrophication, ozone depletion, or resource depletion [10], but these are rarely required in regulatory contexts. These impact categories are referred to as *Midpoint impact categories*, as they can be further aggregated using a similar approach into *Endpoint impact categories*, that express the impacts on areas of protection [17].

The LCIA should be done in a way that quantifies the contributions to impact categories, across life-cycle phases, contributing processes and materials so that comparisons can be made to identify the most impactful part of the product, service or system life cycle.

2.1.1.4 Interpretation

The final phase involves analysing the results in the context of the initial goal and scope, identifying key contributors, and assessing the robustness of the results. This may include sensitivity analysis (evaluating how results change with key assumptions), uncertainty analysis (estimating data quality effects), and completeness checks.

Interpretation also includes formulating conclusions and, where relevant, recommendations for improvements in design, sourcing, or practices. It is an iterative step that can inform revisions to earlier phases if inconsistencies or critical limitations are identified.

Together, these four phases ensure that the LCA provides a transparent, structured, and scientifically grounded assessment of the climate and environmental impacts of buildings across their life cycle.

2.1.1.5 Sensitivity Analysis in LCA

Sensitivity analysis is commonly applied component of the interpretation phase of life cycle assessment, as defined in ISO 14044 [13]. It aims to test the robustness of LCA results by exploring how changes in model parameters, data quality, or methodological assumptions influence outcomes. Rather than attempting to produce a definitive result, sensitivity analysis supports transparency by revealing the influence of uncertainty and variability within the system under study.

A commonly used sensitivity analysis approach in building LCA is to investigate how changes in key parameters or modelling assumptions affect environmental outcomes, in a scenario-based sensitivity analysis. Rather than relying on probabilistic distributions or random values, this method involves the deliberate adjustment of one or more input variables to represent plausible alternative conditions [18]–[20]. The approach is particularly valuable in complex systems such as buildings, where many interrelated processes and data uncertainties exist.

This controlled variation allows for the identification of patterns without the need for extensive real-world datasets. It is typically used to explore ”what-if” questions, assess potential regulatory outcomes, or inform decision-making under data limitations. Studies such as Häfliger et al. [18] and Horvath et al. [19] have demonstrated the relevance of scenario-based approaches in capturing the sensitivity of LCA results to data quality and methodological framing in the building context.

In the context of regulatory LCAs, scenario analysis supports transparent, reproducible exploration of modelling choices and their implications for reported impacts. While not statistically generalisable, the approach isolates and communicates the effects of specific assumptions, contributing to more informed interpretation and policy development.

2.1.2 Standardised Approach and Use of EPDs in Building LCA

In building LCA, environmental product declarations (EPDs) provide a standardised, transparent method for quantifying the environmental impacts of construction materials. An EPD is a third-party verified summary of an underlying full LCA, structured according to norms such as EN 15804 and product category rules [21], [22]. EPDs provide essential metadata—such as functional units, calculation rules, and assumptions—that support comparability and compliance with standards.

The EPD framework ensures that building LCAs use consistent product-level data across projects. When performing a building LCA, the quantity of each material is typically multiplied by the corresponding EPD's emission factors, expressed by midpoint impact categories (e.g., global warming potential in kg CO_2-equivalents), to calculate life cycle stage impacts consistent with the structure defined in EN 15978 [12]. EPDs thus enable systematic and reproducible translation from product-level inputs to building-level emissions [21].

When product-specific EPDs are unavailable, practitioners may use technically equivalent or generic category-average EPDs, though these alternatives introduce greater uncertainty and reduce comparability across assessments. The standardisation of inputs via EPDs underpins robust building LCA practices and supports both regulatory compliance and performance benchmarking within the framework of EN 15978 and related European regulations.

The standardised EPD-based approach streamlines the assessment process by embedding parts of the LCI and LCIA into the product level. Environmental impacts are precalculated by the product manufacturer and expressed per unit of material that the LCA practitioner can then apply these factors directly to the quantities installed in a given building project. This improves efficiency and comparability across assessments and facilitates higher numbers of buildings being assessed. However, the approach introduces fixed methodological assumptions that limit flexibility and reduce transparency. These trade-offs reflect a balance between simplification and modelling precision.

2.1.3 Life Cycle Modules A4 and A5

The modular structure of building LCAs as defined in EN 15978 [12], which divides the building life cycle into distinct stages and modules for consistent and comparable assessment. These modules are grouped into four main stages shown in figure 2.1.

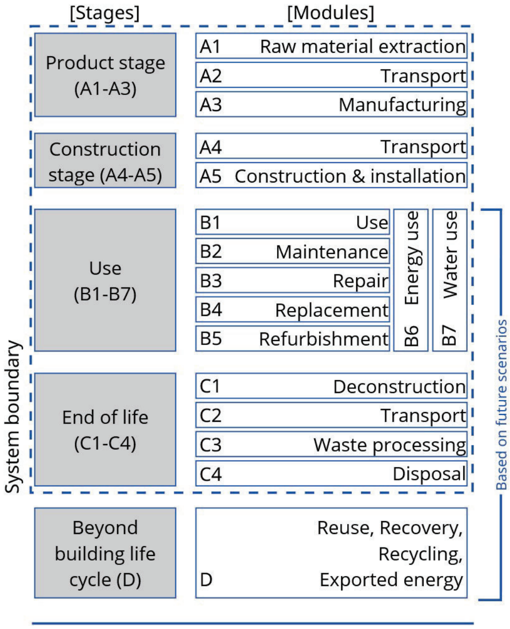

Figure 2.1: Life cycle stages of European Standard EN 15978[12].

Within this structure, Modules A4 and A5 reflect the climate impacts associated with the construction phase, with the following general inclusions defined in the standard [12]:

Module A4 – Transport to the Construction Site

This module accounts for emissions related to transporting materials and products, but not persons. The entire transport-chain should be accounted for including storage and distribution from the last production point. For machinery, transport from the site and back to the storage is included[12]. Key parameters include transport mode (e.g., truck, ship), distance travelled, fuel type, the weight of materials, load factor, and empty running[7]. In practice, Module A4 is often calculated by multiplying material-specific transport distances by emission factors derived from EPDs or datasets in accordance to the applied standard.

Module A5 – Construction and Installation Processes

Module A5 includes emissions from on-site activities, including earthworks and landscaping, installation of construction materials, storage of products, temporary construction related to the site, ready mix concrete curing, prefabrication of construction elements off-site, heating, cooling, ventilation, humidity control, water consumption, management of waste products during construction including transport to waste management, production of wasted materials, transport of wasted materials (production to site) and waste treatment of materials wasted during the installation process [12]. The last point notably implies, that the embedded impacts of wasted materials, including A1–A3 are accounted for in the A5 module. This is the case, as the general A1–A3 modules only account for the installed materials and products.

Focusing solely on selected parts of the life cycle is not generally recommended, but can be necessary in situations of limitations on time and research, where understanding of certain parts of the life cycle is valuable.

2.2 Status quo of construction process impact assessment

This section reviews the current body of research on climate impacts associated with construction processes (modules A4 and A5), beginning with literature from a Danish context, followed by relevant international studies. The topic is shown to be understudied, with relatively few sources providing detailed results for these modules.

2.2.1 Danish context

Most available Danish literature stems from research related to the 2025 Building Regulations, particularly by BUILD at Aalborg University. The primary contribution is the project “Ressourceforbrug på byggepladsen” (2021–2024)[7], which produced a comprehensive report and an article titled “Carbon Emissions during the Building Construction Phase: A Comprehensive Case Study of Construction Sites in Denmark” by Kanafani et al.[23]. These studies informed both the methodology and threshold values introduced in the 2025 regulatory update[6], as discussed in Section 2.4.

Kanafani et al. (2023)[23] identify nine studies assessing upfront carbon emissions, but only one includes Danish building cases. In this 2022 study by Röck et al.[24], approximately 13% of buildings analysed are located in Denmark, and are not represented separately. More recently, Hasselsteen and Kanafani (2024)[25] published a Danish case study reporting A4 + A5 impacts of 67 $\mathrm{kgCO_2e/m^2}$, or 1.3 $\mathrm{kgCO_2e/m^2}$year over a 50-year reference period. Of these, 54% stemmed from construction waste, 33% from transport, and 13% from fuel and energy. No further Danish studies were identified.

2.2.2 International literature

Expanding to an international scope provides more results, though detailed reporting of A4 and A5 remains limited. Kanafani et al. (2023)[23] review nine relevant studies, six of which report numerical values, some aggregating A4 and A5. Reported total A4 + A5 impacts range from 0.50–1.59 $kgCO_2e/m^2$year, with A4 between 0.05–0.72 and A5 between 0.45–1.43 $kgCO_2e/m^2$year. As most studies are based on a single case, variation within studies is not reflected [26]–[29].

The before-mentioned 2022 study by Röck et al.[24], based on 769 European buildings, reports a median A4 + A5 value of 0.8 $kgCO_2e/m^2$year. While percentiles are not specified, a box plot suggests first and third quartiles of roughly 0.5 and 1.4 $kgCO_2e/m^2$year. These values are approximate and based on visual interpretation.

No additional international studies were identified beyond those reviewed in Kanafani et al. (2023)[23].

2.3 Denmark's 2025 Building Regulation on Climate Impact

Denmark's 2025 Building Regulations introduce a mandatory climate performance threshold for all new buildings, including construction stage emissions (modules A4–A5) in the required Life Cycle Assessment. These regulations mark a significant tightening of national requirements and reflect broader political ambitions to address the climate impact of the built environment.

2.3.1 Political Context

In 2020, Denmark adopted a legally binding Climate Act targeting a 70% reduction in territorial GHG emissions by 2030 compared to 1990 levels. The following policy response includes the launch of the *National Strategy for Sustainable Construction*, which mandates LCA as a basis for climate performance assessment of new buildings [30].

The first stage of this strategy was implemented in 2023, requiring LCAs for all buildings, covering modules A1–A3 (product stage), B4 (replacement), B6 (operational energy), C3–C4 (end-of-life) and setting a climate impact threshold of 12 kg CO_2e/m^2year for buildings over 1000 m^2[5]. The 2025 amendment expands this requirement to nearly all new buildings, introduces building-type-specific thresholds (averaging 7.1 kg CO_2e/m^2year), and adds a separate threshold for construction process impacts (modules A4 and A5) of 1.5 kg CO_2e/m^2year [6]. These rules went into effect July 1st, 2025.

This newly introduced threshold is based on national-level data analysis by BUILD and published in the report ”Ressourceforbrug på byggepladsen” [7], which identified median values of 0.4 and 1.0 kg CO_2e/m^2year for A4 and A5 respectively. This data was drawn from 52 construction projects and used to establish the regulatory limit, adjusted to 1.5 kg CO_2e/m^2year.

2.3.2 Overview of regulatory A4 and A5 assessment methods

The regulatory method for assessing impacts from construction processes (modules A4 and A5) is based on the methodology developed in the *Ressourceforbrug på byggepladsen* report by BUILD and formalized in the 2025 amendment to BR18. It prescribes permitted data sources, calculation principles, and emission factors for each process category outlined below.

Calculation Method

Calculations must follow the EN 15978 standard, which defines a modular structure for building LCA, as described in Section 2.1.1. Module A4 emissions from material transport are calculated using standard emission factors (kg CO_2e/kg) defined for 35 material groups. These factors, developed by BUILD, are based on assumed average transport modes, distances, and emission intensities. Emissions are derived by multiplying the installed quantity of each material by its respective factor (found in Appendix A, Table A.1).

A5 emissions from construction waste are similarly calculated using standard emission factors for 15 waste categories (found in Appendix A, Table A.2). These emission factors are based on A1-A3, C3-C4 and D values from the dataset "Danish Generic LCA-data", which provides approved data to be used for LCA in regulatory contexts, and is found in the Building Regulations appendix 2 table 7[7]. The data-set was developed based on an "accurate, conservative approach" by analysing EN 15804 compliant EPDs of commonly used products within the Danish context [31].

For mixed waste fractions, the regulations dictate that the highest impact factor among the constituent materials is applied to the entire waste fraction. Emissions are calculated by multiplying the estimated waste quantity by the corresponding emission factor.

Energy-related emissions (from fuel, electricity, and heating) are quantified using consumption during the construction process and standard emission factors provided in the regulation.

In both A4 and A5, alternative calculation may be based on valid and relevant EPDs that comply with EN 15804 and are applicable to the specific material or product. EPDs may be project-specific, product-specific, or representative of average products within a category.

Additional A4–A5 processes—such as transport of machinery, transport of waste and logistics hub activities are assigned the fixed emission values: 0.02 kg CO_2e/m^2year for each category, and removal of soil and removal of construction waste: 0.06 kg CO_2e/m^2year. Alternatively, these may be assessed based on documented energy or fuel use.

All emissions are aggregated and normalised to the unit of kg CO_2e/m^2year over a reference period of 50 years and may not exceed 1.5 kg CO_2e/m^2year.

2.4 The BUILD Report: Empirical and Methodological Basis

This section outlines the central findings and methodology of the background report *Ressourceforbrug på byggepladsen* (BUILD Report 2023:14), which forms a core empirical and methodological foundation for the amended Danish building regulations. The report was commissioned by the Danish Social and Housing Authority and conducted by BUILD at Aalborg University during the period 2021–2024 [7].

2.4.1 Scope of the BUILD Report

The BUILD report aimed to develop standardised emission factors and documentation practices for the construction stage of new buildings in alignment with EN 15978. The objective was to create a data-driven basis for regulatory implementation by mapping current practices and estimating climate impacts through a combination of field data and modelling. This was achieved through a case-based approach, incorporating detailed data from 52 Danish construction sites, as well as nine additional used to test standard values. The report also contextualised these findings with international regulatory developments and methodologies.

2.4.2 Methods and Results

The analysis of A4 focused on transport of construction materials, including the development of standard emission factors for 35 product groups. These factors were based on EPDs, industry data, and representative transport routes and distances. When applied across the selected projects, the resulting median A4 impact was shown to be 0.4 $\text{kgCO}_2\text{e/m}^2$year.

A5 emissions were assessed through empirical data collection from 52 projects, covering on-site electricity and heating use, fuel consumption, and construction waste generation. Construction waste was assessed using a dataset of emission value for relevant waste fractions, which were developed as part of the objectives of the study. Notably the study employed a weighted average based on estimated composition shown in Appendix B, Table B.12 to assess climate impacts of mixed waste fractions.

The study accounted for projected energy mix changes towards 2025, by applying the the energy projection method from the 2023 building regulations [5]. The median climate impact of module A5 was estimated at 1.0 $\text{kgCO}_2\text{e/m}^2$year. Waste was found to be the dominant contributor, representing more than half of the total A5 impact. When combined, A4 and A5 contribute an estimated 1.4 $\text{kgCO}_2\text{e/m}^2$year—equivalent to 17% of the total lifecycle emissions limit of a typical new building under Danish conditions, based on the average threshold value of 7.1 $\text{kgCO}_2\text{e/m}^2$year for modules A1–A3, B4, B6, and C3–C4.

The report also proposed the fixed standard values to facilitate reporting for processes where specific data are difficult to obtain, including transport of machinery, transport of waste, logistics hub activities, removal of soil and removal of construction waste.

3 Methodology

This section describes the methods used to assess climate impacts from construction processes, using a real-world building as the analytical platform for exploring implications, challenges, and compliance under the 2025 Danish Building Regulations.

3.1 Outline

As shown in Section 2.2, climate impact of construction site processes remains an underdeveloped research area. The aims of the thesis are therefore intentionally broad, seeking to capture a comprehensive picture of the challenges and implications involved. All research questions and deliverables are ultimately grounded in applying the Life Cycle Assessment (LCA) method to assess A4 and A5 climate impacts within the Danish regulatory context.

Figure 3.1 illustrates the overall study design, which consists of a foundational analysis followed by a focused analysis. The foundational analysis assesses A4 and A5 climate impacts for the case study using the 2025 building regulations methodology. A project-specific approach is applied wherever possible, in a way that is representative of how such assessments would be performed in a regulatory setting. This part of the analysis answers Research Question 1 and is informed by two main categories of data: emissions and impact data, and case records of the physical and contextual parameters and characteristics.

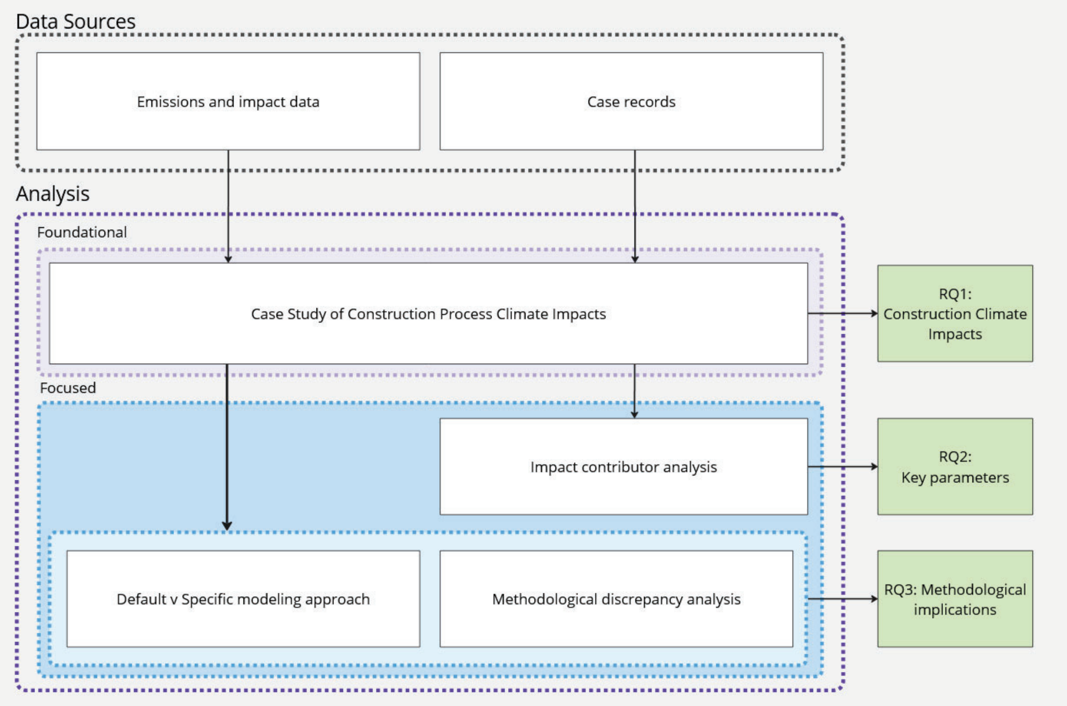

Figure 3.1: Flowchart of study design and analytical approach

The focused analysis builds on these baseline results, using them as a reference point for targeted explorations. First, a key impact contributor analysis identifies the main sources of climate impact, highlighting opportunities for actual reductions in future construction projects (Research Question 2). Second, a methodological sensitivity analysis investigates the implications of varying assessment approaches and assumptions, including a comparison between default and project-specific methods and an examination of discrepancies between the regulatory approach and the method used in the BUILD background study that informed the threshold (Research Question 3).

The distinguishment between Research Question 2 and Research Question 3 is essential for this thesis. Where the Key impact contributor analysis aimed at answering RQ 2 focuses on identifying opportunity for climate impact mitigation, by identifying emission hot spots, and testing opportunities for optimizing and improving the physical parameters that cause emissions of GHGs, the methodological sensitivity analysis aims exclusively at examining the boundaries and implications of the methodology required by the regulations, and aimed at answering RQ 3.

3.2 Baseline Case description

The construction project included in the case study forms part of the larger Nærheden urban development, which is an ongoing transformation of a former greenfield area in Hedehusene, west of Copenhagen, into a new neighbourhood. The examined subproject, referred to as *Hedehusene* throughout this report, consists of 123 apartments and 9 townhouses, totalling approximately 14,000 m^2 of gross floor area. The buildings are constructed using prefabricated concrete elements, a method that dominates the Danish multi-storey residential sector due to its cost efficiency, rapid assembly, and established supply chains. The design, size, and construction approach are therefore broadly representative of new-build multi-storey housing projects across Denmark[32], and the results can be expected to have wider relevance for similar developments. As the site was previously undeveloped, the construction processes and logistics reflect the conditions of building in an entirely new urban district rather than in a constrained infill setting.

The project holds the sustainability focused DGNB certification [33], which facilitated comprehensive data availability. For certification purposes, detailed documentation of material use and a high proportion of products with EPDs were collected and archived, making a retrospective life cycle assessment possible in this case. Such data completeness is atypical for projects without certification. While DGNB certification might be assumed to result in lower environmental impacts, evidence from the Sweco LCA database indicates that certified projects do not generally exhibit lower life cycle impacts for phases A1–A3, B4, B6, and C3–C4 [34]. This implies, that the impacts found in the assessment may not be influenced by the certification. However, the influence of DGNB certification on construction site impacts remains unexamined in existing literature.

Given these characteristics, the project provides both a realistic and sufficiently documented platform for exploring the methodological and practical sensitivities of A4 and A5. Its representativeness within Danish multi-storey construction ensures that findings can inform both case-specific conclusions and broader regulatory or methodological considerations.

(a) Aereal view **(b)** Building rendering

Figure 3.2: Images of Nærheden

3.2.1 Goal & scope definition

As described in theory section 2.1.1, this is a mandatory step of the LCA methodology as per the ISO standards 14040 and 14044 [8], [13]. As much of the study's background and objectives have already been outlined in preceding sections, the description provided here is deliberately concise and focused on the essential elements required by the standard.

Goal of the study

The intended application of this study is to assess climate impacts from construction process–related activities for a multi-storey residential building in Denmark, and to explore the methodological and practical sensitivities within the 2025 Danish Building Regulations framework for the A4 and A5 modules. It aims to identify challenges, implications, and compliance characteristics of the regulatory methodological approach, as well as potential opportunities for impact mitigation. The intended audience includes industry practitioners involved in building design and construction, LCA practitioners, policy makers, and academic researchers.

As shown in the BUILD report[7], A4 and A5 impacts can vary substantially between projects. Since this thesis examines only a single project, the results are not intended for direct comparison of regulatory compliance or absolute impact values. While the analysis investigates the specific case in detail, it also evaluates the regulatory methodology itself, with the aim of illustrating broader trends and implications rather than providing direct representativeness.

Scope of the study

This study applies a process-based, attributional life cycle assessment in accordance with ISO 14040 and ISO 14044, focusing on life cycle modules A4 and A5 as defined in EN 15978[8], [12], [13]. The primary modelling approach follows the methodological requirements of the Danish Building Regulations 2025, using project-specific data where available and regulatory default values where required. The study is based on a single real-world case and supplemented with scenario-based sensitivity analyses to explore the effects of varying methodological choices and physical parameter assumptions. The scope is defined by the following:

Functional unit: m^2 × Year, with climate impacts expressed in kg CO_2e per m^2 per year over the 50-year reference study period, in accordance with the Danish Building

Regulations functional unit definition.

System boundaries: The assessment is limited to life cycle modules A4 (transport to the construction site) and A5 (construction and installation processes) as defined in EN 15978. All other life cycle modules are excluded, except for wasted materials where A1–A3, C3, C4, and D impacts are allocated to A5 in accordance with the regulatory method and standards. All impact sources included in the assessment are shown in Figure 3.3

Geographical boundary: Denmark, with the case project located in a suburban development near Copenhagen.

Temporal boundary: Data is based on a retrospective assessment of a construction project completed in 2025, using the year of construction as the temporal reference.

Impact categories: Climate change, expressed in kg CO_2e, characterized using the IPCC GWP100 charactization approach as defined in IPCC Ar6 chapter 7 (2021)[16]. This is the same impact category applied by the BUILD study [7] and required by the building regulations [15].

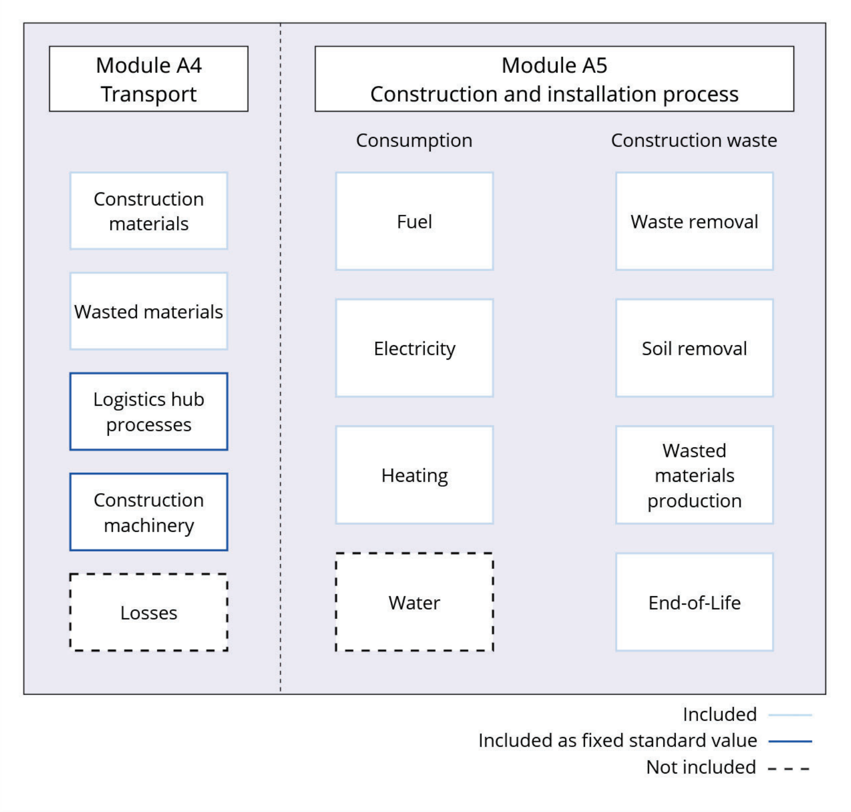

Figure 3.3: Applied system boundaries

Data quality requirements

In accordance with ISO 14040/14044, the study applies data quality requirements to ensure that all input data are relevant, reliable, and accessible.

Relevance is addressed by prioritising recent, geographically appropriate, and product-specific datasets. All EPDs used in the study must be valid at the time of assessment, third-party verified, and compliant with relevant standards. Danish EPDs are preferred where available, with international EPDs applied when necessary. For transport climate impact, the most recent GLEC framework dataset (2024)[35] providing Well to Wheel (WTW) emission factors in the unit [g CO_2e/t-km] is used, whenever not available through EPDs. The most commonly applied GLEC emission factor is for road transport with >20 t GVW at a value of 115 g CO_2e/t-km (WTW).

Completeness and representativeness are ensured by modelling the full quantity of materials specifically for the case whenever possible. The target is to achieve more than 95% coverage of impacts from project-specific data, with the remainder assessed using regulatory default data. All EPDs are product and project specific to the installed materials are linked in Appendix B Table B.2. All significant processes within the A4 and A5 system boundaries are included, with no exclusions beyond those permitted under the building regulations.

Data is managed and assessed in Excel spreadsheets [36] using the calculation approaches defined in section 3.3.2. Raw data, sources, and intermediate results are shown in Appendix B, Table B.2.

Reliability is maintained through the use of measured or metered consumption data where possible, supported by documented allocation procedures for shared resources. Waste fraction composition is assumed only for mixed fractions where plastic content is expected, in accordance with regulatory requirements.

3.3 Baseline LCI & LCIA

In this study, the classic separation of Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) as defined in section 2.1.1 is not possible, as emission-specific mass flows (e.g., kg CO_2, CH_4, etc.) cannot be modelled from the available data. Instead, the inventory and impact assessment are inherently linked, where all sources are quantified directly in terms of aggregated climate change emission factors expressed in CO_2e, rather than emission factors for individual substances. When using emission factors for e.g. construction waste (see Section 3.3.2.7), impact category contributors can not be disaggregated into emissions of substances as the composition of contributing emissions is not reflected by the factor.

As per Section 2.1.2, this approach reflects standard practice in building LCAs, where data from EPDs, literature, or regulatory default values already incorporate characterization of GHGs according to the GWP100 method of the IPCC, as required by EN 15978. As a result, the ISO/EN characterization step is applied implicitly and no separate LCIA modelling has been carried out in this thesis.

While not all aggregated emission factors are sourced from EPDs, the same principle is applied uniformly to all impact sources, including materials, transport processes, fuel and electricity use, and waste treatment. This method limits the flexibility to apply alternative characterization models, but it reduces complexity and aligns with the methodological framework of the Danish Building Regulations.

To ensure transparency, key physical parameters (e.g., fuel and electricity consumption, transport distances, waste amounts) are presented alongside the aggregated climate impacts. This supports interpretation of results despite the absence of a disaggregated emission flow inventory.

3.3.1 Data overview

Table 3.1 shows a summary of data sources applied in the case analysis of both impact type, and physical parameter type. A detailed description of each impact source is found in the following Section 3.3.2.

Table 3.1: Data overview of specific approach

	Impact Source	**Data required**	**Data source**
A4	Transport of materials	Producer locations	EPDs and inquiries
		Transport modes	EPDs and inquiries
		Impact data	EPDs, GLEC framework[35], BR18 Appendix 2, table 10[37]
		Transport distances and route	Google maps mapping[38] and inquiries
	Transport of waste	Waste quantity	Waste transporter invoices
		Transport modes	EPDs and inquiries
		Impact data	EPDs, GLEC framework[35], BR18 Appendix 2, table 10[37]
		Transport distances and route	Google maps mapping[38] and inquiries
	Transport of machinery	Impact data	Fixed standard value in BR18 Appendix 2, table 10[37]
	Logistics hub processes	Impact data	Fixed standard value in BR18 Appendix 2, table 10[37]
A5	Electricity	Consumption	Construction site metering
		emission factor	BR18 Appendix 2, table 8.1[37]
	Heating	Consumption	Utility company invoices
		emission factor	BR18 Appendix 2, table 8.1[37]
	Fuel	Consumption	Construction site diesel tank metering
		emission factor	BR18 Appendix 2, table 8.2[37]
	Construction waste	Waste quantity	Waste transporter invoices
		Waste fractions	Waste transporter invoices
		Waste fraction impact data	BR18 Appendix 2, table 11[37]
	Removal of waste	Waste reciever location	Waste transporter invoices
		Waste quantity	Waste transporter invoices
		Transport distances and route	Google maps[38]
		Transport emission factor	GLEC framework[35]

3.3.2 Project specific assessment approach

This thesis distinguishes between a ”specific” and ”default” assessment approach, where the specific approach refers to project specific, detailed assessments of an impact source, and the default refers to the approach applying the default impact values to a given source. The default approach is detailed further in the following section 3.3.4.

As defined in theory section 2.3.2, the regulations allow for use of both approaches. In the case study, a specific approach is applied whenever data quality allows for it. This section goes through the methods used for assessing A4 and A5 climate impacts with the specific approach. A summary of the comparison of specific and default methods as applied in this thesis is given in Table 3.2, with detailed descriptions in the following subsections. All default emission factors not stated in Table 3.2 are defined in Appendix A.

Table 3.2: Comparison of specific and default assessment methods across A4 and A5 impact sources. Using data as described in Table 3.1.

	Impact source	**Specific approach**	**Default approach**
A4	Transport of materials	Material weight × specific transport distance from production location to site × EPD or GLEC emission factor. Done for each material and each transport link.	Material weight × regulation emission factor. Done for each material.
	Transport of waste	Total specific material transport impact × waste percentage.	Fixed regulation standard factor of 0.02.
	Transport of machinery	Fixed regulation standard factor of 0.02.	Fixed regulation standard factor of 0.02.
	Logistics hub processes	Fixed regulation standard factor of 0.02.	Fixed regulation standard factor of 0.02.
A5	Electricity	Total consumption × regulation emission factor.	Total consumption × regulation emission factor.
	Heating	Total consumption × regulation emission factor.	Total consumption × regulation emission factor.
	Fuel	Total consumption × regulation emission factor.	Total consumption × regulation emission factor.
	Construction waste	Waste fraction from transporter × regulation emission factor for given fraction. Done for all fractions.	Waste fraction from transporter × regulation emission factor for given fraction. Done for all fractions.
	Removal of soil	Quantity of soil removed during site preparations × distance × GLEC emission factor. Quantity is 0 for given case.	Fixed regulation standard factor of 0.06.
	Removal of waste	Total waste quantity × mean transport distance × GLEC emission factor (195 g CO_2e/tkm).	Fixed regulation standard factor of 0.06.

A full overview of the results of the physical parameters is provided in Appendix B.1 Table B.1.

3.3.2.1 Sources not specifically assessed (A4)

The impact sources within the defined scope that were assessed solely using the Danish Building Regulations' fixed standard values are transport of machinery and logistics hub processes. The construction site for this project is part of a larger development in a previously undeveloped area, with several concurrent projects, many by the same developer. For transport of machinery, as machines were shared across projects during the construction period, determining the extent of use attributable to the case study was not feasible, which meant applying the fixed standard value was necessary. For logistics hub processes, only two material transports were identified as involving such facilities: photovoltaic modules imported from Singapore by container ship, with one hub process at each harbour, and vapour barrier temporarily stored at an intermediate location before final delivery to the construction site. This limited occurrence may reflect the scale of the project, as high material quantities are more likely to be delivered directly to site rather than stored, a pattern more typical for smaller projects. Alternatively, it may indicate a data gap where such processes were not recorded.

In both cases, the reliance on standard values is a result of insufficient project-specific data, and the associated impacts are likely to be of lower representativeness compared to other sources assessed with primary data. These sources are accounted for with the emission factor of 0.02 $\text{kgCO}_2\text{e/m}^2$year each.

3.3.2.2 Transport of construction materials (A4)

Transport of construction materials to the site was assessed using project-specific data for 99% of the material mass, corresponding to 96% of the associated climate impacts. For the remaining 1% by mass, where project-specific data was unavailable, the standard values prescribed in the Danish Building Regulations were applied.

Producer locations were identified from product-specific EPDs or obtained directly from suppliers. Transport distances were calculated using Google Maps to reflect the most probable route. In cases of uncertainty with several plausible routes, the specific route was verified through producer inquiries. For sea transport, including ROPAX ferries, information on vessel type, route distance, and operator was sourced from the shipping company's website. This enabled application of mode-specific emission factors following the GLEC framework[35] or EPD-provided values.

The total climate impact from construction material transport was calculated as:

$$\text{Impact}_{\text{Material transport}} = \sum_{i=1}^{n} m_i \cdot d_i \cdot \text{EF}_i$$

where:

- m_i = mass of material i [t]
- d_i = one-way transport distance for material i [km]
- EF_i = emission factor for the transport mode used [$\text{kgCO}_2\text{e/t} \cdot \text{km}$]
- n = total number of material transport links

With some materials having multiple transport links (e.g., factory to port, port to port, port to site) Impact intensities for EPDs of each material were prioritised. If EPDs did not declare module A4 or provides impact intensities in a non-transparent form, intensities of the GLEC-framework are applied.

No explicit allocation between partial truckloads was performed, as all emission factors already incorporate typical load factors for the transport mode and vehicle type. Return trips were not considered, in accordance with the GLEC methodology and regulatory practice, where return trips are included in the assumed load factor of a given vehicle[35]. Full overview of specific construction material transport is given in Appendix B Table B.2.

3.3.2.3 Transport of waste A4

Transport of waste refers to the transport of construction materials and packaging from producer location to the construction site that ultimately becomes waste on site. It is assumed that these materials share the same mean transport distances and transport links as the installed construction materials, since they originate from the same producers and supply chains. Consequently, waste transport impacts are quantified as a proportional share of the total construction material transport impacts, rather than by applying a standard transport vehicle and corresponding default emission factor. This approach ensures that the waste transport assessment is specific to the actual transport routes and modes used for the project.

As the waste at this stage has not yet been separated into fractions, no differentiation is made between material types. The composition is implicitly assumed to reflect that of the transported construction materials. Downstream removal from site is assessed separately under *Removal of waste* in A5.

The total climate impact from waste transport is calculated as:

$$\text{Impact}_{\text{waste transport}} = \text{Impact}_{\text{material transport}} \times \frac{Q_{\text{waste}}}{Q_{\text{installed materials}}}$$

where:

- $\text{Impact}_{\text{material transport}}$ = total climate impact from transport of installed construction materials [kg CO_2e]
- Q_{waste} = total waste quantity generated on site [kg]
- $Q_{\text{installed}}$ = total installed material quantity [kg]

Total material and waste quantities can be found in Appendix B, Table B.1. This method assumes an even distribution of waste generation across all transported materials. In actuality, waste generation rates vary between material types and packaging intensity, with some materials—such as made-to-order concrete elements—likely having minimal waste, while others, such as floorboards and gypsum plasterboards, have unavoidable cuttings. For the present project, this distribution could not be verified, as data collection was retrospective. Ideally, waste transport impacts would be determined by collecting data on the transported quantities of each construction material (including packaging) and comparing these to installed quantities, thereby identifying actual waste volumes per material. In addition, some excess materials from the project were utilised at neighbouring sites, which would require allocation to account for accurately. Data for such allocation was not available for this case.

3.3.2.4 Electricity (A5)

Electricity consumption during the construction process is quantified in a straightforward manner, identical in both the specific and default assessment approaches. Consumption data was recorded monthly by the site electricians and sourced from a total of 12 project-specific meters: two meters for the apartment buildings (the original meter was replaced during the project for unknown reasons), one meter for each of the nine townhouses, one meter for the mixing area, and one shared meter serving the worker site facilities which required allocation. This approach covers all electricity consumption during A5, as no outside electricity consumption occurred.

The total climate impact from electricity use is calculated by multiplying the documented consumption by the regulatory emission factor for electricity (0.0801 kgCO_2e/kWh), as defined in the Danish Building Regulations Appendix 2, Table 8.1 [37]. The electricity consumption can be found in Appendix B Table B.1 under ”Construction site energy use (A5)”. Actual climate impacts of electricity consumption fluctuate depending on temporal variations in the energy mix of the supply grid. However, in line with the regulatory method, this assessment applies a static emission factor, ensuring methodological consistency and simplicity.

Allocation of the shared meter consumption is described separately in Section 3.3.3.

3.3.2.5 Heating (A5)

Heating during the construction process consisted exclusively of district heating. Consumption data was sourced from utility company invoices covering the full construction period.

The total climate impact from heating is calculated by multiplying the documented consumption by the regulatory emission factor for district heating (0.0418 kgCO_2e/kWh), as defined in the Danish Building Regulations Appendix 2, Table 8.1 [37]. The district heating consumption can be found in Appendix B Table B.1 under ”Construction site energy use (A5)”. No allocation is required for heating.

As with electricity, actual impacts depend on temporal variations in the energy mix of the supply grid, although to a lesser extend [39]. In line with the regulatory method, this assessment applies a static emission factor, ensuring methodological consistency and simplicity.

3.3.2.6 Fuel (A5)

Fuel consumption was predominantly monitored via the construction site’s central fuel tank, supplemented by a smaller quantity supplied by a subcontractor operating their own separate fuel tank. No other consumption is suspected. All fuel used consisted of diesel. Climate impacts are quantified by applying the regulatory emission factor for diesel, found in Appendix 2, Table 8.1 of the building regulations [37], of 3.44 kgCO_2e per litre, directly to the recorded consumption volumes, as defined in Appendix B Table B.1 under ”Construction site energy use (A5)”.

Allocation of fuel use from the site tank between this project and other concurrent projects within the development is required and is described in Section 3.3.3. This allocation is necessary due to shared fuel resources across multiple sites during the construction period.

3.3.2.7 Construction waste (A5)

Construction waste impacts are quantified using the regulatory standard values for each waste fraction, as a fully specific assessment is not possible in a retrospective process due to the high level of monitoring required during construction. Waste quantities and fraction types are sourced from the project’s waste transporter. In accordance with the Danish Building Regulations, construction waste impacts in A5 include:

- A1–A3 impacts for the wasted materials, as the A1–A3 assessment of the remaining mandatory LCA only covers installed materials.

- C3–C4 impacts, as the treatment of waste generated during construction is allocated to A5.

- D benefits, as the materials in the waste are reused/recovered/recycled within a short time scope.

Unlike waste transportation, the composition of construction waste is accounted for as the waste fractions recorded on site. Waste impacts are not accounted for via product-specific EPDs. This is due to several factors:

1. Waste impacts are more sensitive to material composition since they include A1–A3 modules. As waste composition does not directly reflect construction material composition, a composition based on the mean construction materials is not as representative of the actual impacts.

2. Regulations require that mixed fractions are assessed using the highest emission factor of any material present in the fraction, which overrides potentially lower EPD-specific impacts.

3. A fully specific assessment requires detailed, continuous data collection that is not available retroactively.

4. Given these challenges, fully specific construction waste assessments are expected to be rare under the regulatory framework. As this assessment aims to reflect a standard A4/A5 regulatory-compliant approach, a semi-specific method is applied.

This semi-specific approach applies the standard regulatory emission factors for each waste fraction described in Section 2.3.2. These emission factors are based on the broader dataset of ”Danish Generic LCA-data” in Appendix 2, Table 7 of the building regulations [15], which are based on EPDs relevant in the Danish context. It should be noted, that these EPDs, while compliant with EN 15804 are assumed to include varying methods for projecting EoL impacts, and reflects a simplification of actual waste related impacts and possible benefits. The trade-off’s of aggregating and simplifying emission data is discussed in Section 2.1.2.

14 different waste fractions were reported by the transporter, with eight of these being single material fractions, two being semi-mixed fractions, and 4 being mixed fractions. For single-material fractions, the most appropriate regulatory factor is applied directly. Semi-mixed, defined as mixed fractions composed of only a few materials with similar emission factors, included Rubble and mixed clay/concrete and are assessed using the unglazed clay tiles/bricks factor. The four mixed fractions are; combustible waste, mixed construction waste, landfill waste, and Hard-to-recycle waste are assumed to contain some amounts of plastic from packaging and other materials, and as per regulations, the highest emission factor (plastic) is applied to the entire quantities of these fractions.

A full mapping of waste transporter fractions to regulatory emission factors is provided in Appendix B including waste quantities for each fraction.

The total climate impact from construction waste is calculated as:

$$I_{\text{waste}} = \sum_{i=1}^{n} Q_i \times EF_i \tag{1}$$

where:

- Q_i = Quantity of waste fraction i [t]
- EF_i = Regulatory emission factor for waste fraction i [kg CO_2e/t]
- n = Number of waste fractions

3.3.2.8 Removal of soil (A5)

This refers to the transport of soil excavated during site preparations to the waste receiver. This project had no removal of soil, as all excavated soil was repurposed on neighbouring construction sites. The impacts related to excavation and transport of soil between sites is covered by the fuel consumption, meaning a value of 0 is included for this impact source.

3.3.2.9 Removal of waste (A5)

This source refers to the transport of construction waste from the construction site to receiving treatment facilities, and is assessed separately from the *transport of waste* process in A4. Waste quantities are identical to those used in the waste impact assessment, with transport distances mapped using Google Maps to identify the most probable route from the site to the waste receiver, as informed by the waste transporter.

Two receiving facilities were used, both located within 6 km of the construction site. Transport is assumed to be performed by a medium goods vehicle (GVW) 7.5–20 t diesel truck, in accordance with the GLEC framework, which specifies a load factor of 63% and empty running of 17%. The emission factor applied is expressed in units of [kg CO_2e/t · km], consistent with the regulatory and GLEC methodology.

No differentiation between waste fractions was made for removal impacts, all fractions are assumed to use the same vehicle type and distance per fraction-specific mass. Total waste quantity and removal distance can be found in Appendix B, Table B.1.

3.3.3 Allocation

Allocation was applied only for fuel and electricity consumption, where shared use between multiple construction projects meant direct measurement for the case project was not feasible. System expansion as recommended by ISO 14044[13] was not feasible, at it requires inclusion of the other involved projects.

3.3.3.1 Fuel

Fuel consumption from the main site tank was shared among six nearby projects during the construction period of 19 months. The allocation key was based on the number of active months for each project during this period multiplied by its total floor area. This approach ensured allocation being based on the physical parameters of floor area and active time, as per the ISO standard. For project *Hedehusene*:

$$\text{Share}_{Hedehusene} = \frac{\text{Months}_{Hedehusene} \times \text{Area}_{Hedehusene}}{\sum_{j=1}^{n}(\text{Months}_j \times \text{Area}_j)}$$

$$\text{Allocated fuel}_{Hedehusene} = \text{Total shared fuel} \times \text{Share}_{Hedehusene}$$

3.3.3.2 Electricity

Of the 12 meters used to monitor electricity consumption, only the worker site facilities meter recorded shared use. For the first six months of the eight-month active period for electricity, consumption was shared with one other site and allocated according to relative building floor area, resulting in 32% of consumption being attributed to the case project for this period. For the final two months, 100% of the consumption was allocated to the case project.

3.3.4 Default assessment approach

This approach refers to assessing climate impacts of a case using the default standard values provided by the regulations. The default data is unaffected by construction site location, as the transport emission factors are based on standard transport distances linked to transport mode emission factors. These standard values are the result of the 2023 BUILD background study *Ressourceforbrug på byggepladsen*[7]. The approach for assessing climate impacts of contributing sources is defined in this section. Several of the standard factors are not based on any physical parameters specific to the assessed building, these are referred to as *Fixed standard values*, and explained in detail below.

3.3.4.1 Identical to specific

Some impact sources are assessed using the same approach as for the specific method. This includes the following sources : Electricity, District Heating, Fuel, Construction waste, that are explained in the above section 3.3.2

3.3.4.2 Fixed standard values

Certain impact sources included in the building regulations can be assessed using fixed impact values, expressed in units of [kg CO_2e/m^2year], which are independent of any physical parameters of the assessed case. In this report, these are referred to as *fixed values* and include: transport of waste, transport of machinery, and logistics hub processes (each assigned 0.02 kg CO_2e/m^2year), as well as removal of soil and removal of waste (each assigned 0.06 kg CO_2e/m^2year).

In total, these standard values sum to 0.18 kg CO_2e/m^2year, corresponding to 12% of the regulatory impact threshold. These factors are set in the BUILD report and are not based on project-specific data, but rather described as "constants based on qualified estimates". For the default assessment approach, no further calculation is required beyond applying these constants.

3.3.4.3 Transport of construction materials

In the default approach, transport of construction materials is assessed using the standard dataset provided in the Danish Building Regulations shown in Appendix A, Table A.1. This dataset contains emission factors in the unit [kg CO_2e/kg], which include both a fixed transport distance and the associated impact per tonne-kilometre for a representative vehicle mix. The factors were developed in the BUILD report through analysis of relevant product-specific EPDs for the Danish context, estimating average transport distances and intensities for material groups, and are increased by a factor of 1.25 to account for uncertainty.

To apply the dataset, only the construction material quantities are required. Each material is mapped to a material group with a corresponding standard factor. Materials not explicitly included in the dataset are assigned to the most similar group based on composition or application. The complete mapping of case materials to standard emission factors is provided in Appendix B, Table B.3.

The method reflects an average Danish context and is intended for regulatory consistency rather than project specificity. Materials with significantly longer or shorter transport distances than the assumed average may therefore be over- or under-represented in the resulting impacts.

3.4 Baseline case as platform for exploration

The baseline case serves as the foundation for all scenario analyses in this thesis. Each scenario is a direct modification of the baseline dataset and modelling setup, ensuring that results are directly comparable. Physical parameters remain constant unless intentionally varied, and any changes are isolated to the parameter under investigation. This maintains consistency in data sources, data quality, and emission factors, except where these are the subject of variation.

The approach is used to address specific research questions related to both methodological implications and sensitivity to key parameters, including physical characteristics (e.g. transport distance, waste quantity) and modelling choices. It differs from uncertainty analysis in that changes are made deliberately to explore defined conditions, rather than through random variation.

Parameters are varied independently unless otherwise stated, meaning potential interaction effects are not assessed. The scenario setup and modifications are documented to allow reproducibility. This method reduces data requirements compared to sourcing multiple real-world cases and avoids confounding variables, but it lacks statistical representativeness. As such, results may be influenced by characteristics unique to the baseline project, potentially over- or underestimating the effect of a given change.

The analysis applies varying methodological approaches, assumptions and frameworks to produce scenarios throughout. These also imply varying degrees of admissibility within the context of the methods required by the recent Building Regulations. Where different intentions regarding admissibility apply, these are stated.

The evaluation of alternative methodological approaches is conducted based on the premise outlined by IPCC WG1 in chapter 4 of the 6th assessment report [1], where accurate, consistent quantification of climate impacts is a prerequisite for effective and cost-efficient mitigation. Robust measurement and high-quality LCA data improve prioritisation, reduce the risk of burden shifting, and support effective mitigation under budget constraints, both in terms of abatement per unit cost and in absolute terms, by directing limited funds to the most consequential actions while balancing other societal expenditure.

3.5 Comparison to BUILD results

In several analyses, baseline and scenario results are compared to findings from the BUILD report ”Ressourceforbrug på byggepladsen”. The BUILD results reflect total A4 and A5 climate impacts, as well as the composition of individual impact sources, based on a large dataset from Danish construction sites. For comparability, the results used from the BUILD study are limited to the same life cycle stages as this study (A4 + A5), though some methodological differences remain.

The BUILD results are reported as the 25th, 50th (median), 75th, and 90th percentiles, representing the distribution of impacts observed in the dataset. Comparing case and scenario results to these percentiles enables each result to be “placed” within the observed national range, providing insight into its relative magnitude. This comparison can be applied both to the total A4 + A5 impacts and to the proportional contribution of each impact source.

While BUILD’s dataset is extensive, variability in project type, data quality, and methodological assumptions limits direct comparability. The comparison is therefore intended for contextualisation rather than compliance evaluation.

Finally, the methodological approach applied in the final regulations differs in certain respects from that used in the BUILD study. This complicates interpretation, as observed differences may arise from either physical project characteristics or from methodological differences in impact quantification.

3.6 Key impact contributors

In line with Research Question 2, the analysis focuses on key contributing impact sources, identified in the baseline case and informed by findings from the BUILD report. The BUILD study highlights transport of construction materials and construction waste as major contributors, and these categories are therefore examined in greater detail to identify potential reduction measures using the variation and scenario construction approach defined in section 3.5.

3.6.1 Construction waste

To assess the influence of construction waste generation on total A4 and A5 impacts, a sensitivity test was conducted by varying the total waste quantity of the baseline case by ±50%. All other parameters, including waste composition, transport distances, and emission factors, were kept constant to isolate the effect of waste quantity alone. Impacts for each scenario were recalculated using the same methodological approach as the baseline case, applying the regulatory standard values for each waste fraction. The resulting A4+A5 totals were compared to the baseline to evaluate the proportional change and the potential for impact reduction through improved on-site waste management. The magnitude of the waste quantities are evaluated in relation to Technological Institutes estimated common waste quantities of 20-100 kg of construction waste per square meter floor area build [40], corresponding to 1.7% to 8.7% for the given case. The maximum waste quantity required to stay within the regulatory threshold, with all other parameters equal, is also assessed.

3.6.2 Transport

This analysis examines how geographical factors influence climate impacts from the transport of construction materials, using two complementary approaches: variation in material producer locations and variation in construction site location. In both cases, all other parameters from the baseline case (Section 3.3) are kept constant, ensuring that only the geographical parameter under investigation is changed. Transport impacts are calculated using the same method as in the baseline, multiplying material quantities by transport distances and the corresponding regulatory emission factors.

The methods described are intended to remain within the bounds of BR18 regulatory admissibility.

3.6.2.1 Material producer locations

The potential for reducing A4 transport impacts is examined by substituting construction materials with technically equivalent products manufactured closer to the construction site, without altering product performance, functional requirements, or installed quantities. All non-transport parameters and the baseline building design are held constant, ensuring that any change in results is attributable solely to producer location. A screening is performed for the ten materials with the highest transport-related climate impacts in the baseline case. Candidate alternatives are identified by searching the EPD databases EPD-Denmark [41], EPD-Norway [42], and ECO Portal [43], applying the following criteria:

- Substitutes must be produced in closer proximity to the construction site in Hedehusene.
- Only substitutes with near-identical technical characteristics and intended use are considered.
- All candidate substitutes must have a valid, third-party verified EPD.

For route modelling, emission factor selection, and computation, the same principles apply as for transport of materials for the baseline as defined in section 3.3.2.2.

The substitutions identified through this process together form the variation scenario, which will be compared to the original baseline scenario on a material and total basis.

The analysis investigates opportunities to reduce A4 (transport-to-site) impacts through alternative material sourcing only. It does not evaluate whole-life trade-offs, and any reductions in A4 may be offset by increases in other life-cycle modules (e.g., A1–A3, A5, B, C, or D), which are outside the scope here. The screening for candidate substitutions is indicative rather than exhaustive and may miss products that would be identified in a full procurement process. Feasibility of the identified substitutions has not been tested against project-specific developer requirements and some candidates may therefore be unsuitable in practice. The substituted materials with EPDs, locations and transport distances are shown in Appendix B, Table B.6.

3.6.2.2 Construction site location

The baseline construction site location in Hedehusene, close to Copenhagen, and with many material producers in close proximity may be advantageous in regards to material transport impact reduction. As the regulations do not vary based on geography, locations with certain geographical characteristics may be less likely to comply with the regulatory threshold with equal building characteristics.

This section describes the methods used in the analysis of how relocating the construction site influences transport distances and the associated climate impacts from material transport. Two alternative theoretical locations are selected to represent contrasting Danish contexts under ongoing expansion: Klitmøller in Northern Jutland, a small town in a peripheral setting, which is seeing an influx in new residents, and may soon open up for new development [44], and Odense in Central Denmark, the nations third largest city with ambitions of a more than 10% population growth and a long list of planned development projects[45].

The baseline building design, functional requirements, and all non-transport parameters remain constant across scenarios to isolate the effect of geography.

Material sourcing approach for the theoretical locations are sought to imitate the principles of sourcing for baseline construction site in Hedehusene by applying the following rules:

- Where feasible, materials are sourced from the nearest suitable producer that supplies a comparable product with a valid, third-party verified EPD. Product characteristics and intended application must match the baseline selection.

- For products in the Hedehusene case supplied by producers operating multiple facilities spread throughout the country, the facility operated by the same producer closest to the scenario site is selected to ensure identical characteristics.

- Materials with specific properties retain the baseline producer and location if substitution is assumed to require building design changes.

- Internationally sourced materials retain their baseline producers, as these are assumed to be selected primarily for characteristics unrelated to construction site location.

For route modelling, emission factor selection, and computation, the same principles apply as for transport of materials for the baseline as defined in section 3.3.2.2.

A full overview overview of production locations and transport distances for the alternate site locations can be found in Appendix B, Table B.4.

While similar construction projects as the Hedehusene case are probable to occur in Odense, as several projects of over 100 residences are under way [45], they are not expected in Klitmøller as it is a small town of less than 1300 residents according to Statistics Denmark[46]. However, as the threshold is weighted by floor area it serves to provide insights into projects on the outer borders of Denmark, and as the regulations include several building types, the patterns and implications examined by this analysis still apply.

As materials are selected through a non-exhaustive screening, certain products that might have been chosen in a full procurement process may have been overlooked, potentially inflating transport distances. For materials supplied by the same producer but from a different facility, a more proximate producer might have been selected in a real-world scenario, likewise increasing the calculated distances. Since the theoretical transport routes for these materials could not be verified with all producers, the resulting estimates carry increased uncertainty. For certain key suppliers, such as the prefabricated concrete element producer, contact was made to validate the plausibility of the theoretical scenarios, but actual procurement decisions in a real project may still differ.

Scenarios are compared by both total A4 + A5 climate impacts, as well as by contribution of the 10 highest contributing materials. While waste transport and removal are affected by a geographical relocation, these are not corrected, as contributions are assumed to be negligible.

3.7 Comparison of default and project-specific assessment approaches

The project-specific approach is more demanding in terms of data and documentation than the default method, a factor that can increase costs for developers, as noted by BUILD [7]. Where the results of the two approaches are similar, there is little incentive to collect project-specific evidence, which weakens transparency and limits the effectiveness of mitigation (Section 3.4). This subsection sets out how the difference between the default and project-specific approaches is evaluated.

Both methods (Sections 3.3.4 and 3.3.2) are applied to the same baseline dataset. Physical parameters and case characteristics are held constant, only the assessment method varies. As the approaches have an overlap regarding the sources electricity, district heating, fuel, logistics hubs, transport of machinery, and construction waste, only some sources are expected to vary from by assessment approach. These sources are: transport of construction materials, transport of waste, removal of soil and removal of waste.

Outputs are reported as total A4+A5 impacts for each method and contributions by source to highlight where differences arise. Results are interpreted against the regulatory threshold and, where informative, positioned relative to BUILD percentiles for context.

The methods described are intended to remain within the bounds of BR18 regulatory admissibility.

3.7.1 Mixed approach

The Danish Building Regulations also permit a combined, "mixed" approach [15], in which selected sources are assessed specifically while others use the default dataset. This option can reduce documentation effort, while still reflecting targeted, project-specific measures in the transport impacts. As defined in Section 3.3.4, the default impact values for construction material transport are based on fixed average transport distances for each material group. This condenses the underlying distribution of distances into a single representative value applied across projects. In any given project, actual transport distances will fall at different points along that distribution. Having the option to select which impacts are specifically assessed also provides the option to selectively move impacts on the upper tail of the distribution toward the centre. The reported impact reduction effectiveness of applying the mixed approach compared to the default and specific is assessed using the following procedure:

For the baseline case, a mixed scenario is constructed by replacing default transport impacts with project-specific impacts for the material transport groups showing the largest absolute overestimation under the default method relative to the specific baseline. For this scenario, two groups are identified. All physical parameters, material quantities, and transport modes remain unchanged, only the modelling approach varies.

Total material transport impacts of the mixed approach is given by,

$$I_{\text{mixed}} = I_{\text{default}} - \sum_{k\in S} I_k^{\text{default}} + \sum_{k\in S} I_k^{\text{specific}},$$

where $I_{approach}$ denotes total A4 construction material transport impact for given approach, k indexes material transport groups, and S is the set of groups reassessed specifically.

The mixed impact I_{mixed} is then compared with the fully default baseline (not variable based on site location) and fully specific scenarios for the baseline and the alternative site locations (Section 3.6.2.2), to evaluate how geography interacts with the mixed approach.

3.8 Analysis of methodological discrepancies

The assessment method required by the Danish Building Regulations [15] varies in key aspects from the BUILD background study [7], which assessed A4 and A5 impacts for 52 construction cases and underpins the regulatory threshold (set near the BUILD median). Because the two approaches are not identical, comparisons are not strictly on equal terms, and the representativeness of the BUILD percentiles for regulation-compliant assessments is reduced. This subsection sets out how these methodological differences are addressed in the analysis.

Key methodological differences considered

- Waste assessment: In the BUILD study, mixed fractions are assessed using composition-weighted factors based on an estimated average mix. In BR18, a mixed fraction is assessed by applying the highest-impact constituent factor to the entire fraction.

- Waste fraction set and mapping: Category definitions and available factors differ between BUILD and BR18.

- Energy factors: The emission factors for electricity and district heating used in the BUILD study differ from those specified in the current BR18 edition.

The following subsections describe the scenario setup used to examine how these methodological differences affect reported totals and impact composition, with all physical parameters held constant. The scenarios use methods that are not admissible for regulatory submission and are included solely to illustrate the implications of approaches outside the current framework.

3.8.1 Waste

Baseline waste data include mixed fractions with unknown compositions (Section 3.3.2). Plastic is assumed present in the mixed fractions *Combustible*, *Mixed construction waste*, *Landfill*, and *Hard-to-recycle*, as this is common in e.g. packaging material. Four scenario variants are constructed while holding all physical parameters constant, and are based on the following approaches:

- Scenario 1, Baseline method: Mixed fractions assessed by applying the highest-impact constituent factor (plastic) to the full fraction.

- Scenario 2, Improved sorting: Plastic allowed only in the “Mixed construction waste” fraction. For “Combustible,” “Landfill,” and “Hard-to-recycle,” glass is the highest-impact constituent.
- Scenario 3, Optimal sorting: Mixed fractions hypothetically split into single-material fractions and assessed using BR18 single-fraction factors. Composition of the mixed fractions based on the estimates in the BUILD report.
- Scenario 4, BUILD method and factors: The baseline waste quantities and fractions are assessed using BUILD’s mixed-fraction method and BUILD’s factors for a direct comparison to the BUILD percentiles.

The specific mapping of transporter waste fractions to regulation categories is included in Appendix B, Table B.13.

Totals across S1–S4 are compared, and for S1–S3 contributions are compared relative to quantity. Scenarios are also benchmarked to the BUILD waste percentiles to position the case within the national distribution under BUILD’s own method and the regulatory method.

3.8.2 Energy

The regulations specify electricity and district heating factors that differ from those used in the BUILD study. Current 2025 BR applies emission factors for these impact sources based on an updated approach described in the report, ”Emissionsfaktorer El, fjernvarme og ledningsgas 2025-2075” [47] by Artelia, commisioned by Danish Social and Housing Ministry. The report states, that due to differences in modeling approach, previous and updated emission factors can not be compared [47]. Since BUILD reports impacts rather than consumption, we first infer consumption using the BUILD factor, then re-express the impact using the regulation factor. The emissions factors used in the BUILD study are taken from the 2023 version of the Building regulations (electicity: 0.135 kgCO$_2$e/kWh, district heating: 0.0878 kgCO$_2$e/kWh), with current 2025 regulations applying updated factors defined in Appendix A, Table A.3. The impact values are corrected using the following approach:

$$I_{\text{Energy,BR}} = I_{\text{Energy,BUILD}} \times \frac{EF_{\text{Energy,BR}}}{EF_{\text{Energy,BUILD}}}$$

where I is the reported impact and EF the emission factor (kgCO$_2$e per kWh) under the indicated method.

For the baseline case, we apply both sets of factors to the metered electricity and district heating to quantify the difference under the current building regulations factors versus the earlier factors. For the BUILD percentiles, the ratio-based correction places the published values on a current regulations-consistent basis for comparison to the regulatory threshold and to the baseline and scenarios.

3.9 Impact range assessment

This analysis constructs two methodological boundary scenarios that bracket the range of *reported* A4 and A5 climate impacts for the case, given alternative assessment choices. Physical parameters are held constant and equal to the baseline dataset (material quantities, waste quantities and fractions, baseline producer locations, and energy and fuel consumption). Only methodological assumptions and data sources vary.

For each impact source, the upper bound uses the highest value among the variants already quantified in the preceding analyses (e.g., project-specific, default, mixed for transport, waste scenarios). If only one variant exists for a source, that value contributes to both bounds. This same approach is taken for the lower bounds.

Scenario results are presented alongside the baseline project-specific case to show the magnitude attributable to method choice. Where relevant, values are also interpreted relative to the regulatory threshold and BUILD percentiles to contextualise the range.

These boundaries represent plausible outcomes under alternative methods, not bounds on actual emissions, which is constant across cases as no physical processes or inputs are altered. The range is intended to include values from the alternate waste scenarios (Section 3.8.1), which means the methods applied may not be admissible for regulatory documentation.

4 Results & analysis

This section reports the results of the baseline case study and subsequent focused analysis. Climate impacts are reported either as total values with the unit kgCO$_2$e or relative to the functional unit defined in this thesis, and expressed in kgCO$_2$e/m^{2}year. This functional unit is the same required in the Danish Building Regulations (BR18)[15]. The results are ordered with the baseline case study results followed by focused analytical exploration.

4.1 Baseline case study findings

Baseline climate impacts from the case study construction site emission sources are quantified using the methodology described in Section 3.3, and first analysed independently to identify the main contributing sources. The results are then compared with the regulatory threshold and BUILD impact data to assess deviations from expected patterns and to establish a reference point for subsequent analyses.

4.1.1 Total A4 + A5 Climate impacts

The climate impact results of the baseline case summarized in Table 4.1 show that module A5 has the largest contribution with a value of 1.49 kgCO$_2$e/m^2 corresponding to 86.6% of the total A4 + A5 impacts, with A4 contributing the remaining 13.4%. The A5 impact value alone reaches the regulatory threshold with the A4 module contribution resulting in a total value of 1.72 kgCO$_2$e/m^2, that exceeds the threshold by 0.22 kgCO$_2$e/m^2.

Comparison with existing literature indicates that the baseline value slightly exceeds previously reported A4 + A5 ranges of 0.50–1.59 kgCO$_2$e/m^{2}year. Both modules individually also fall above the documented ranges of 0.05–0.72 for A4 and 0.45–1.43 kgCO$_2$e/m^{2}year for A5 (Section 2.2).

Table 4.1: Baseline case A4 and A5 climate impacts

Module	**Impact [kgCO$_2$e/m^{2}year]**
A4	0.229
A5	1.49
A4+A5	**1.72**

The composition of impacts shown in Figure 4.1 indicates a highly dominant contribution from the Construction waste as the main source of climate impacts in the baseline case making up 94% of A5 and 81% of A4 + A5 impacts.

Transport of construction materials is second making up 80% of A4 but only 11% of A4 + A5 impacts.

However, as mentioned in theory Section 2.3.2 construction waste impacts as assessed through the regulatory methods may not accurately reflect the real-world climate impacts. The impact assessment method of construction waste is further analysed in results Section 4.4.1.

Transport of machinery and logistics hubs processes are not assessed on a project specific level as data was not sufficient for reliable assessment. Instead the regulatory standard values of 0.02 $kgCO_2e/m^2$year are applied for these impact sources, which together account for 2.3% of A4+A5 impacts.

A full overview of values and results from the baseline results is shown in Appendix B, Table B.5.

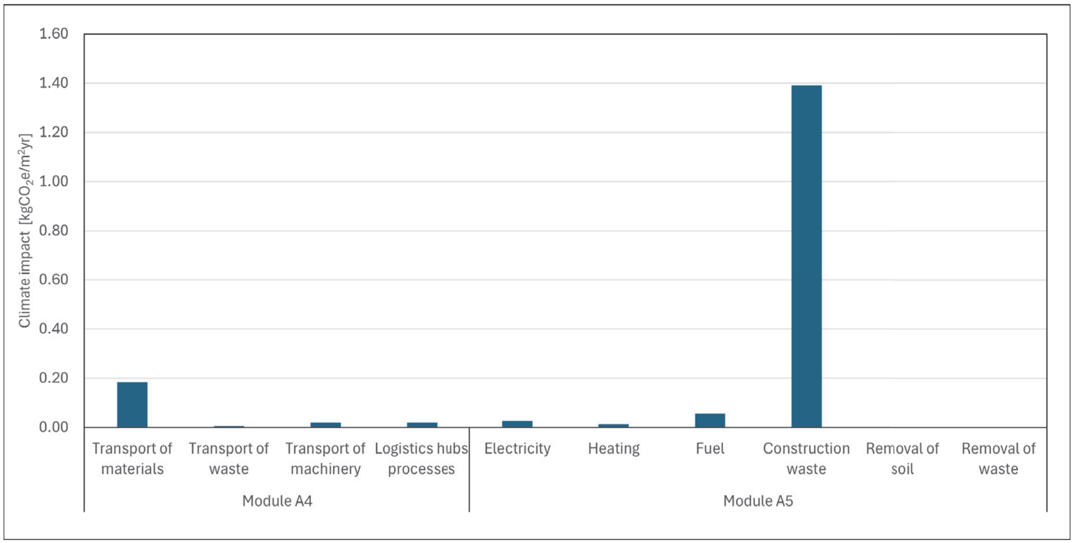

Figure 4.1: Climate impacts of the baseline case in $kgCO_2e/m^2$year, for life cycle modules A4 and A5 across included emission sources.

4.1.2 Contribution analysis of key impact sources

As identified in the previous section, construction waste and transport of materials are the dominant contributors to total impacts, representing 80% and 11% of total A4 + A5 impacts, respectively. The following analysis disaggregates these categories to quantify the contributions of their individual constituent sources.

Construction waste

Six specific waste fraction eaxh with contributions >1% of construction waste impacts, and one grouping of the remaining 8 fractions noted as *Other* are included in the following analysis. The six waste fractions account for 97% of construction waste impacts, and 72% of waste quantity. The remaining fractions account for 3% and 28% of impacts and quantity respectively.

As shown in Figure 4.2 the majority of climate impacts from construction waste can be attributed to Combustible waste, which accounts for 77% of impacts, and only 29% of the waste quantity, implying a high impact intensity of the fraction.

The fraction with the highest waste quantity, Clay tiles and concrete mixed, shows a similar waste quantity of 31%, but only accounts for 6% of climate impacts, implying a low impact intensity.

The fractions Mixed construction waste, Landfill waste and Hard-to-recycle materials show similar patterns to the Combustible waste fraction of impact contributions disproportionate to quantity, as these fractions account for 13% of climate impacts and only 5% of waste quantity.

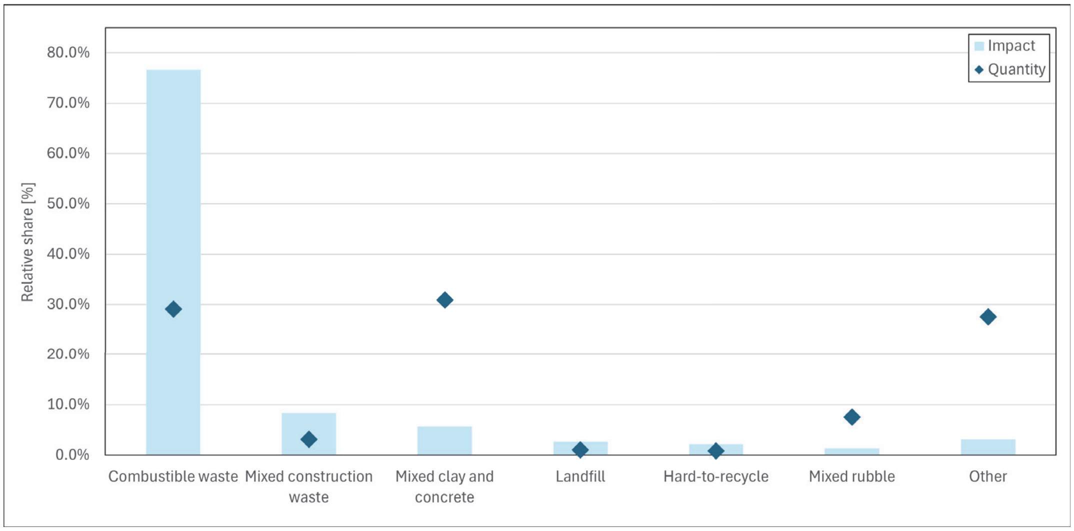

Figure 4.2: Relative share of waste impacts and quantity as percentage of totals for each parameter. Distributed across waste fractions as reported by waste transporter. Fractions with impact contributions >1% are shown separately and ordered by impacts, with remaining 8 fractions aggregated in *Other*.

Common for Combustible waste, Mixed construction waste, Landfill waste and Hard-to-recycle materials are a mixed waste composition assumed to contain plastic waste. Following the waste assessment method described in Section 3.3 which is dictated by the building regulations, mixed fractions are assessed using the highest emission factor of the materials found in the fraction, which for these fractions are plastic and PVC.

As plastic and PVC with similar and very high emission factors are only estimated to account for a share of 20% for Combustible waste, 2% of Mixed construction waste and 10% of landfill and Hard-to-recycle waste[7], this method produces results that may not accurately reflect the impacts of the fraction in question.

Fraction composition and effect on climate impacts is further analyzed in results Section 4.4.1.

Impact sensitivity to waste quantity

To assess the sensitivity of total A4 + A5 impacts to construction waste quantity, the baseline waste amounts were varied by ±50%. The resulting changes in total impacts, shown in Figure 4.3, indicate a variation of ±0.70 $\text{kgCO}_2\text{e/m}^2$year, corresponding to ±41% relative to the baseline. This demonstrates a high sensitivity of total impacts to waste generation levels.

When compared to the range of waste percentages estimated by the Danish Technological Institute (1.7%–8.7%)[40], the analysis suggests that very low waste quantities are required to remain within the regulatory threshold. Even at the baseline waste percentage of 3%, impacts exceed the threshold. For a waste percentage of 4.5%—still in the lower half of the reported range—total impacts rise to 2.42 $\text{kgCO}_2\text{e/m}^2$year, well above the allowable limit. To achieve an impact value below 1.5 $\text{kgCO}_2\text{e/m}^2$year with the current methodological approach, waste percentage for the baseline case may not exceed 2.5%, which corresponds to a 17% reduction in total waste quantity. This indicates that A4 + A5 impacts can be reduced effectively by minimising construction waste generation, making waste prevention a particularly impactful mitigation strategy within the regulatory framework. However, it may also reflect the methodological discrepancy as described above.

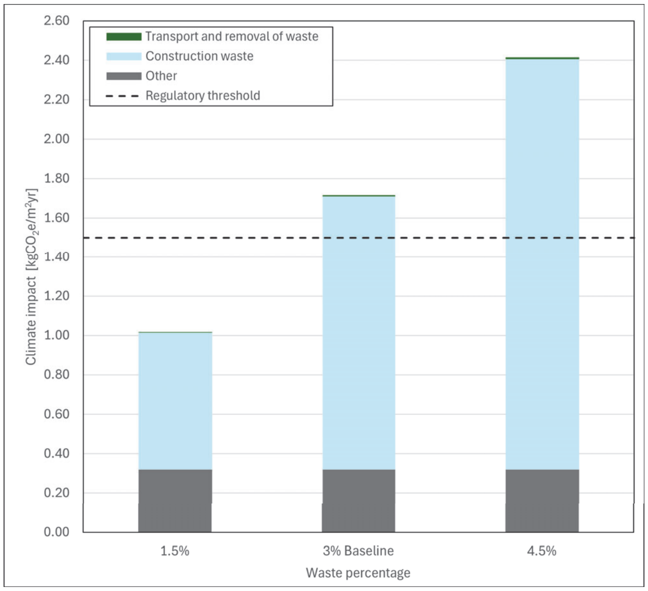

Figure 4.3: Sensitivity of total A4 + A5 climate impacts to variations in total construction waste quantity for the baseline case. Results are shown for a 50% reduction, baseline quantity, and 50% increase.

Construction material transport

Material transports with contributions above 4% of the total (9) are assessed individually, while the 23 transports and materials not specifically assessed by the baseline case are aggregated in the category *Other*. The nine assessed material transports account for 75% of impacts and 52% of transported quantity, with *Other* contributing the remaining 25% and 48%, respectively. The mean transport distance for the nine assessed materials is 120 km, compared with 39 km for *Other*, giving an overall mean of 81 km. A complete overview of results is provided in Appendix B, Table B.2.

As shown by Figure 4.4, transport impacts are less dominated by as single contributor when compared to the waste contributions in Figure 4.2. The most contributing material transport is for Aerated concrete blocks and mortar, which contributes 23% of the total transport impacts, with a quantity corresponding to only 2% of the total material quantity. This can be attributed to a transport distance (secondary axis), that is considerably longer than the average of even the top nine, at 800 km. A similar pattern is seen for several of the other materials including Elevator system, Wooden floorboard and Glazed windows. Other materials share the pattern, but to a lesser extent, such as Clay bricks, where an above average transport distance of 310 km and a higher material quantity of 5% results in the material having the second highest transport impact. The same principles apply for the Precast concrete stairs and Precast concrete beams.

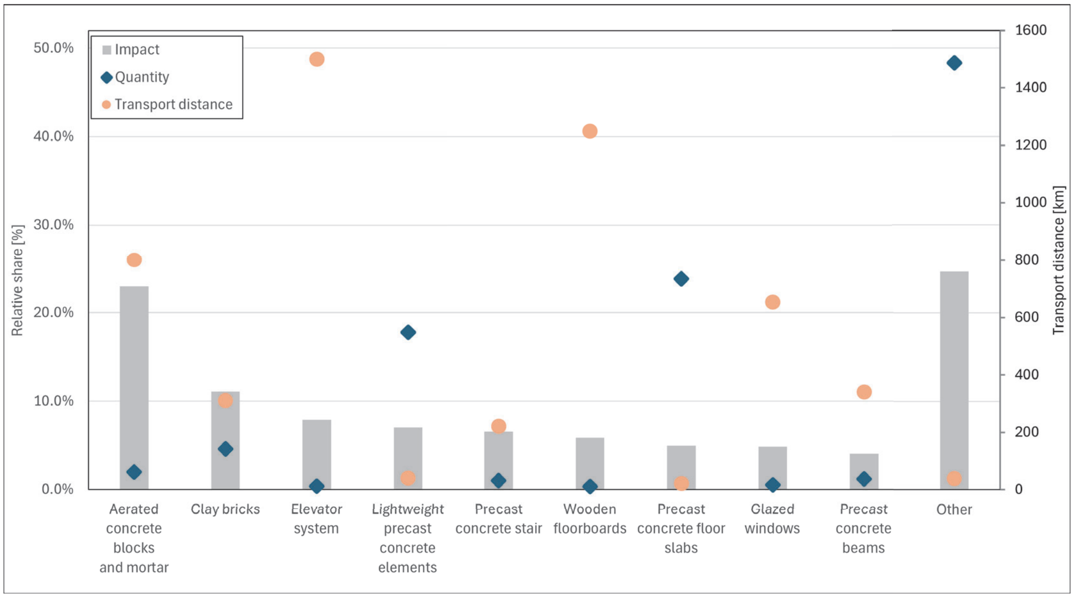

Figure 4.4: Primary axis: Relative share of material transport impacts and quantity as percentage of totals for each parameter. Secondary axis: Material transport distance. Distributed across construction materials. Materials with impact contributions 4% are shown separately and ordered by transport impact, with 23 remaining materials and the materials without case specific assessment aggregated in *Other*.

The opposite pattern is seen for Lightweight precast concrete elements and Precast concrete floor slabs, where the shorter transport distances of 40 km and 21 km respectively, are offset by high material quantities of 18% and 24% of total material weight, causing high impact shares within the top 9 of 7% and 5%.

For the *Other* category, relative material quantity is disproportionally large compared to transport impacts, at 48% and 25% suggesting lower impact intensity for the category. This is supported by the lower mean distance of 39 km. This shows, that a majority of impacts are caused by a minority of the materials.

Material transport impacts are further analysed in the results Section 4.2.

4.1.3 Comparison of baseline results to regulatory threshold

The baseline case study A4 + A5 impact is compared to the regulatory threshold, with percentiles from the BUILD report[7] included as reference points to the threshold and the national status quo of A4 + A5 impacts. The composition of the totals is also presented to further support the comparison.

As shown in Figure 4.5, the baseline case exceeds the regulatory threshold of 1.5 $kgCO_2e/m^2$year, reaching a total A4+A5 impact of 1.72 $kgCO_2e/m^2$year. Excluding construction waste, the remaining impacts are comparable to those of the BUILD 25th percentile, however the notably larger construction waste impacts of the baseline case drive the total impacts closer to the level of the 75th percentile.

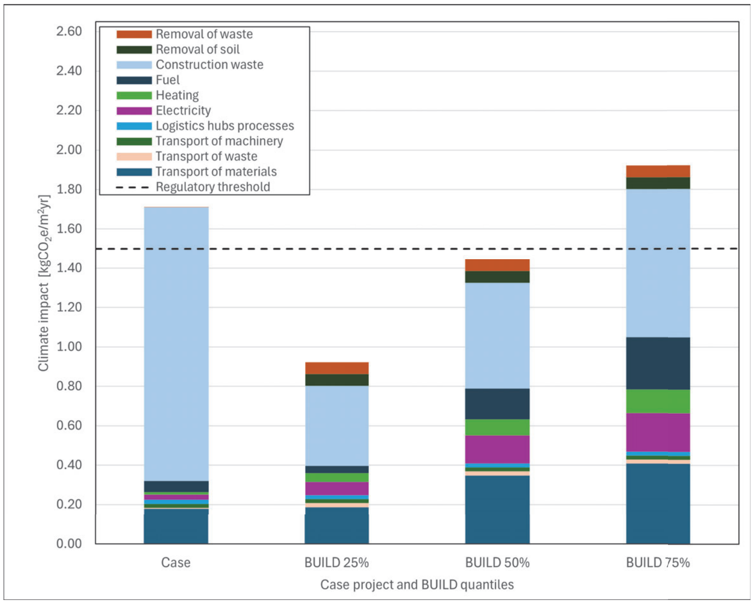

Figure 4.5: Climate impact comparison of baseline case, quantiles from *Ressourceforbrug på byggepladsen*[7], and regulatory threshold, including impact composition.

This comparison however is not done completely on equal terms, as the BUILD percentiles apply the constant standard values across the board. In the figure it is shown that the specific assessment for Removal of waste, Removal of soil and Transport of waste provide a notable reduction in climate impacts. Especially Removal of soil and Removal of waste at values of 0 and near 0 create a discrepancy compared to the standard values of 0.06 kgCO$_2$e/m^{2}year for each of the sources. Reducing these two values to 0 would in itself cause a reduction of 8% relative to the threshold.

The reductions gained from specific assessment of these standard values are more than offset by the substantially higher contribution from construction waste impacts. As described in Method Section 3.8 the BUILD analysis applies an alternative set of emission factors for the waste fraction as compared to the baseline case, and most notably includes factors for the mixed fractions, that represent an average composition of the given fraction. The baseline case is assessed using the updated emission factors from the building regulations, and assigns the emission factor of the highest appearing material for the entire mixed fraction it is part of. This methodological difference could explain discrepancy, as waste quantity of the baseline case is modest, at 3% relative to the construction materials. The inconsistency in assessment method hinders direct comparison, but indicates a sensitivity of Construction waste impacts to methodological approach, which is further explored in Section 4.4.1.

4.2 Sensitivity to geography

The geographical sensitivity of transport-related climate impacts is assessed by varying the locations of material producers and construction sites. This variation allows the analysis to examine changes in transport impacts and to represent alternative material sourcing and construction site scenarios.

4.2.1 Variation analysis of material sourcing

Possible substitutions for the 10 most contributing construction materials in the baseline case are identified. Because the developer required valid EPDs for all selected materials where possible, the search for alternatives was conducted in EPD databases for products similar to those installed in the baseline building. See Section 3.6.2.1 for a detailed description of the scenario design method.

For three construction materials, suitable substitutions with more proximate production locations were identified, while for the remaining seven, no alternatives meeting the criteria were found. The climate impacts and transport distances of the substitutions, compared to the baseline, are shown in Figure 4.6.

An overview of all assessed options for alternative materials is included in Appendix B.2.1.

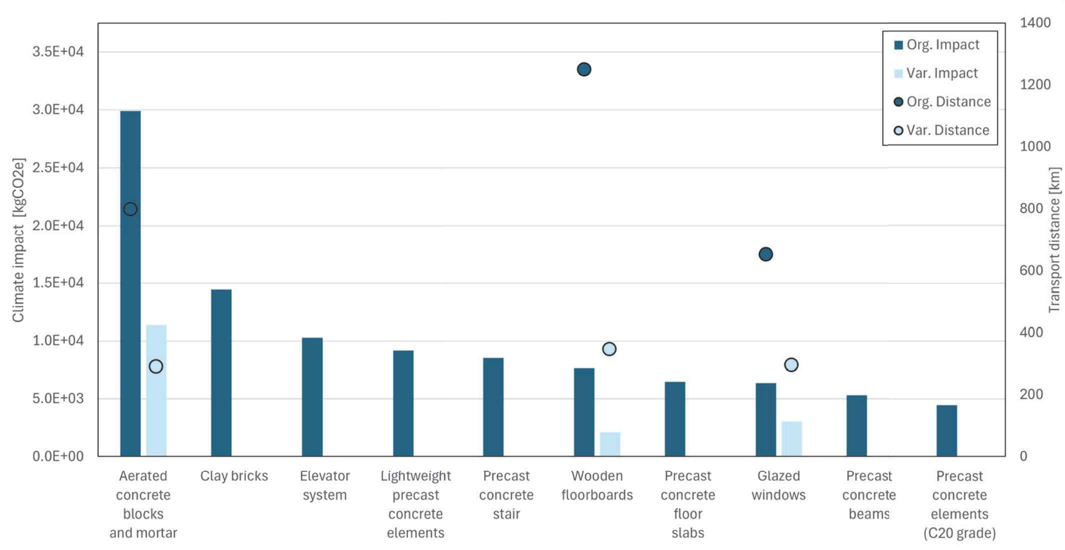

Figure 4.6: Comparison of total transportation climate impact of the 10 most contributing construction materials and suitable substitutions. Secondary axis: Transport distances for original and substituted material.

Figure 4.6 shows that substituting the three construction materials led to substantial reductions in the climate impacts associated with their transport from production site to construction site compared to the baseline. The substitutions resulted in transport impact reductions of 62%, 72%, and 52% for aerated concrete blocks and mortar, wooden floorboards, and glazed windows, respectively. In total, this corresponds to a 21% reduction in material transport climate impacts.

Each material substitution achieves a greater percentage reduction in transport distance than in climate impacts, the total climate impact reduction (21%) slightly exceeds the overall reduction in transport distance (19%). This is because the substituted materials have higher-than-average impact intensities, thereby contributing disproportionately to the total transport climate impacts and further emphasising the above average impact intensity of the substituted materials relative to the remaining. Had more materials in the top 10 been substituted, this trend may have been increased.

Although the variation results in reduced transport impacts, the fact that only three of the top ten materials had suitable substitutions suggests that these materials may already have been selected with transport distance in mind. The total transport impacts for the baseline case (0.18 $kgCO_2e/m^2year$) are lower than the BUILD 25th percentile value (0.19 $kgCO_2e/m^2year$), which further supports this interpretation.

It should be noted that reducing impacts in one life cycle module will not necessarily reduce total impacts, as improvements in one part of the system can lead to negative outcomes in others. When selecting for climate performance, construction materials must be evaluated using a whole life cycle approach to avoid burden shifting. With this in mind, the substitutions may not result in actual total life cycle climate impact reductions, despite what this analysis might imply.

4.2.2 Variation analysis of construction site location

The results from Section 4.2.1 showed that the potential transport distance reduction from substituting the most contributing construction materials was relatively low. This does not address whether the location in Hedehusene inherently favours shorter transport distances relative to the average Danish construction location, and whether this could explain the low transport impacts compared to the BUILD percentiles in Figure 4.5. If this is the case, similar buildings at other locations may produce higher impacts from the transport of materials, even with identical building characteristics.

The analysis explores how the geographical location of the construction site affects transport distances and climate impacts. Two scenarios are constructed by theoretically relocating the baseline construction site in Hedehusene to the alternative locations Klitmøller and Odense, representing the characteristics defined in Section 3.6.2.2. While the building design and functional requirements remain unchanged, material sourcing is adjusted where appropriate to reflect the new locations, following the approach described in Section 3.6.2.2. The analysis tests the hypothesis that the geographical location of the construction site can influence transport distances and, consequently, total transport impacts. A full overview of transport parameters and resulting scenario impacts is provided in Appendix B, Table B.4.

Figure 4.7 shows material producer locations for the ten most contributing domestically sourced construction materials in each scenario. Domestic producers are displayed as they best illustrate and visually communicate the changes caused by site relocation within Denmark. Internationally sourced materials typically involve long-distance transport outside the regional context, meaning that the relative change in distance from site relocation is proportionally smaller and therefore has less influence on total transport impacts.

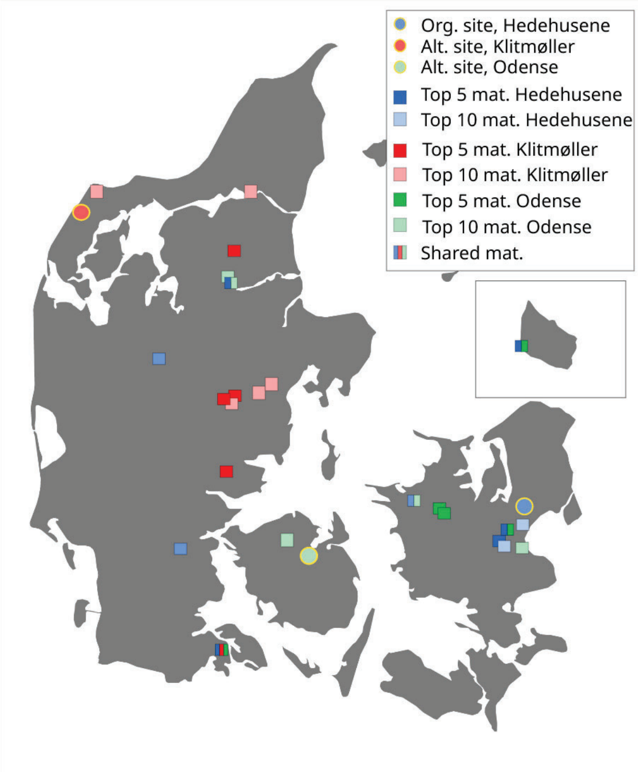

Figure 4.7: Map of Denmark showing the original and alternative construction site locations (Hedehusene, Klitmøller, and Odense), along with producer locations for the ten most contributing domestically sourced construction materials in each scenario. Background map by Vemaps.com[48].

Relocating the construction site to Klitmøller or Odense reduces the number of major material producers located in close proximity. For the Hedehusene site, five of the top ten contributing materials are sourced from within 100 km, including two of the top five. In contrast, both Klitmøller and Odense have only one of their top ten materials sourced within this distance, and none within the top five.

This geographical shift is reflected in the average transport distances as Klitmøller shows the highest mean distance at 167 km, followed by Odense at 118 km. Hedehusene (Baseline) has the lowest mean distance at 81 km—less than half that of Klitmøller. A similar pattern appears for transport impacts. Compared to the baseline, Klitmøller shows an 80% increase in total transport impacts, while Odense shows a 34% increase. Figure 4.8 shows the total impacts, as well as the contribution of material transport for each site location scenario next to the regulatory threshold. While transport impacts remain highly affected by the relocations, total impacts for the affected scenario, Klitmøller, increase by only 9%, showing that total impacts are relatively unaffected by even a doubling of mean transport distance, considering the much higher construction waste contribution. The figure also displays, that the regulatory threshold is exceeded excluding material transport impacts, meaning the location for this case has no influence on compliance given the applied assumptions.

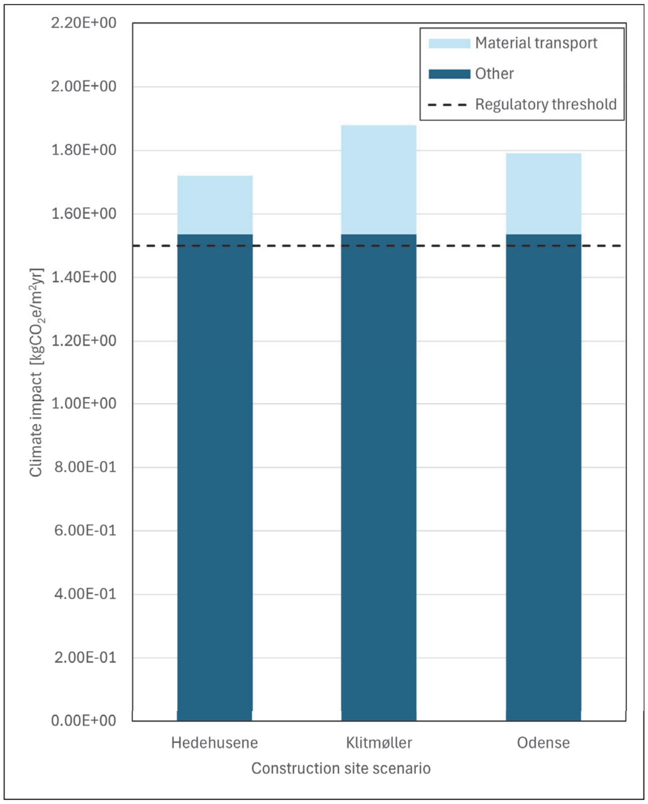

Figure 4.8: Total A4 + A5 climate impacts for the baseline site location (Hedehusene) and alternative locations (Klitmøller and Odense). Waste transport, and removal not corrected for site relocation.

Figure 4.9 shows the composition of the ten highest contributing material transport impacts, with the remaining impacts aggregated as *Other*. Internationally sourced materials are included. The overall trend in total impacts is reflected in the individual transports: Klitmøller generally has the highest impacts, followed by Odense. However, for precast concrete stairs, beams, and the *Other* category, Odense shows the highest impacts. The baseline scenario, Hedehusene, does not record the highest impact for any of the top ten materials.

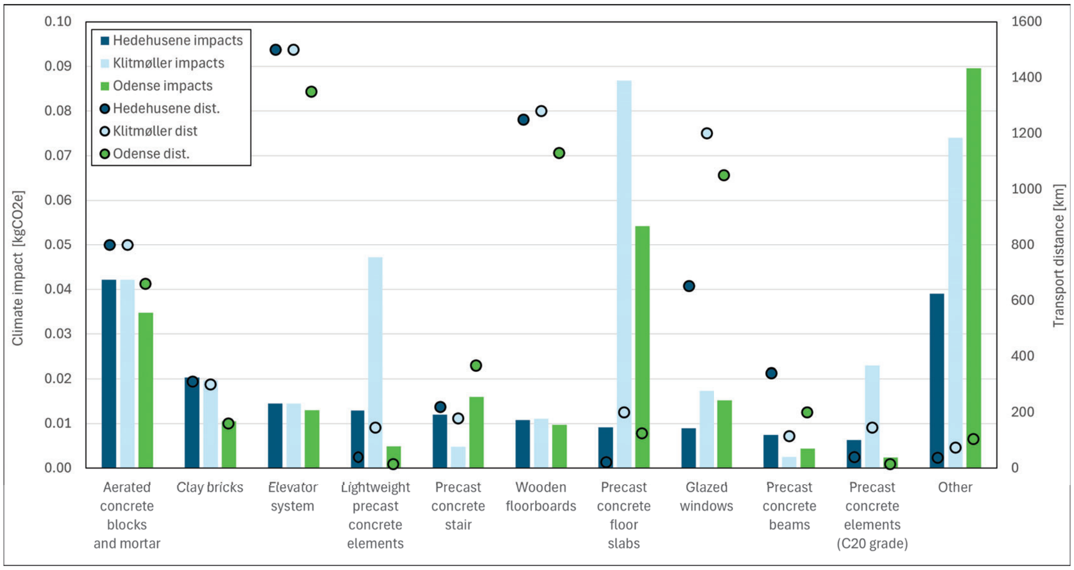

Figure 4.9: Transport climate impacts for the baseline site location (Hedehusene) and alternative locations (Klitmøller and Odense). Values are shown for the ten highest contributing construction materials, with remaining impacts aggregated as *Other*. Materials are sorted by impact for Hedehusene.

The figure shows consistent impacts for certain products such as aerated concrete blocks and mortar, elevator systems, and wooden floorboards, which are all sourced internationally. Other materials, including all types of precast concrete elements, show high sensitivity to site relocation, with impacts for Klitmøller and Odense being 346% and 84% higher than baseline for the total impacts of this category. These are domestically sourced and installed in large quantities, with shorter baseline transport distances compared to other materials in the graph. Consequently, a small absolute increase in distance leads to a large relative increase. For example, precast concrete floor slabs rank among the top ten contributors in the baseline scenario at a transport distance of only 21 km. In the Klitmøller and Odense scenarios, this distance increases by factors of nearly 10 and 5, respectively, resulting in a proportional multiplication of impacts, as the transport modality and impact intensity factor remain unchanged across scenarios. This indicates that transport impacts are highly sensitive to changes in construction site location, especially for heavy domestically sourced materials.

While the graph shows general increases in impacts for the ten most contributing material transports, the trend continues into lower-contributing materials. The *Other* category shows increases of 90% for Klitmøller and 129% for Odense, suggesting that even materials with low baseline impacts may be sensitive to site location. This may occur when a low-impact material in one case has an unusually short transport distance that is not representative of its typical sourcing distance.

In summary, the baseline site location of Hedehusene shows the lowest total transport impacts and the lowest impacts for most materials, indicating a favourable location for low-impact material transport. However, this may also reflect a more effective selection of material producers in the baseline case than in the theoretical scenarios generated by this analysis.

When considering the remaining impact sources however, the highest relative increase in material transport impacts of 80% in the Klitmøller scenario produced a total increase worth considering only in low margin cases on the cusp of non-compliance.

4.3 Impact sensitivity to varying assessment specificity

Until this point, climate impacts have been modelled using a detailed, project-specific approach whenever applicable. This subsection examines how alternative modelling choices permitted by the regulations affect the results, by comparing baseline impacts to those obtained using the default data defined in the Danish Building Regulations and based on the background report *Ressourceforbrug på byggepladsen*[7]. The project-specific approach more accurately represent real-world climate impacts, as the default approach relies on generalised data and fixed values that ignore project-specific parameters. This makes the specific approach more advantageous for prioritising impact reduction measures and resources. Regulatory encouragement of the project-specific approach could therefore promote more effective climate impact mitigation. This analysis evaluates whether applying the more complex approach results in lower climate impact values compared to the default approach.

4.3.1 Total impacts

Total A4 and A5 climate impacts of the case are assessed using either the detailed, project-specific approach or the default approach applying the standard values defined in the regulations. Figure 4.10 shows the total A4 + A5 climate impacts. Not all sources are affected by a change in modelling approach, as some are assessed identically. These include Construction waste, Fuel, Heating, Electricity, Logistics hubs processes, and Transport of machinery.

Numerical values included in Figure 4.10 are shown in Appendix B.3.

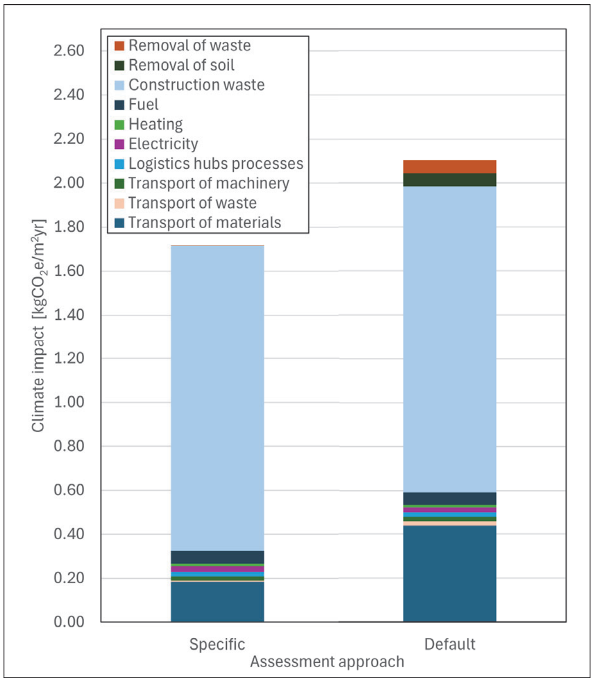

Figure 4.10: Climate impacts per functional unit, [m^2 × year] for project-specific and default data sourcing and assessment methods, including impact composition.

Part of the observed increase in total impacts is linked to the use of fixed standard values in the default approach. These values, applied to their corresponding impact sources, remain unchanged regardless of all parameters, and therefore differ from values obtained in the project-specific assessment. The sensitivity of these sources to the modelling approach is examined in the following Subsection 4.3.2.

The total impact increases by 22.6% when applying the default approach. This is primarily due to an increase in material transport impacts from 0.18 $\text{kgCO}_2\text{e/m}^2$year to 0.44 $\text{kgCO}_2\text{e/m}^2$year, corresponding to a 138.4% increase. This suggests that the default approach assumes more climate-intensive material transport than the project-specific assessment. As the emission factors for transport modalities are similar on a per-kilometre basis in both approaches, the difference is likely due to discrepancies in assumed transport distances rather than transport mode. This change in material transport impacts is examined in greater detail in Subsection 4.3.3 of this section.

4.3.2 Fixed standard values

As shown in Figure 4.10, the impact sources Transport of waste, Removal of soil, and Removal of waste are influenced by the assessment approach. Common to these sources is that they may be assessed using standard values, applied at the end of the calculation in units of $\text{kgCO}_2\text{e/m}^2$year. These values are fixed, meaning they are unaffected by the physical parameters of the construction process and do not vary between projects subject to the regulations. Two additional sources, Transport of machinery and Logistics hubs processes—are also associated with this type of standard value. In total, these standard values amount to 0.18 $\text{kgCO}_2\text{e/m}^2$year, corresponding to 12% of the regulatory threshold of 1.5 $\text{kgCO}_2\text{e/m}^2$year.

In the project-specific assessment of the case, the three sources (1) Transport of waste, (2) Removal of soil, and (3) Removal of waste contribute a total of 0.006 $\text{kgCO}_2\text{e/m}^2$year, corresponding to only 4% of the combined value of their fixed standard factors. The two remaining sources, Logistics hubs processes and Transport of machinery, are assessed using the fixed standard values of 0.02 $\text{kgCO}_2\text{e/m}^2$year each, due to data constraints. Together, these sources account for 0.046 $\text{kgCO}_2\text{e/m}^2$year in the project-specific assessment, corresponding to 26% of the impacts estimated in the default approach for these sources when using only standard values.

This indicates that there is a potential impact-reduction benefit to assessing these sources at a project-specific level for the given case. However, the baseline case has characteristics that reduce the general representativeness of these findings. For transport of waste (production site to construction site), the modest waste quantity of 3% may explain the low project-specific impact of 0.006 $\text{kgCO}_2\text{e/m}^2$year compared to the fixed standard value of 0.02 $\text{kgCO}_2\text{e/m}^2$year. To reach the fixed value, the waste percentage would need to increase to 11%, which is high but not unrealistic.

For removal of soil, the impact is zero because no soil was removed during site preparations, and instead excavated soil was repurposed at neighbouring construction sites, with the associated impacts covered under A5 fuel consumption. For removal of waste, the case again involved modest waste quantity (3%) and a short mean removal distance of 2.6 km. Testing the removal distance required to reach the fixed standard value of 0.06 $\text{kgCO}_2\text{e/m}^2$year shows that a distance of 433 km would be needed for the given waste percentage. This suggests that, while the construction site is favourably located with respect to waste removal, the fixed standard value may also overestimate the actual impacts of this process, as the implied distance is far greater than even the mean material transport distance.

4.3.3 Transport impacts

Transport impacts are further broken down in Figure 4.11, which shows results for the five highest contributing materials in both the project-specific and default approaches. The figure highlights a clear discrepancy in which construction materials are included in each top five list. Only two materials, aerated concrete blocks and mortar, and lightweight precast concrete elements, appear in both lists.

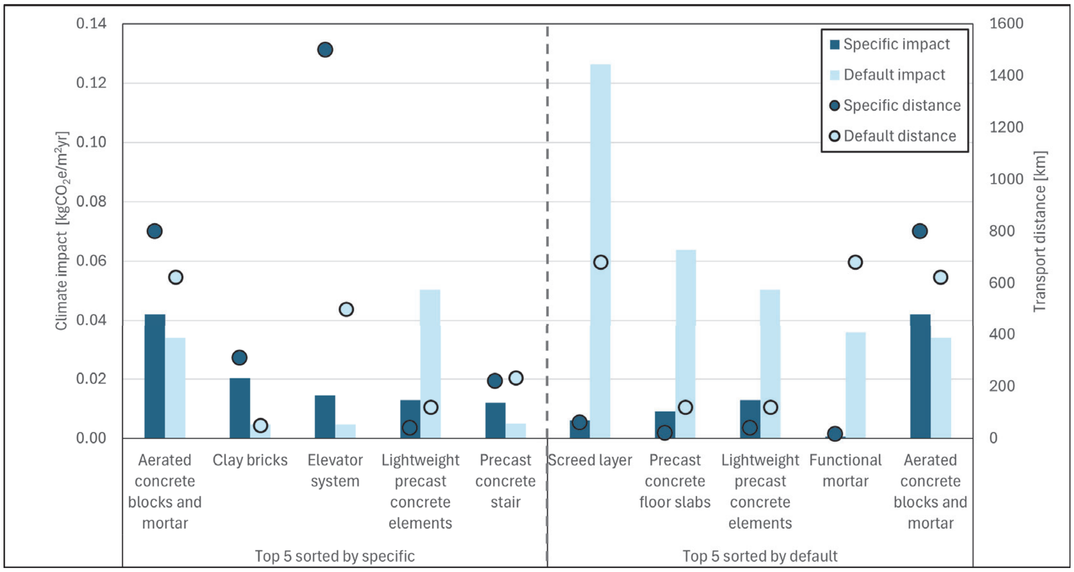

Figure 4.11: Transport impacts of the top five most contributing materials as ranked by project-specific impacts (left) and default impacts (right). Corresponding transport distances are shown on the secondary vertical axis.

The figure also shows notable differences in both impacts and transport distances for all materials in the two top fives, with the exception of aerated concrete blocks and mortar. Materials included in the default top five generally have much higher values than in the project-specific assessment. For example, the screed layer has an impact value 21 times higher in the default assessment, with its transport distance being approximately 11 times higher. This suggests that the standard value applies a higher impact intensity factor, even when accounting for the 1.25 uncertainty factor included in the standard factors for material transport impacts. For functional mortar, the impacts are 57 times higher in the default assessment, with a 43-fold increase in transport distance. These materials are categorised as ”cement-based mortar and render” in the default scenario, which assumes a transport distance of 682 km compared to the real-world distances in the case of 60 km and 16 km for the screed layer and functional mortar, respectively.

Another notable material transport category in the building regulations is ”concrete wall and slab elements”, which assumes a transport distance of 121 km. In this analysis, the materials precast concrete floor slabs and lightweight precast concrete elements fall under this category. As shown in the figure, the project-specific transport distances for these materials are 21 km and 40 km respectively. In total these two material groups represent 71% of material transport climate impacts for the default assessment. This difference may partly reflect a favourable location, as also indicated by the analysis in Section 4.2.2.

4.3.4 Assessment by mixed approach

As outlined in Section 2.3.2, the 2025 building regulations permit a mixed assessment approach, whereby impact sources within the A4 and A5 modules may be modelled using a combination of the project-specific and default approaches for transport impacts. Following the findings in Section 4.3.1, which identified significant discrepancies in transport impacts, particularly for materials assessed using the ”cement-based mortar and render” and ”concrete wall and slab elements” emission factors in the default scenario, this analysis explores a hybrid scenario in which material transport normally assigned these impact values when using the default method is modelled using the project-specific approach, while all other materials are assessed using the default approach, corresponding to 14 represented material groups.

Because the project-specific approach reflects actual transport distances, whereas the default approach relies on standardised assumptions, the discrepancy between the two is expected to vary depending on the project’s average transport distance. To investigate this sensitivity, the analysis includes the baseline site in Hedehusene as well as the two alternative theoretical locations, Klitmøller and Odense, defined in Section 4.2.2. All three scenarios share identical physical characteristics apart from geography, meaning that their impacts assessed by the default method remain identical. This isolates the influence of site-specific transport variation of the two transport categories.

The results, presented in Figure 4.12, show a clear benefit to applying the mixed approach in all three scenarios. For the baseline construction site in Hedehusene, the mixed approach reduces transport impacts by 61% to 0.17 $kgCO_2e/m^2year$. For Klitmøller and Odense, transport impacts are reduced by 29% and 53%, respectively. The variation in reduction across locations is expected: because Klitmøller has a higher average transport distance, the relative effect of applying project-specific values is less pronounced.

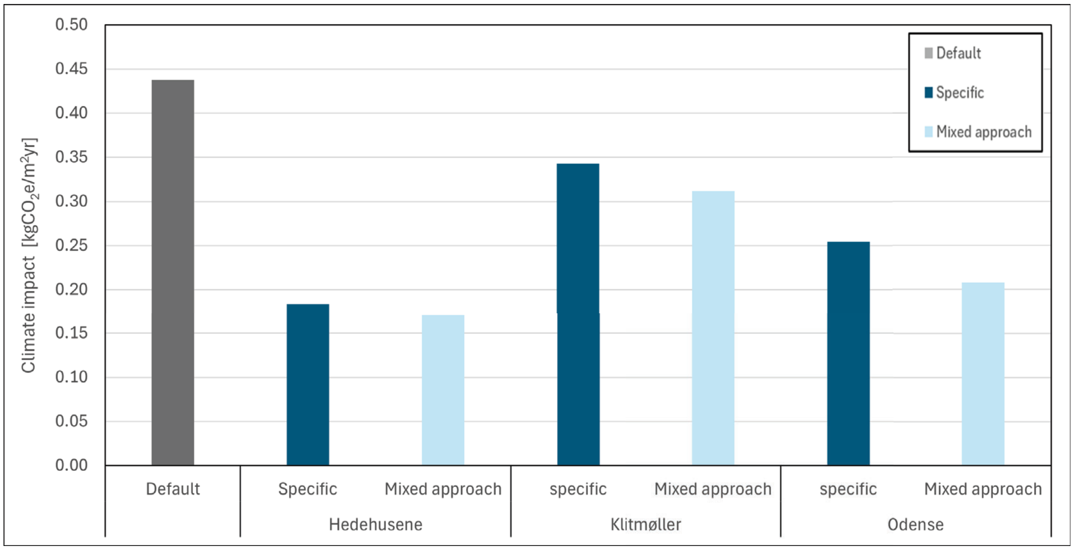

Figure 4.12: Total material transport climate impacts for default, project-specific, and mixed approaches for the baseline case and alternative construction site locations.

Notably, in all three construction site scenarios, the mixed approach results in lower transport impacts than the fully project-specific approach. This occurs because the remaining materials in the mixed approach have lower impacts under the default method than under the specific method. In general, default transport distances and impact values are shown to produce higher total transport impacts, but when high-impact outliers are replaced with project-specific data, the remaining default-assessed materials yield lower values, thereby resulting in a higher total value when included in the assessment. This implies, that targeting certain contributors could produce a more favourable result than accounting for all materials specifically, thereby best representing the actual associated impacts.

This is most pronounced for the Odense location, where a mixed approach provided further reduction of 11% from the specific approach relative to the default. Looking back to Figure 4.9, Odense shows transport distances for the ”concrete wall and slab elements” that lie in between the other scenarios, thereby resulting in a similar relative position when comparing the scenarios to the default assessment approach. Notably, Odense has a higher impact in the *Other* category, meaning impacts of the more marginal contributors are underestimated to at greater extent for this location when applying the default approach as compared to the two other locations. This combination of overestimation of the main contributing categories, and underestimation of the marginal ones, appears to create the conditions of the mixed approach resulting in lower values than the fully specific.

4.4 Impact sensitivity to methodological differences: regulations vs reference

This section compares the impacts resulting from different assessment methods and assumptions applied to identical case parameters, focusing on methodological discrepancies between the 2025 Building Regulations[15] and the BUILD report[7]. Since the regulatory threshold is based on median A4 + A5 impacts identified in the BUILD report through statistical analysis of real-world construction projects, variations in the regulatory assessment method may directly affect the representativeness and applicability of the report's findings. The sensitivity of the resulting impact values to these methodological differences is examined through a scenario-based exploratory analysis of construction waste as well as electricity and district heating consumption.

4.4.1 Scenario-Based comparison of Waste Impacts

The updated regulatory method includes a revised approach for assessing construction waste, where the impact of a mixed fraction is calculated by applying the highest emission factor of any constituent material to the entire fraction. In contrast, the BUILD report bases emission factors for mixed fractions on an estimated average composition. Through the analysis in sections 4.1.2 and 4.1.3, construction waste impacts were implied to be sensitive to methodological choices. As the actual composition of the mixed waste fractions in the baseline case is unknown, this sensitivity is further examined by applying different waste composition assumptions to the baseline waste fractions, producing the waste scenarios *Improved sorting* and *Optimal sorting*, with the baseline waste scenario being the one used throughout the analysis up until this point. The scenarios reflect the characteristics described in Method Section 3.8.1. In addition, a fourth scenario, *BUILD method*, is included in which the baseline waste fractions are assessed using the emission factors from the BUILD report rather than those in the building regulations. For context, the BUILD 25th, 50th, and 75th percentiles for construction waste are also shown to illustrate the statistical basis for the regulatory threshold. A full overview of the scenarios is provided in Appendix B.4.

Figure 4.13 compares the total construction waste impacts for all transporter waste fractions. The baseline scenario yields the highest impact by a wide margin, with a value of 1.39 $kgCO_2e/m^2$year, accounting for almost the entire regulatory threshold of 1.5 $kgCO_2e/m^2$year for A4 + A5 impacts. This corresponds to 81% of the total A4 + A5 impacts for the case, compared to only 38–43% for the BUILD percentiles.

In earlier analysis, the baseline case most closely aligned with the BUILD 25th percentile, which is also true for *Optimal sorting*, where waste contributes 54% of total A4 + A5 impacts. Applying the BUILD approach to the baseline waste fractions in *BUILD method* reduces impacts by 62% to 0.531 $kgCO_2e/m^2$year, closely matching the BUILD 50th percentile. This shows that, when assessed under the same assumptions as the BUILD report, the baseline waste impacts are far lower than when using the regulatory method. For the scenario, *Improved sorting*, in which plastic is present only in the mixed construction waste fraction (with glass as the highest-impact material in other mixed fractions), achieves a 50% reduction relative to the baseline, yielding a value similar to the BUILD 75th percentile. The relative contributions of construction waste to total A4 + A5 showed higher values for both the Baseline , and the *Optimal sorting* scenarios relative to the BUILD percentiles, indicating a higher share of waste contribution for the case, regardless of waste sorting approach.

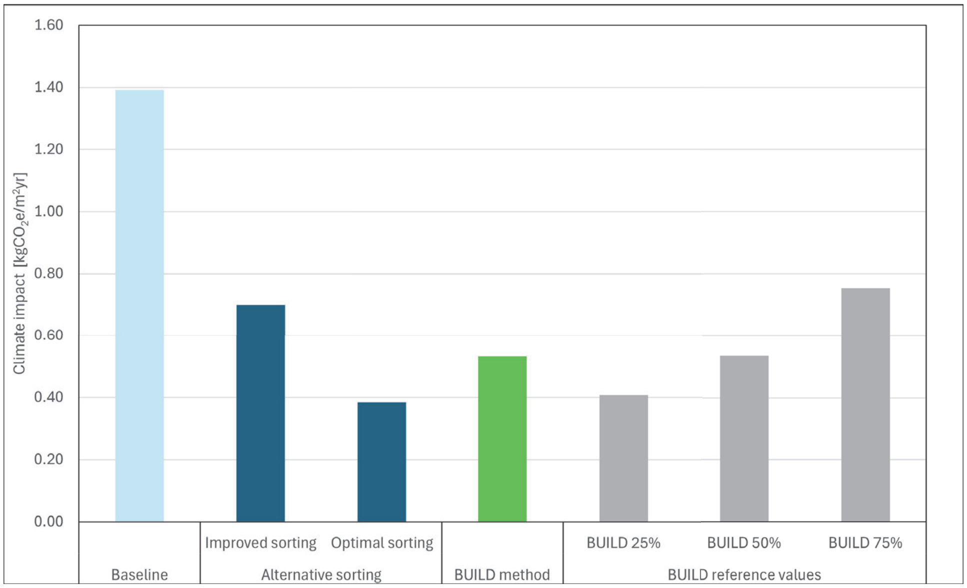

Figure 4.13: Comparison of construction waste climate impacts of baseline, alternative methods, and BUILD percentiles.

Figure 4.14 shows the contributions for the Baseline and alternative sorting scenarios, broken down by transported waste fractions and their relative waste quantities. In total, mixed fractions account for 72.5% of the total waste quantity, with the remaining 27.5% being single-material fractions when the semi-mixed categories ("mixed clay and concrete" and "mixed rubble") are included in the mixed category. While technically mixed, the fractions in the semi-mixed category are each composed of only a few materials with similar emission factors, contributing only 7% of baseline impacts despite representing 38% of waste by weight. When these are excluded from the mixed category, mixed fractions account for 90% of impacts and 34% of the waste quantity.

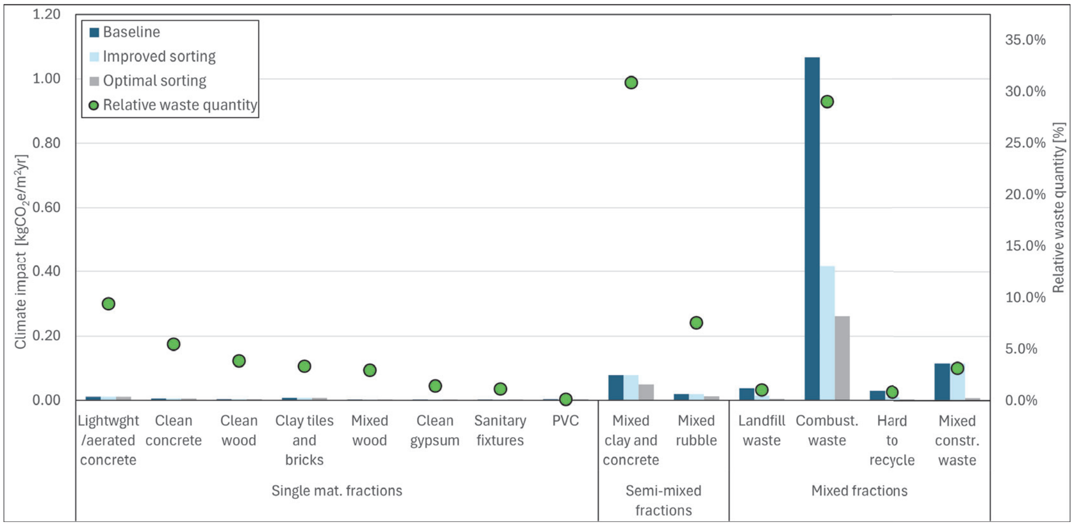

Figure 4.14: Comparative contribution analysis of climate impacts for waste scenarios *Baseline*, and the alternative sorting scenarios, *Improved sorting* and *Optimal sorting* in [kgCO_2e], distributed by transported waste fractions and sorted by single-material and mixed fractions.

Across all scenarios, the majority of impacts from mixed fractions are due to combustible waste. In the baseline, combustible waste accounts for 77% of impacts; in the scenarios *Improved sorting* and *Optimal sorting*, absolute impacts from this fraction are reduced by 61% and 76% respectively, but still contribute 60% and 68% of respective total waste impacts. The analysis shows that construction waste impact values are highly sensitive to assumptions about the composition of mixed fractions. Excluding plastic from combustible, hard to recycle and Landfill alone waste as exemplified by *Improved sorting*, reduces total A4 + A5 impacts by 40%, while optimal waste sorting at the construction site as exemplified by *Optimal sorting* achieves reductions of 59%.

It should be noted that, while improved sorting can influence the actual climate impacts of construction waste, most of the reported impacts for each wasted material stem from A1–A3 production emissions that are attributed to A5. Under the regulatory method, the full A1–A3 impacts of the highest-impact material in a mixed fraction are applied to the entire fraction, when only the C3–C4 and D modules are affected by the waste management processes. This means that the reported A5 impacts are highly sensitive to waste quantities, composition, and on-site sorting, whereas the actual GHG emissions from waste management are affected to a much lesser degree, and the waste scenarios *Improved sorting* and *Optimal sorting* may reflect the actual construction waste climate impacts of the baseline case more accurately.

4.4.2 Energy factors

As outlined in theory Section 3.8, the emission factors for electricity and district heating consumption in the 2025 Building Regulations differ from those used in the background report *Ressourceforbrug på byggepladsen*, which underpinned the previous regulations. The difference is not solely due to actual improvements in electricity and district heating production, but also reflects an updated assessment approach to determining their associated impacts, as described in Section 3.8.2. This section examines the effect of that change by assessing the baseline case using both the updated and previous factors, and comparing the results to the consumption percentiles from the BUILD report to evaluate their proportions relative to the statistical foundation of the threshold.

Figure 4.15 presents the A5 electricity and district heating impacts for both sets of factors. The updated factors are lower, leading to a reduction in the calculated impacts of around 45% for all scenarios. For the baseline case, this reduction is small, corresponding to only 2% of the regulatory threshold. For the BUILD 25th percentile, the reduction is about 3%, for the 50th percentile about 7%, and for the 75th percentile about 10%. Correcting the BUILD 75th percentile for the updated factors would lower its total A4 + A5 impact from 1.77 $kgCO_2e/m^2year$ to 1.60 $kgCO_2e/m^2year$. This suggests that cases with high electricity and district heating consumption are more likely to remain within the regulatory threshold of 1.5 $kgCO_2e/m^2year$ when assessed using the updated values.

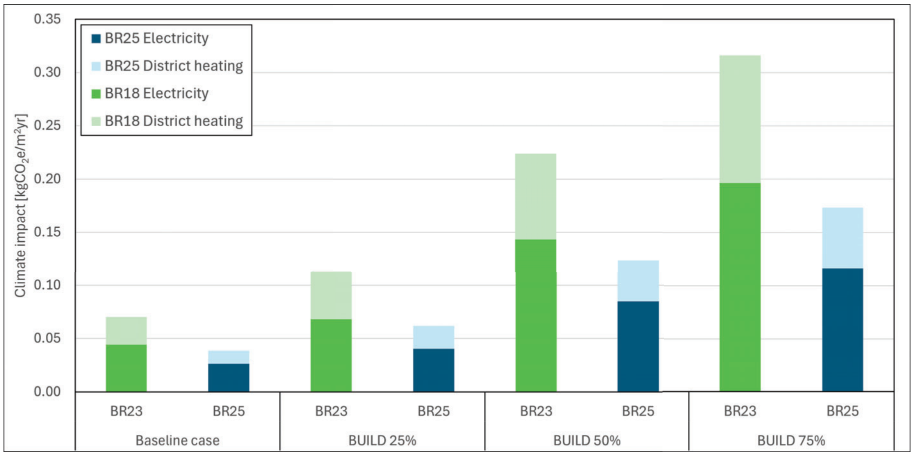

Figure 4.15: Climate impact in $kgCO_2e/m^2year$ of consumption of electricity and district heating assessed using emission factors from Danish building regulations 2023 and 2025 (BR23 & BR25). Assessed for 4 scenarios: the case and BUILD 25%, 50% and 75% percentile scenarios.

It is worth noting that, for any given case, the reduction in impacts due to the updated energy consumption factors is likely smaller than the increase associated with the updated construction waste method (Section 4.4.1). Overall, an increase in total A4 + A5 impacts can be expected under the 2025 regulations, although the share from electricity and district heating will be lower than under the previous factors.

4.5 Boundaries of total reported impacts

As a final analysis, two scenarios are constructed to represent upper and lower bounds of possible climate impacts from sources included in the A4 and A5 modules. The scenarios synthesise results from preceding sections and isolate the effect of methodological choices, such as assessment approach and emission factors, without altering physical parameters like transport distances, waste quantities, or energy consumption levels. In both cases, the physical parameters of the baseline case remain unchanged, and all differences between scenarios arise solely from varying methodological assumptions and data sources identified in preceding analyses.

The methods applied to the lower value scenario would not be suitable for regulatory use, as the construction waste is represented by scenario *Optimal sorting* from section 4.14, where mixed fractions are assessed using an assumed composition, which is not permitted by the building regulations. As argued, however, this result may be a closer estimation of the actual climate impacts of construction waste for the scenario as compared to the result fit for the regulations. The upper value scenario is based exclusively on the standard values in the building regulations. This approach makes the composition and total identical to the *Default* scenario from section 4.3.1, as the standard values were found to produce the highest impact results.

The scenarios highlight the range of variation introduced by methods applied and illustrate the overall sensitivity of A4 and A5 impact results to methodological differences. The upper and lower value scenarios are compared to the impacts as assessed by the project-specific approach used for the baseline scenario, where all assessments fully abide by the regulations' approved methodological approaches. Worth noting is that, whereas the lower value scenario applies the *Mixed-approach* results included in section 4.3.4 for material transport, the baseline scenario does not, even if this would be fully accepted within the regulations' context, since the baseline case represents a project-specific but standard assessment. This difference does not produce notably different results for material transport.

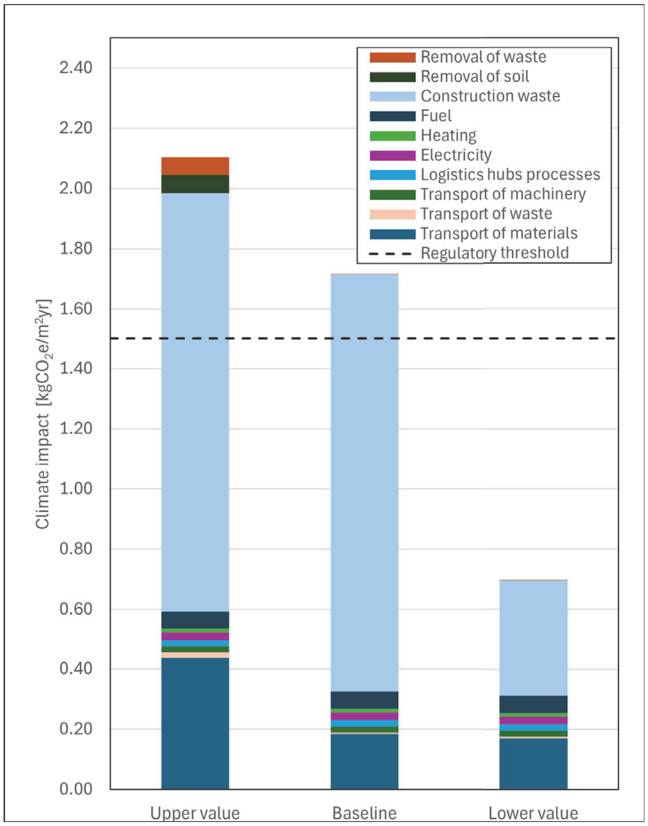

Figure 4.16: Comparison of baseline to boundaries for total A4 + A5 impacts depending on assessment approaches. Boundaries exemplified by scenarios "Upper values" and "Lower values" representing upper and lower potentials for reported A4 and A5 climate impacts.

For some sources such as energy consumption, impacts are not affected as only one methodological approach is permitted. Regardless, the difference between the upper and lower total values is notable, as shown in Figure 4.16. The lower value corresponds to only one third the upper value, at 0.7 $kgCO_2e/m^2$year and 2.1 $kgCO_2e/m^2$year respectively. Comparing the lower value to the baseline, a 59% reduction is seen. This reduction is almost entirely caused by the alternative waste assessment approach, causing a 1.0 $kgCO_2e/m^2$year reduction. This reduction is larger than the remaining impacts and large enough to reduce the total impacts from 115% to only 47% of the regulatory threshold. It should be noted that applying the *Improved sorting* waste scenario with the remaining sources constant would also result in regulatory compliance, at a total A4 + A5 impact value of 1.0 $\text{kgCO}_2\text{e/m}^2$, corresponding to only 68% of the threshold value. This suggests that a scenario representing optimal waste handling at the construction site may not be necessary, as a more moderate scenario of keeping plastic out of all except one mixed fraction is sufficient to reduce the reported climate impacts to well below the regulatory threshold. As previous analysis showed, the waste quantity and composition of the case are not irregular, and this analysis implies that applying the waste emission factors for the entirety of the mixed fractions as dictated by the regulations produces reported impacts well above the threshold, even for cases that are relatively low impact for the remaining sources. Additionally, the variation between the two boundary scenarios is greater at 1.4 $\text{kgCO}_2\text{e/m}^2$, than the variation between the BUILD lowest and highest percentiles (25% and 90%), where the difference is 1.3 $\text{kgCO}_2\text{e/m}^2$.

This degree of variation means that, for otherwise identical projects, compliance with the regulatory threshold may depend more on the methodological approach applied than on actual differences in construction processes or performance. Such sensitivity reduces the robustness of the regulation as a consistent benchmark for climate impact performance.

5 Discussion

This study set out to assess construction process–related climate impacts for a real-world building project using the methodology prescribed by Denmark's 2025 Building Regulations. In doing so, it examined the implications of applying the regulatory method to a common Danish construction context and explored how variations in physical and methodological parameters influence *reported* climate impacts. The broader objective has been to inform effective mitigation strategies for A4 and A5 emissions within a national regulatory framework.

The following discussion builds on the results presented in Section 4, and reflects on the research questions introduced in Section 1, focusing first on the baseline case assessment before considering sensitivity to geography, assessment approach, and methodology.

5.1 Baseline case findings

The baseline assessment (Section 4.1.1) yields a total A4 + A5 impact of 1.72 $\text{kgCO}_2\text{e/m}^2$year, exceeding the regulatory threshold by 15%. Impacts are heavily dominated by module A5, particularly from construction waste, which contributes approximately 80% of the total. This is markedly higher than in the BUILD reference dataset, where the highest observed waste share was around 45% [7]. These values also exceed the ranges as identified in the literature (Section 2.2).

Importantly, the case's waste quantity is not exceptional. The baseline waste share of 3% is situated at the lower end of the Danish Technological Institute's estimated range of 20–100 kg waste per m^2 floor area [40], corresponding to 1.7–8.7% for this project. This suggests that effective measures for waste reduction have already been implemented, and the high reported waste impact is not the result of excessive waste generation. Rather, the variation analysis in Section 4.1.2 shows that total reported impacts are highly sensitive to waste quantities and a 17% reduction in on-site waste generation would be required for the case to meet the threshold, a considerable reduction given the already low generation.

A more detailed breakdown reveals that the *Combustible* waste fraction is the dominant contributor, accounting for around 62% of total A4 + A5 impacts (Section 4.1.2). While this fraction is also prominent in the BUILD study, its influence there did not translate to such a high share of overall impacts, again pointing to differences in assessment method rather than physical composition alone.

Transport of materials is the second-largest contributor, at approximately 11% (0.18 $\text{kgCO}_2\text{e/m}^2$year). This lies below the 19–24% (0.19-0.49 $\text{kgCO}_2\text{e/m}^2$year) range reported in the BUILD study. When sources assessed via fixed standard values are excluded, the pattern becomes more pronounced with the case still showing an 11% transport share, while the BUILD range increases to 24–28%. In absolute terms, the case aligns with the 25th percentile of the BUILD transport data, suggesting that its relative underrepresentation stems more from elevated waste impacts than from unusually low transport emissions (Section 4.1.3).

Overall, these findings indicate that the case's exceedance of the threshold may not be driven by outlier physical performance but rather by the methodological treatment of construction waste as mandated by the regulations.

These findings directly address Research Question 1, and indicate that the case project's A4 + A5 impacts are dominated by construction waste, and exceed the regulatory threshold by 15% despite physically typical waste generation and transport patterns. This suggests that the exceedance reflects regulatory methodology rather than atypical on-site performance.

5.2 Variations in geography

Given that material transport was identified as one of the more significant contributors to A4 + A5 impacts in the baseline case, a scenario-based analysis was conducted to examine how geographical variation in both material sourcing and construction site location might influence climate performance. As the physical parameters for construction waste were outweighed by the methodological variations, this analysis is the main contributor to answering Research Question 2. In summary, the geographic factors such as supplier location and site positioning influence transport emissions and can shift total A4 + A5 impacts by up to 9%, but these effects remain secondary to construction waste impacts under the regulatory framework.

5.2.1 Material sourcing

Material sourcing was explored as a potential lever for reducing transport-related climate impacts. However, in the baseline case, the effect appears limited as only three of the ten highest-contributing materials had technically viable substitutes with shorter transport distances. These substitutions achieved individual transport reductions of 62%, 72%, and 52%, resulting in a net A4 material transport impact reduction of 21% across the scenario corresponding to a total A4 + A5 reduction of 2%.

Two important caveats apply. First, technical feasibility remains uncertain. The screening could not fully account for case-specific requirements that were considered during the actual procurement process. As such, the proposed substitutions may not be realistic in practice due to unconsidered factors. Second, reducing A4 impacts through material substitution does not ensure a reduction in whole-life climate impacts. Substituting materials can influence emissions in other life cycle modules, and as noted in Section 2.1.3, A4 typically constitutes a small share of total life cycle emissions. A substitution that reduces transport impacts could, in some cases, increase total climate impacts.

Taking these considerations into account, and in light of the relatively low baseline transport impacts compared to the BUILD dataset, the material sourcing of the case can be regarded as close to optimal with respect to A4. This suggests that targeted material substitution may offer greater climate benefits for projects with higher baseline transport emissions. As reported by the BUILD study [7], the median A4 impact from material transport is nearly twice as high as that of the case project which indicates a reduction potential on a broader scale. While the low transport impacts of the baseline case could reflect conscious sourcing choices, it may also be partially attributable to the construction site having favourable geographic location relative to suppliers.

5.2.2 Construction site location

The effect of relocating the construction site was assessed using two alternative Danish locations: Klitmøller and Odense. These scenarios yielded mean transport distances of 167 km and 118 km, respectively, compared to 81 km for the baseline site. The resulting increases in A4 transport impacts were substantial at 80% for Klitmøller and 34% for Odense, demonstrating a clear sensitivity to site geography within national boundaries.

Klitmøller, the most remote scenario, showed the greatest impact increase, primarily due to longer transport routes for heavy, domestically sourced materials. The Odense scenario also showed elevated impacts despite its central location, which can be attributed to a sparser local supplier base on Funen. As shown in Figure 4.7, only one of the ten highest-contributing materials was sourced within 100 km of the Odense site, compared to five in the baseline scenario. Some of this difference may stem from limitations in the scenario development process, which aimed to replicate the baseline's sourcing principles but lacked the resolution of a full procurement process, thereby potentially overlooking nearer viable alternatives and thus inflating calculated impacts.

When all A4 + A5 sources are considered, the effect of site relocation on total reported impacts is more modest. Relocating the project to Klitmøller increases the total A4 + A5 impacts by approximately 9%, even though transport distances more than double. This contrast highlights the dominant impact of construction waste under the regulatory methodology. It underscores that, while geography can affect transport impacts, compliance is more strongly shaped by waste composition and treatment assumptions. Effective waste prevention and sorting therefore remain more impactful strategies for reducing A4 + A5 emissions under the regulatory framework.

5.3 Specificity approach as the variable

The results show that the chosen assessment method has a substantial influence on reported A4 + A5 climate impacts and can significantly affect regulatory compliance outcomes. Within the framework of the 2025 Danish Building Regulations, multiple approaches are permitted for quantifying emissions from transport and waste, depending on the availability of project-specific data. The following discussion considers the implications of the default, specific, and mixed approaches, as well as the role of fixed standard values. The results show that permitted differences in assessment specificity can change reported A4 + A5 impacts by more than 20%, enough in some cases to alter compliance outcomes, with transport impacts being particularly sensitive to default assumptions.

5.3.1 Default and specific methods

Applying the default modelling approach results in a 23% increase in total A4 + A5 impacts compared to the project-specific method. Notably, this increase exceeds the relative differences produced by the geographical variation scenarios, even when they result in transport distance being more than doubled, as in the Klitmøller case. The main driver of this increase is material transport, which rises by 138% under the default approach.

In the default method, each material is assigned to a regulatory material group with an embedded average transport distance. The scale of the observed increase suggests that actual transport distances in the baseline case are significantly shorter than those assumed in the regulatory dataset. This is further supported by the fact that the difference exceeds the uncertainty factor of 1.25 also embedded in the default factors.

An examination of material contributions for each of the approaches reveals shifts in which materials rank as dominant sources. Only two materials appear among the top five contributors in both approaches. For some materials, transport impacts differ by up to a factor of 57 between the methods. Two default categories—"cement-based mortar and render" and "concrete wall and slab elements"—are particularly influential, accounting for 71% of total transport impacts under the default method. These findings suggest either a favourable supplier location for the baseline case or an overestimation in the default emission factors for these categories.

5.3.2 Mixed approach

The influence of these dominant categories was further investigated using a mixed assessment approach, in which the default method is used for most materials but replaced by specific assessment for the before mentioned categories showing the largest overestimation. This scenario was applied to all three construction site locations. Across all cases, the mixed approach yielded lower transport impacts than the fully default approach, with the most pronounced reduction—61%—observed for the Hedehusene site.

This finding demonstrates that selectively applying project-specific assessment to a few key materials can, under certain conditions, result in a lower total than assessing all materials specifically. This could indicate a potential loophole, where using the mixed method to selectively replace only high default impact categories could allow projects to report artificially low, but still methodologically valid, transport climate impacts. In this analysis, only two of sixteen material groups were reassessed, yet these accounted for the majority of the transport reduction. Extending the method to additional materials may yield further reductions, although diminishing returns are likely.

While these findings suggest a theoretical risk of strategic modelling, its practical impact on compliance appears limited. However, the Odense case indicates that certain project characteristics can amplify the effect, and in specific instances, the mixed approach may be sufficient to bring otherwise non-compliant projects below the threshold

5.3.3 Fixed standard values

The remaining increase in total impacts under the default method stems from the application of fixed standard values to three sources: *transport of waste*, *removal of soil*, and *removal of waste*. These sources collectively contribute 0.18 kgCO$_2$e/m^{2}year under the default approach, a value comparable to the transport impact reported for the baseline case using project-specific data.

In this study, project-specific results for these sources were consistently lower than the corresponding fixed values. The reason for this discrepancy is unclear, as the underlying assumptions behind the fixed values are not published by BUILD. However, several characteristics of the case plausibly contribute to the difference: no soil was removed, waste quantities were modest, and removal distances were short. These case-specific conditions likely lead to lower-than-average impacts for these sources.

If this pattern holds true at a general level, project-specific assessment could, in marginal cases, determine whether a project complies by the threshold. However, as the combined fixed-value sources account for at most 12% of the threshold, so such cases are assumed to represent a limited share.

5.4 Effects of methodological change from BUILD study to regulations

The comparative analysis in Section 4.4 demonstrates that methodological differences between the 2025 Building Regulations and the BUILD report [7] significantly influence reported climate impacts from construction processes, even when physical project parameters remain constant. This is particularly important given that the regulatory threshold of 1.5 kg CO$_2$e/m^2/year is derived from BUILD's statistical dataset. If the assessment method used to demonstrate compliance differs from that used to define the threshold, comparability is compromised and uncertainty introduced.

5.4.1 Construction Waste Assessment

The most prominent discrepancy is found in the treatment of mixed construction waste fractions. While the BUILD method applies a composition-weighted average based on estimated fraction composition, the BR18 methodology requires that the highest-impact constituent be applied to the full fraction [15]. As shown in Figure 4.14, applying the building regulations method to the case results in a construction waste impact of 1.39 kg CO_2e/m^2 (Baseline), compared to 0.86 kg CO_2e/m^2 under the *BUILD method*—a 38% decrease for identical waste quantities.

The scenarios *Improved sorting* and *Optimal sorting* simulated alternative waste sorting, while applying the updated emission factors for waste fractions, and similarly to the *BUILD method* scenario, produced notably lower impact results. The *Improved sorting* scenario, simulating an easily implement improved waste sorting reduces the baseline value by 50%, while the *Optimal sorting* scenario, which assumes full separation into single-material fractions, results in a total A4 + A5 impact of only 0.71 kg CO_2e/m^2, corresponding to the lowest value assessed. Comparison of the scenarios, *Optimal sorting* and *BUILD method* suggests, that the updated emission factors of the regulations would result in a reduced climate impacts if assessment method had been kept constant. However, *Improved sorting* displays, that much of the improvement can be made by keeping plastic waste in only one of the mixed fractions, and instead having the highest-impact constituent part being glass, which has the highest corresponding emission factor behind plastic and PVC. This also shows that the reduced value of waste factors is consistently negated by the stricter methodology.

This shift in assessment logic has important implications. Projects with comparable physical waste handling may report significantly different climate impacts depending on the assumptions made for the mixed waste fractions. As the regulatory threshold is based on BUILD percentiles, this divergence introduces an unintended bias where projects now face a higher risk of exceeding the threshold not due to poorer performance, but due to methodological reinterpretation.

5.4.2 Energy emission factors

Smaller but still notable discrepancies arise from updated emission factors for electricity and district heating. The BUILD report applied different emission factors than those specified in the current BR18 framework. When BUILD energy impacts are recalculated using current BR18 values (Equation 3.8.2), an approximate reduction of 45% is observed across the baseline case and BUILD percentiles. The total corresponding reductions in impacts however showed negligible margin for the baseline case and BUILD 25th percentage. When considering the consumption implied of the BUILD 75th percentage, a reduction of 10% relative to the regulatory threshold is implied. This suggests that consumption must reach a high value relative the general levels to substantially influence compliance margins.

5.4.3 General implications

In terms of compliance, these findings illustrate changes in both directions. While impact values of the regulatory dataset may be reduced slightly, any case with mixed waste fractions risks having this reduction being more than negated, as waste impacts may be several times higher as compared to the values expected from identical fractions and quantities assessed under the BUILD methodology.

While the waste assessment approach implemented in the regulations highly incentivise improved waste sorting practices, actual climate impacts are not effectively estimated. Besides the EoL modules C3 and C4, the emission factors for A5 construction waste notably include the A1-A3 modules of the wasted materials, as these are not accounted for in the general A1-A3 assessment which only accounts for installed materials. As material production generally attributes the majority of whole life cycle climate impacts for a given material [4], this approach not only applies waste treatment related impacts for the entire fraction, it also applies production related impacts, where the material of which the emission factor may only contribute few percentage points of the composition of the waste fraction, thereby overestimating the prioritisation warranted of waste sorting. This approach is misaligned with the principles defined in Section 3.4, that encourage impacts being accurately assessed in the context of climate regulations as to increase the effectiveness and prioritisation of mitigation strategies.

5.5 Relative magnitude of methodological boundaries

The boundary analysis (Section 4.5) shows that methodological choices alone can produce a range of 1.4 $\mathrm{kgCO_2e/m^2}$year in reported A4 + A5 impacts. This exceeds the spread between the 25th and 90th percentiles in the BUILD dataset, indicating that methodology can drive differences comparable to, or greater than, those observed across a wide range of real-world projects.

The effect size also surpasses the variation achieved by altering physical parameters in this study. For example, relocating the construction site to the most distant scenario increased total impacts by only 9%, and targeted material substitutions reduced total impacts by 2%—both far smaller than the methodological range. This suggests that, within the current framework, compliance outcomes may be more sensitive to how impacts are assessed than to changes in physical performance.

Comparing all results, methodological variation produced a greater range in reported impacts than either physical project changes or the observed spread between most and least impactful projects in the BUILD dataset, underscoring the dominant role of assessment choices in determining compliance.

5.6 Synthesis of findings in relation to research questions

The research questions defined in Section 1.1 have been addressed implicitly throughout the results and discussion, where each thematic subsection explores aspects of the case in relation to physical performance, regulatory methodology, and assessment approach. This subsection consolidates those insights by providing concise, targeted answers to each question. In doing so, it serves to clarify how the findings relate directly to the study's core objectives and provides a structured overview of the conclusions drawn from the analysis.

Research Question 1

The baseline case study assessed using the BR18 methodology yields total A4 + A5 impacts of 1.72 kg $\mathrm{CO_2e/m^2}$year, exceeding the regulatory threshold by 15%. Impacts are dominated by module A5, with construction waste alone contributing approximately 80% of the total. Waste quantities were within typical ranges, suggesting that the exceedance results from the methodological treatment of mixed waste fractions rather than physically excessive waste generation. Transport of materials contributes 11% of total impacts, placing the case near the 25th percentile of the BUILD dataset for A4 emissions, however, when considering total A4 + A5 impacts, the case aligns more closely with the 75th percentile.

Research Question 2

Impacts are shown to be highly sensitive to waste quantities and assumed composition. A 50% variation in total waste resulted in a change of approximately 40% in total A4 + A5 impacts. As the assessed case already lies at the lower end of the typical waste range, this suggests limited remaining potential for reduction through waste prevention alone. Changing the assumptions for composition of mixed waste fractions to a plausible, implementable scenario, reduced total impacts by 40%, placing the case well within compliance. Geographic variation in supplier location and site positioning showed a measurable, though more modest, influence on transport emissions. Substitution opportunities were identified for only three of the ten most impactful materials, reducing A4 transport by 21% and total A4 + A5 impacts by just 2%. Relocating the site to Odense and Klitmøller increased average transport distances by 46% and 106%, raising total impacts by 4% and 9%, respectively. These findings confirm that, under the regulatory framework, construction waste parameters are the primary drivers of A4 + A5 results, while geographic factors play a secondary role.

Research Question 3

Permitted variation in assessment approach between default, specific, and mixed methods—resulted in differences in total reported A4 + A5 impacts exceeding 20%. Although compliance was not affected in this case, the magnitude of these differences is sufficient to influence compliance margins in other projects. The default approach increased total impacts by 23%, primarily due to a 138% rise in transport emissions. A mixed approach reassessing just two high-impact material groups reduced transport impacts by up to 61% compared to the fully default scenario, illustrating the potential for strategic modelling within regulatory boundaries.

The methodological shift from the BUILD approach to the regulatory framework, particularly the introduction of the “highest-impact constituent” rule for mixed waste fractions, highly affected reported impacts. For identical waste quantities, this change increased construction waste impacts by 160% when comparing the regulatory method and emission factors to those of the BUILD study. A scenario simulating optimal waste sorting and assessed using the BUILD method but with updated regulatory emission factors produced even lower impacts than the original BUILD-based scenario, demonstrating that stricter methodology, rather than updated factors, is the primary driver of the increase.

Overall, methodological choices produced a range of 1.4 kg CO_2e/m^2year in reported A4 + A5 impacts. This is a larger variation than that caused by any physical parameter tested in this thesis or observed across the BUILD dataset.

5.7 Policy and practical implications

This thesis highlights key implications for both policymakers and practitioners working with life cycle climate assessments and building construction under Denmark’s 2025 Building Regulations. This section serves as a synthesis of the most important findings, and provides actionable recommendations for building design, construction site practices, regulatory documentation, and policymakers.

5.7.1 Actionable recommendations for design and construction practices

For professionals involved in building design, material procurement, and on-site construction planning and practices, several measures can reduce reported climate impacts, actual emissions and support regulatory compliance.

In design and procurement:

- **Minimise unnecessary procurement.** Materials that are procured but not installed and end up as construction waste transfer their full production impacts to A5. Given the narrow compliance margins relative to whole-building LCA, avoiding over-ordering is crucial. Surplus materials should be repurposed in other projects to prevent avoidable emissions.

- **Favour lighter materials**. Since transport emissions scale linearly with weight, reducing material mass contributes directly to lower A4 impacts. Choosing a lighter construction method inherently reduces both transport at waste impacts.

- **Source materials domestically**, where feasible. Even material quantities making up only a few percent of total quantities can disproportionately affect A4 impacts if sourced from distant suppliers. International sourcing should be pertained to materials and products not represented by the Danish market.

- **Source heavy materials locally**. Where high-mass products are required, sourcing locally can substantially reduce associated emissions, as a short increase in transport distance can lead to large increases in emissions for heavy materials.

- **Adopt a whole-life cycle perspective**. While regulatory compliance is essential, material selection should prioritise minimising total life cycle impacts across all modules—not just A4 and A5—to ensure that local optimisation does not lead to higher emissions elsewhere in the building's life cycle

In construction site management:

- **Reduce on-site waste generation**. Preventing waste at the source is the most effective means of lowering both reported and actual climate impacts from construction. Waste minimisation should therefore be a central priority in site planning and execution.

- **Enforce strict on-site sorting of construction waste**. Under the regulatory method, mixed fractions containing even small amounts of high-impact materials (e.g., plastic, PVC) are assessed using the highest relevant emission factor. Reducing prevalence across fractions improves climate performance both in terms of regulatory compliance, and actual impact reduction.

- **Recognise that proper sorting consistently reduces reported impacts**. Improved sorting reliably yields lower emissions under the regulatory method, and is directly actionable at the site level.

Together, these practices not only improve the likelihood of regulatory compliance, but also contribute to genuine climate mitigation by reducing emissions and ensuring that reported impacts more accurately reflect on-site performance.

5.7.2 Recommendations for LCA practitioners

For professionals conducting regulatory LCAs, the thesis recommends using project-specific assessment methods wherever possible.

While this may appear to facilitate regulatory compliance without changing physical performance, this approach leads to more accurate representation of actual emissions and strengthens the basis for targeted mitigation.

Recommended practices include:

- **Collect detailed data for construction waste fractions**. Properly distinguishing plastic-containing waste from other mixed fractions can significantly reduce reported A5 impacts, without compromising methodological validity. This avoids the precautious assumption of plastic being included in mixed waste fractions where this is not the case.

- **Apply project-specific transport distances for key material categories**. A mixed-method approach is recommended, but should only be used to correct clear overestimates in default values. Selective substitution of high-impact categories must be done transparently to avoid skewing results.

- **Document cases where fixed-value processes do not apply**. For example, if no soil is removed or if waste is transported only short distances, using default emission factors can substantially overestimate actual impacts.

This approach does not undermine the regulation's intent. Rather, it ensures that reported emissions reflect real performance, enabling more rational prioritisation of mitigation efforts. In doing so, practitioners strengthen the regulatory framework's robustness and credibility.

5.7.3 Policy recommendations

The analysis demonstrates that certain methodological elements in the regulatory framework, particularly the treatment of construction waste, may introduce significant overestimation of reported emissions. While the intention of incentivising improved sorting is well-founded, assigning disproportionately high impacts can distort mitigation priorities and lead to inefficient allocation of resources.

Recent Danish research confirms that improving on-site waste sorting does yield meaningful climate benefits [49], but such practices should be supported by proportionate and evidence-based emission factors.

Furthermore, differences in methodology and assumptions can produce a spread of reported A4 + A5 values greater than the full range observed across typical project variation in the BUILD dataset. As shown in Section 4.5, the same case may fall below or above the threshold depending solely on assessment choices, raising concerns about methodological consistency and fairness.

To address these issues, two principal policy responses are recommended:

- **Recalibrate the regulatory threshold** to reflect the more conservative methodology introduced in the regulations. This would restore alignment between the percentile-based threshold and actual compliance rates.

- **Revise the waste assessment methodology** to better reflect real emissions, by proportionally attributing impacts based on actual material shares rather than worst-case assumptions.

Either adjustment would improve the regulation's transparency, fairness, and climate effectiveness—ensuring that compliance is driven by real-world performance, not the chosen methodological approach.

5.8 Limitations of the study

While the analysis provides detailed insight into the influence of physical and methodological parameters on construction-related climate impacts, several limitations should be acknowledged.

First, the thesis is based on a single case project, which limits the generalisability of the quantitative findings. While the selected case is representative of common Danish construction practices, differences in project type, size, or procurement strategy may lead to different impact distributions or sensitivities, which are not accounted for in this thesis.

Second, the scenario approach used throughout this thesis provides analyses that are based on assumptions or estimated parameters, particularly for alternative transport distances, material substitutions, and waste sorting outcomes. Although these were developed using transparent methods, they are subject to uncertainty and can not fully reflect real-world procurement or on-site conditions.

Third, the thesis exclusively assesses climate impacts with GWP as the impact category as per the IPCC GWP100 characterisation method[16]. While climate change remains a global challenge in need of mitigation, other environmental challenges are affected by the impact sources assessed in this thesis. These challenges are unaddressed, but could potentially be negatively impacted by the recommendations of this report. Some notable impact categories affected by the construction site processes are:

- Particulate matter formation (PMF) - Fuel consumption, especially diesel combustion emits particles that are damaging to human health. Reducing transport distances will have a positive effect on improving air quality and thereby human health.

- Resource depletion - Reducing construction waste generation and improving waste sorting, thereby increasing opportunity for recovery of valuable materials, reduces pressure on extraction of raw materials.

- Acidification Potential (AP) - Fuel combustion causes emissions of acidifying pollutants such as SO_2 and NO_x, cause acidification that damages ecosystems.

- Eutrophication potential (EP) - Fuel combustion causes emissions of Nitrogen containing pollutants such as NO_x that cause excessive nutrient levels damaging ecosystems.

While the presence of these impacts are known, they are not quantified and analysed, limiting the opportunity for recommendations for overall environmental impact mitigation.

Fourth, this thesis fails to apply data and uncertainty testing that is common and recommended for LCA studies. This is done to expand the scope of the single case without requiring high amounts of verification, but ultimately reduces the robustness of the findings.

Finally, the analysis focuses exclusively on modules A4 and A5. Focusing exclusively on selected life cycle modules while excluding others is inherently paradoxical, as it contradicts the holistic nature of the life cycle perspective. However, such scoping is often a practical necessity. All LCA studies are constrained by time, data availability, and analytical resources. In cases where the objective is to conduct a detailed and context-specific analysis, narrowing the system boundaries becomes a justified methodological choice. This allows for a deeper investigation of the most relevant processes, acknowledging that a full-system assessment may not be feasible under given circumstances.

These limitations do not diminish the validity of the conclusions but should be kept in mind when interpreting the results or applying them in broader regulatory or design contexts.

6 Conclusion

This thesis investigated climate impacts associated with construction processes (modules A4 and A5) under the methodological framework of Denmark's 2025 Building Regulations. The analysis centred on a residential construction project located in a Copenhagen suburb, consisting of both multi-storey buildings and townhouses, with a total area of approximately 14,000 m^2. Through this detailed case thesis, supported by scenario-based variations and methodological comparison, the research provided insights into the determinants of reported climate impacts, their sensitivity to physical and methodological parameters, and the practical, and regulatory implications of these findings.

The baseline assessment revealed that reported A4 + A5 impacts exceeded the regulatory threshold by 15%, driven primarily by the treatment of construction waste. Waste alone contributed approximately 80% of total impacts, despite the case showing low waste generation. This indicates that the regulatory method's treatment of mixed fractions, that applies the highest-emission factor to entire fractions, plays a decisive role in determining compliance outcomes.

Sensitivity analyses through constructed scenarios showed that physical variations such as site location, supplier geography, and material substitutions have measurable but relatively modest effects on total impacts. By contrast, changes in assessment approach between default, specific, and mixed methods as well as in methodological frameworks (e.g., BUILD vs. building regulations) produced far larger differences in reported outcomes. Methodological choices alone yielded a 1.4 kg CO_2e/m^2year variation, greater than the physical spread observed between the 25th and 90th percentile in the BUILD dataset.

These findings raise important concerns about the newly implemented regulatory methodology. Specifically, they highlight a misalignment between the threshold-setting reference dataset and the regulatory assessment method. The regulatory assessment method is argued to reduce the accuracy and composition of assessed impacts, thereby possibly reducing effectiveness and prioritisation of mitigation strategies. The thesis thus underscores the need for improved alignment between regulatory objectives, assessment methodology, and actual emissions performance.

In practical terms, the report offers recommendations for industry actors on how to reduce both reported and real emissions through improved procurement, waste prevention, and site-level sorting practices. For regulators, it suggests that recalibration of threshold values and reconsideration of waste assessment logic may be necessary to ensure fairness, transparency, and climate effectiveness in compliance outcomes.

6.1 Future Work

While this thesis has provided insight into the drivers and sensitivities of A4 and A5 climate impacts under Denmark's 2025 Building Regulations, several areas remain where further research is needed to strengthen understanding and inform more effective regulatory design and industry practice.

Assessment method for mixed waste fractions

The current regulatory approach to mixed waste fractions was introduced to address concerns about deliberate mis-sorting of high-impact materials into lower-impact mixed categories. However, as discussed, this method distorts actual climate impacts. Future research should explore alternative approaches that more accurately reflect emissions while still deterring strategic mis-sorting. A robust, verifiable framework is needed that balances environmental integrity with practical enforcement.

Analysis of real-world compliance outcomes

This thesis was based on a single detailed case. Expanding the analysis to a representative sample of real-world projects would provide more robust statistical evidence of how methodological choices affect reported impacts. Such research could inform potential recalibration of the regulatory threshold to reflect the implications of the 2025 methodology.

Whole-life cycle trade-offs

This thesis has argued that efforts to reduce A4 and A5 impacts may not always lead to lower total life cycle emissions. The introduction of separate thresholds for A4 & A5 and other life cycle stages (A1–A3, B, C) increases the risk of burden shifting, where improvements in one stage lead to higher impacts in another. While the extent of this trade-off remains unclear, it contradicts fundamental life cycle assessment principles and warrants systematic investigation.

7 Declaration of Generative AI use

Generative AI (ChatGPT by OpenAI) [50] has been used to support the preparation of this report. Its contributions have included assistance with text refinement, clarification of complex formulations, improvement of sentence structure, and generation of consistent formatting across sections. The AI tool was also used to ensure linguistic accuracy, maintain consistent tone, and check for structural coherence. All technical content, interpretations, and analytical decisions remain the responsibility of the author.

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A Regulation emission factors

The default emission factors applied throughout the thesis are shown in this section.

A.1 Transport (A4)

Table A.1: Building Regulation transport emission factors from Appendix 2, Table 10 [37].

Main group	**Sub group**	**Emission factor [kgCO$_2$/kg]**
Concrete	In-situ	0.0024
	Wall and slab elements	0.011
	Other elements	0.0214
Wood	Construction wood	0.0074
	Panels, boards and floors	0.0491
	Elements	0.0814
Steel	Reinforcement steel	0.0091
	Panels and profiles	0.0124
Aluminium	Panels and profiles	0.0086
Gypsum	Plasterboards	0.0166
	Mortar and plaster	0.0209
Clay	Bricks	0.0045
	Roof tiles	0.009
Cement based products	Aerated concrete	0.0701
	Expanded clay aggregates	0.0041
	Fiber cement	0.2011
	Cement based mortar and render	0.105
Calcium silicate	Calcium silicate brick	0.0185
Zink	Zink cladding	0.0695
Bitumen	Bitumen roofing membrane	0.0378
Facade openings	Windows and doors	0.0846
	Curtain wall facades	0.019
Natural stone	Natural stone	0.0614
insulation	EPS	0.0609
	Calcium silicate	0.0029
	Cellulose	0.0721
	Wood fiber	0.092
	Mineral wool	0.0196
Membranes and surface treatment	Vapour barrier	0.9375
	Paint	0.0798
Technical building installations	Solar PVs	0.296
	Mechanical	0.0561
	Drainage	0.0561
	Water	0.0561
	Heating, ventilation, cooling	0.0561

A.2 Construction waste (A5)

Table A.2: Building regulations waste fractions sourced from Building Regulations Appendix 2, Table 11[37].

textbfWaste fraction	**Emission factor [kgCO$_2$/kg]**
Natural stone	0.29
Unglazed clay tiles/bricks	0.36
Concrete	0.17
Iron and metals	1.97
Fiber reinforced gypsum	0.33
Standard gypsum	0.33
Stone wool	0.69
Glass wool	0.69
Asphalt	0.07
Wood	0.14
Plastic	5.17
PVC	4.95
Glass	2.02
Cardboard packaging	0.44
Sanitary fixtures	0.36

A.3 Energy consumption (A5)

Table A.3: Building regulations energy consumption emission factors from Appendix 2, Tables 8.1 and 8.2[37].

Energy type	**EF - value**	**Unit [kgCO$_2$/kg]**
Electricity	0.0801	kgCO$_2$/kWh
District heating	0.0418	kgCO$_2$/kWh
Fuel (Diesel)	3.44	kgCO$_2$/L

B Results

Intermediate results, figure data and data sourcing is shown in this section.

B.1 Baseline case

Table B.1: Summary of key physical parameters for the baseline case, grouped by category. The clarifying notes describe scope, boundaries, and relevant LCA modules.

Parameter	Value	Unit	Clarifying note
Building context			
Buildings weighted floor area	14188.3	m^2	Weighted floor area as defined in regulations [15]
Reference service life (RSL)	50	years	Standard life cycle duration defined in regulations
Material quantity			
Installed materials	1.63E+07	kg	Construction materials transported to site (A4), and installed in building
Wasted materials	5.04E+05	kg	Construction materials transported to site (A4) and wasted during A5
Material waste -%	3.1%	-	Waste percentage defined as $\frac{\text{Wasted material qty}}{\text{Installed material qty}}$
Material transport (A4)			
Mean material transport distance	80.94	km	Weighted mean of distance covered during material and waste transport from producer to site for all materials
Road – share of material transport	94%	–	Share of material transport covered by road
Sea – share of material transport	6%	–	Share of material transport covered by sea
Rail – share of material transport	0%	–	Share of material transport covered by rail
Diesel consumption	3.33E+04	L	Diesel for construction material transport (A4)
HFO consumption	4.76E+01	L	Heavy Fuel Oil for construction material transport (A4)
MDO consumption	2.90E+03	L	Marine Diesel Oil for construction material transport (A4)
Electricity consumption	0	kWh	Electricity for construction material transport (A4)
Construction site energy use (A5)			
Electricity	2.32E+05	kWh	Consumption of grid electricity at construction site (A5)
District heating	2.10E+05	kWh	Consumption of district heating at construction site (A5)
Diesel	1.18E+04	L	Diesel consumption at construction site (A5)
Waste quantity			
Construction waste	5.04E+05	kg	Construction materials wasted during A5
Soil	0	kg	Soil removed during construction site preparations
Waste removal (A5)			
Average waste removal distance	2.62	km	Weighted mean distance for waste removal from site
Waste removal diesel consumption	7.48E+01	L	Estimated diesel consumption for waste transport from site (A5)
Soil removal diesel consumption	0	L	Diesel use for soil removal from site (A5)

B.1.1 Transport - Specific

Table B.2: Transport-related emissions of construction materials assessed using project-specific data. Emission factors noted with ^{E} reflect sourcing from product specific EPD, and ^{G} reflect a GLEC[35] emission factor corresponding to the vehicle type from the materials EPD, or as informed by producer.

Construction material	**Weight** [kg]	**Vehicle**	**Distance** [km]	**EF** [kgCO$_2$/kg · km]	**Production location**	**Impact** [kgCO$_2$e]	**EPD ID**
Screed layer, sand	7.58E+05	HGV>20t	64	7.91E–05^{E}	Løgtved, DK	3.81E+03	NEPD-8425-8096-DK
Screed layer, cement	1.00E+05	HGV>20t	30	1.67E–04^{E}	Køge, DK	5.02E+02	S-P-09560
Lightweight precast concrete	2.90E+06	HGV>20t	40	7.91E–05^{E}	Borup, DK	9.17E+03	MD-22012-DA-22012-13
Precast concrete elements (C20)	1.41E+06	HGV>20t	40	7.91E–05^{E}	Borup, DK	4.46E+03	MD-21066-DA-21066-31
Precast concrete floor slab	3.89E+06	HGV>20t	21	7.91E–05^{E}	Viby, DK	6.47E+03	NEPD-6757-6071-DK
Precast concrete elements (C35)	4.47E+05	HGV>20t	49	7.91E–05^{E}	Ringsted, DK	1.73E+03	MD-21066-DA-21066-31e
Precast concrete columns	1.19E+05	HGV>20t	21	7.91E–05^{E}	Viby, DK	1.98E+02	NEPD-11996-12029
Precast concrete beams	1.96E+05	HGV>20t	340	7.91E–05^{E}	Hobro, DK	5.28E+03	NEPD-11996-12029
Concrete paving blocks	4.26E+05	HGV>20t	4	1.15E–04^{G}	Hedehusene, DK	1.96E+02	NEPD-5705-4992-DK
Functional mortar	2.42E+05	HGV>20t	16	1.15E–04^{G}	Karlslunde, DK	4.45E+02	EPD-IES-0017256
Aerated concrete blocks	2.90E+05	HGV>20t	800	1.15E–04^{G}	Meppel, NL	2.67E+04	EPD-XEL-20240036-IBA1-DE
Mortar for concrete blocks	3.53E+04	HGV>20t	800	1.15E–04^{G}	Meppel, NL	3.24E+03	EPD-VDP-20230395-IBO1-DE
FUTURECEM in-situ concrete	1.93E+06	HGV>20t	13	7.91E–05^{E}	Greve, DK	1.99E+03	NEPD-8467-8118
In situ concrete	1.78E+05	HGV>20t	13	7.91E–05^{E}	Greve, DK	1.83E+03	NEPD-8467-8118
Vapour barrier	9.5E+02	HGV>20t	1300	1.15E–04^{G}	Wielkie Rychnowo, PL	1.42E+02	Type III Environmental Product Declaration No. 733/2024
Elevator	5.95E+04	HGV>20t	1500	1.15E–04^{G}	Gien, FR	1.03E+04	EPD-IES-0017950
Ventilation units	4.71E+05	HGV>20t	831	1.15E–04^{G}	Emmeloord, NL	4.50E+02	No product specific EPD
Floor boards	5.32E+04	HGV>20t	1250	1.15E–04^{G}	St. Margrethen, CH	7.64E+03	EPD-BAU-20220152-IBH1-EN
Bricks	7.52E+05	HGV>20t	310	6.19E–05^{E}	Sønderborg, DK	1.44E+04	MD-21061-EN
Mastic asphalt	1.35E+05	HGV>20t	36	1.15E–04^{G}	Ringsted, DK	5.57E+02	No product specific EPD
Bitumen membrane	2.46E+04	HGV>20t	289	1.15E–04^{G}	Ikast, DK	8.19E+02	EPD-IES-0016127
Gypsum plasterboard	1.29E+05	HGV>20t	550	5.94E–05^{E}	Frederikstad, NO	4.23E+02	NEPD-5165-4476-EN
Surface coating	2.31E+04	HGV>20t	214	1.15E–04^{G}	Kolding, DK	5.69E+02	NEPD-1996-881-EN
Mineral wool type 1	5.74E+05	HGV>20t	230	5.94E–05^{E}	Vamdrup, DK	8.62E+01	NEPD-3381-2002-EN
EPS roof insulation	8.99E+04	HGV>20t	160	1.15E–04^{G}	Hässleholm, SE	1.65E+03	NEPD-4340-3565-EN
Mineral wool type 2	2.99E+04	HGV>20t	230	5.94E–05^{E}	Vamdrup, DK	1.97E+03	NEPD-2611-1324-EN
EPS type 1	1.96E+04	HGV>20t	31	1.15E–04^{G}	Slagelse, DK	6.97E+01	MD-22132-EN
EPS type 2	2.74E+04	HGV>20t	80	1.95E–04^{G}	Viborg, DK	4.24E+02	MD-23060-EN
Balcony	6.24E+04	HGV>20t	300	1.15E–04^{G}	Karup, DK	2.15E+03	No product specific EPD
Green roofing link 1	3.45E+04	HGV>20t	290	1.15E–04^{G}	Karwice, PL	1.15E+03	Environmental Product Declaration Type III ITB No. 144/2021
Green roofing link 2	–	Ropax ferry 20,000	177	9.43E–05^{G}	–	5.75E+02	–
Solar PV link 1	1.11E+03	HGV>20t	1000	1.15E–04^{G}	Singaport, SG	1.28E+02	NEPD-3421-2033-EN

Table B.2 continued from previous page

Construction material	Weight [kg]	Vehicle	Distance [km]	EF [kgCO$_2$/kg · km]	Production location	Impact [kgCO$_2$e]	EPD ID
Solar PV link 2	–	Container ship	18000	8.90E–06^{G}	–	1.78E+02	–
Glazed windows link 1	8.92E+04	HGV>20t	475	1.15E–04^{G}	Swarozyn, PL	4.87E+03	S-P-07595
Glazed windows link 2	–	Ropax ferry 20,000	177	9.43E–05^{G}	–	1.49E+03	–
Precast concrete stair link 1	1.66E+05	HGV>20t	30	1.15E–04^{G}	Rønne, DK	5.72E+02	No product specific EPD
Precast concrete stair link 2	–	Ropax ferry 2000-5000GT	190	2.52E–04^{G}	–	7.95E+03	–
Not specifically assessed	2.03E+05	–	–	–	–	1.93E+03	–
SUM	**1.63E+07**	–	–	–	–	**1.27E+05**	–

B.1.2 Transport - Default

Table B.3: Assessment of material transport impacts using default data. Transport groups and emission factors from Building Regulations.

Construction material	Weight [kg]	Transport group	Emission factor [kgCO$_2$/kg]	Impact [kgCO$_2$e]
Screed layer	8.53E+05	Cement based mortar and render	0.105	8.96E+04
Precast concrete floor slab	4.12E+06	Concrete - Wall and slab elements	0.011	4.53E+04
Lightweight precast concrete elements	3.25E+06	Concrete - Wall and slab elements	0.011	3.58E+04
Precast concrete elements (C20)	1.58E+06	Concrete - Wall and slab elements	0.011	1.74E+04
Precast concrete elements (C35)	5.44E+05	Concrete - Wall and slab elements	0.011	5.99E+03
Precast columns, concrete	1.78E+04	Concrete - Other elements	0.0214	3.82E+02
Precast columns, reinforcement	1.69E+03	Concrete - Other elements	0.0214	3.62E+01
Precast beams, concrete	6.23E+04	Concrete - Other elements	0.0214	1.33E+03
Precast beams, reinforcement	1.44E+04	Concrete - Other elements	0.0214	3.07E+02
Concrete paving blocks	4.26E+05	Concrete - Other elements	0.0214	9.11E+03
Functional mortar	2.42E+05	Cement based mortar and render	0.105	2.54E+04
Aerated concrete blocks	2.90E+05	Aerated concrete	0.0701	2.03E+04
Mortar for concrete blocks	3.53E+04	Cement based mortar and render	0.105	3.70E+03
FUTURECEM in-situ concrete	1.93E+06	Concrete - In-situ	0.0024	4.64E+03
In-situ concrete	1.78E+06	Concrete - In-situ	0.0024	4.28E+03
Green roofing	5.09E+03	Vapour barrier	0.9375	4.77E+03
Vapour barrier	9.50E+02	Vapour barrier	0.9375	8.91E+02
Solar PVs	1.11E+03	Installations - Solar PVs	0.296	3.29E+02
Elevator	5.95E+04	Installations - Mechanical	0.0561	3.34E+03
Ventilation units	4.71E+03	Installations - heating, ventilation, cooling	0.0561	2.64E+02
Floor boards	5.32E+04	Wood - Panels, boards and floors	0.0491	2.61E+03
Glazed windows	8.92E+04	Windows and doors	0.0846	7.55E+03
Bricks	7.52E+05	Clay - Bricks	0.0045	3.38E+03
Mastic asphalt	1.35E+05	Bitumen roofing membrane	0.0378	5.09E+03
Bitumen roofing membrane	2.46E+04	Bitumen roofing membrane	0.0378	9.32E+02

Table **??** *continued from previous page*

Construction material	**Weight** [kg]	**Transport group**	**Emission factor** [kgCO$_2$/kg]	**Impact** [kgCO$_2$e]
Gypsum plasterboard	1.29E+04	Gypsum - Plasterboards	0.0166	2.15E+02
Precast concrete stairs	1.66E+05	Concrete - Other elements	0.0214	3.55E+03
Surface treatment	2.31E+04	Paint	0.0798	1.85E+03
Mineral wool type 1	5.74E+03	Insulation - Mineral wool	0.0196	1.12E+02
EPS Roof insulation	8.99E+04	Insulation - EPS	0.0609	5.47E+03
Mineral wool type 2	2.99E+04	Insulation - Mineral wool	0.0196	5.87E+02
EPS type 1	1.96E+04	Insulation - EPS	0.0609	1.19E+03
EPS type 2	2.72E+04	Insulation - EPS	0.0609	1.65E+03
Balcony, floorboards	8.39E+03	Wood - Panels, boards and floors	0.0491	4.12E+02
Balcony, steel	6.15E+04	Steel - Panels and profiles	0.0124	7.62E+02
Other materials	2.03E+05	–	–	5.64E+03
SUM	**1.69E+07**	–	–	**3.10E+05**

B.1.3 Transport - Alternative construction sites

Table B.4: Transport-related emissions of construction materials assessed using project-specific data for alternative construction site locations Klitmøller and Odense.

		Klitmøller			**Odense**		
Construction material	**Weight** [kg]	**Impact** [kgCO$_2$e]	**Production location**	**Trans. dist** [km]	**Impact** [kgCO$_2$e]	**Production location**	**Trans. dist** [km]
Aerated concrete blocks and mortar	3.25E+05	3.0E+04	Meppel, NL	800	2.5E+04	Meppel, NL	660
Clay bricks	7.52E+05	1.4E+04	Sønderborg, DK	300	7.4E+03	Sønderborg, DK	160
Elevator system	5.95E+04	1.0E+04	Gien, FR	1500	9.2E+03	Gien, FR	1350
Lightweight precast concrete elements	2.90E+06	3.3E+04	Linå, DK	146	3.4E+03	Søndersø, DK	15
Precast concrete stair	1.66E+05	3.4E+03	Tilst, DK	178	1.1E+04	Rønne, DK	368
Wooden floorboards	5.32E+04	7.8E+03	St. Margrethen, CH	1280	6.9E+03	St. Margrethen, CH	1130
Precast concrete floor slabs	3.89E+06	6.2E+04	Løsning, DK	200	3.8E+04	Viby, DK	125
Glazed windows	8.92E+04	1.2E+04	Swarożyn, PL	1200	1.1E+04	Swarożyn, PL	1050
Precast concrete beams	1.96E+05	1.8E+03	Hobro, DK	115	3.1E+03	Hobro, DK	200
Precast concrete elements (C20 grade)	1.41E+06	1.6E+04	Linå, DK	146	1.7E+03	Søndersø, DK	15
Sand	7.53E+05	6.4E+03	Nysum, DK	108	6.2E+03	Løgtved, DK	104
Balcony	6.24E+04	7.5E+02	Karup, DK	104	1.1E+03	Karup, DK	156
Ready-mix concrete (FUTURECEM binder)	1.93E+06	2.6E+03	Hastholm, DK	17	1.7E+04	Mørkøv, DK	110
Mineral wool insulation 1	2.99E+04	1.9E+03	Vamdrup, DK	222	7.5E+02	Vamdrup, DK	87
Ready-mix concrete	1.78E+06	2.4E+03	Hastholm, DK	17	1.6E+04	Mørkøv, DK	110
Precast concrete elements (C35 grade)	4.47E+05	5.2E+03	Linå, DK	146	5.3E+02	Søndersø, DK	15
Green roofing	3.45E+04	4.0E+03	Karwice, PL	1000	3.4E+03	Karwice, PL	870
EPS Roof insulation	8.99E+04	5.7E+03	Hässleholm, SE	555	3.0E+03	Hässleholm, SE	292
Bitumen roofing membrane	2.46E+04	3.6E+02	Ikast, DK	127	4.0E+02	Ikast, DK	140
Surface coating	2.31E+04	5.6E+02	Kolding, DK	210	1.9E+02	Kolding, DK	72
Mastic asphalt	1.35E+05	1.2E+03	Skive, DK	75	1.7E+03	Ringsted, DK	107
FUTURECEM binder	1.00E+05	1.8E+03	Aalborg, DK	110	2.2E+03	Køge, DK	132
Ventilation units	4.71E+03	4.4E+02	Emmeloord, NL	811	3.6E+02	Emmeloord, NL	660
Functional mortar (FM 5 type)	2.42E+05	4.5E+03	Galten, DK	162	9.4E+02	Kværndrup, DK	34
EPS insulation 1	2.72E+04	1.7E+03	Slagelse, DK	326	4.0E+02	Slagelse, DK	75
Gypsum plasterboard	1.29E+04	4.1E+02	Frederikstad, NO	470	5.2E+02	Frederikstad, NO	680
Photovoltaic panels	1.11E+03	3.0E+02	Singapore. SG	18950	2.8E+02	Singapore, SG	18800
Precast concrete columns	1.19E+05	1.1E+03	Hobro, DK	115	1.9E+03	Hobro, DK	200
Concrete paving blocks	4.26E+05	5.1E+03	Nr. sundby, DK	105	1.3E+03	Ringe, DK	26
Vapour barrier	9.50E+02	1.4E+02	Wielkie Rychnowo, PL	1240	1.3E+02	Wielkie Rychnowo, PL	1150
Mineral wool insulation 2	5.74E+03	4.3E+01	Doense, DK	114	3.3E+01	Vamdrup, DK	87
EPS insulation 2	1.96E+04	2.3E+02	Viborg, DK	104	2.3E+02	Billund, DK	104
Non specific	2.03E+05	1.9E+03	–	–	1.9E+03	–	–
Sum	**1.63E+07**	**2.4E+05**	–	–	**1.8E+05**	–	–

Table B.5: Climate impact of baseline case in kgCO$_2$e/m^{2}year, distributed across modules and processes.

Module	**Process**	**kgCO$_2$e/m^{2}year**
A4	Transport of materials	0.184
	Transport of waste	0.006
	Transport of machinery	0.020
	Logistics hubs processes	0.020
	Sum A4	**0.229**
A5	Electricity	0.026
	Heating	0.012
	Fuel	0.057
	Construction waste	1.391
	Removal of soil	0
	Removal of waste	0.00036
	Sum A5	**1.487**
A4 & A5	**Total**	**1.717**

B.2 Geographical sensitivity of transport impacts

B.2.1 Material sourcing and transport reduction potential

Table B.6: Transport parameters for construction materials with baseline and substitution sourcing. Results of distance and climate impact reductions in % for individual, ten most contributing, and all materials. n.a. indicates no suitable material substitution with significantly shorter transport distance were identified for the given material. EPD ID's for the three substituted materials are:
Aerated concrete blocks and mortar: MD-23056-EN
Wooden floorboards: EPD-MOL-20230148-IBA1-EN
Glazed windows: MD-24152-EN.

Constr. mat.	**Qty [kg]**	**Original**		**Substitution**		**Dist. red.**	**GWP red.**
		Location	**Dist.**	**Location**	**Dist.**		
Aerated concrete blocks and mortar	$3.3 \cdot 10^5$	Meppel, NL	800	Wittenborg, DE	290	64%	62%
Clay bricks	$7.5 \cdot 10^5$	Sønderborg, DK	310	n.a.	–	–	–
Elevator system	$6.0 \cdot 10^4$	Gien, FR	1500	n.a.	–	–	–
Lightweight precast concrete elements	$2.9 \cdot 10^6$	Borup, DK	40	n.a.	–	–	–
Precast concrete stair	$1.7 \cdot 10^5$	Rønne, DK	220	n.a.	–	–	–
Wooden floorboards	$5.3 \cdot 10^4$	St. Marg., CH	1250	Skive, DK	346	72%	72%
Precast concrete floor slabs	$3.9 \cdot 10^6$	Viby, DK	21	n.a.	–	–	–
Glazed windows	$8.9 \cdot 10^4$	Swarożyn, PL	475	Oksbøl, DK	295	55%	52%
Precast concrete beams	$2.0 \cdot 10^5$	Hobro, DK	340	n.a.	–	–	–
Precast concrete elements (C20)	$1.4 \cdot 10^6$	Borup, DK	40	n.a.	–	–	–
Top 10	–	–	–	–	–	23%	27%
All mat.	–	–	–	–	–	19%	21%

B.3 Impact sensitivity to modeling approach

Table B.7: Climate impact of baseline case in $kgCO_2e/m^2year$, distributed across modules A4 and A5, and processes. Processes with common values are indicated with *

Module	Process	Specific	Default
A4	Transport of materials	0.184	0.438
	Transport of waste	0.006	0.020
	Transport of machinery*	0.020	0.020
	Logistics hubs processes*	0.020	0.020
	Sum A4	0.229	0.498
A5	Electricity*	0.026	0.026
	Heating*	0.012	0.012
	Fuel*	0.057	0.057
	Construction waste*	1.391	1.391
	Removal of soil	0	0.060
	Removal of waste	0.00036	0.060
	Sum A5	1.487	1.607
A4 & A5	**Total**	**1.717**	**2.105**

B.4 Construction waste sorting approaches

B.4.1 Baseline

Table B.8: Transporter waste fractions and quantities mapped to Building regulations EF from Table A.2. Applied for assessment of baseline waste in 4.1.1 and *Baseline waste*-scenario in Section 4.4.1.

Waste fraction	Quantity [kg]	Sorted as	BR EF [$kgCO_2e/kg$]	Impact [$kgCO_2e$]
Lightweight/aerated concrete	4.7E+04	Concrete	0.17	8.0E+03
Clean concrete	2.7E+04	Concrete	0.17	4.7E+03
Clean wood	1.9E+04	Wood	0.14	2.7E+03
Clay tiles and bricks	1.7E+04	Unglazed clay tiles/bricks	0.36	6.0E+03
Mixed construction wood	1.5E+04	Wood	0.14	2.1E+03
Clean gypsum	7.1E+03	Standard gypsum	0.33	2.3E+03
Sanitary fixtures	5.7E+03	Sanitary fixtures	0.36	2.0E+03
Clean PVC	6.2E+02	PVC	4.95	3.1E+03
Mixed clay and concrete	1.6E+05	Unglazed clay tiles/bricks	0.36	5.6E+04
Mixed rubble	3.8E+04	Unglazed clay tiles/bricks	0.36	1.4E+04
Landfill waste	5.1E+03	Plastic	5.17	2.6E+04
Combustible waste	1.5E+05	Plastic	5.17	7.6E+05
Hard-to-recycle	4.2E+03	Plastic	5.17	2.2E+04
Mixed construction waste	1.6E+04	Plastic	5.17	8.2E+04
Sum	**5.0E+05**	–	–	**9.87E+05**

B.4.2 Improved sorting

Table B.9: Transporter waste fractions and quantities mapped to Building regulations EF from Table A.2. Applied in*Improved sorting*-scenario in Section 4.4.1.

Waste fraction	**Quantity** [kg]	**Sorted as**	**BR EF** [kgCO$_2$e/kg]	**Impact** [kgCO$_2$e]
Lightweight/aerated concrete	4.7E+04	Concrete	0.17	8.0E+03
Clean concrete	2.7E+04	Concrete	0.17	4.7E+03
Clean wood	1.9E+04	Wood	0.14	2.7E+03
Clay tiles and bricks	1.7E+04	Unglazed clay tiles/bricks	0.36	6.0E+03
Mixed construction wood	1.5E+04	Wood	0.14	2.1E+03
Clean gypsum	7.1E+03	Standard gypsum	0.33	2.3E+03
Sanitary fixtures	5.7E+03	Sanitary fixtures	0.36	2.0E+03
Clean PVC	6.2E+02	PVC	4.95	3.1E+03
Mixed clay and concrete	1.6E+05	Unglazed clay tiles/bricks	0.36	5.6E+04
Mixed rubble	3.8E+04	Unglazed clay tiles/bricks	0.36	1.4E+04
Landfill waste	5.1E+03	Glas	2.02	1.0E+04
Combustible waste	1.5E+05	Glas	2.02	3.0E+05
Hard-to-recycle	4.2E+03	Glas	2.02	8.4E+03
Mixed construction waste	1.6E+04	Plastic	5.17	8.2E+04
Sum	**5.0E+05**	–	–	**4.97E+05**

B.4.3 Optimal sorting

Table B.10: Transporter waste fractions and quantities mapped to Building regulations EF from Table A.2. Applied in*Optimal sorting*-scenario in Section 4.4.1. Emission factors for Rubble, Landfill, Combustible waste, and Mixed construction waste based on compositions shown in Table B.13.

Waste fraction	**Quantity** [kg]	**Sorted as**	**BR EF** [kgCO$_2$e/kg]	**Impact** [kgCO$_2$e]
Lightweight/aerated concrete	4.7E+04	Concrete	0.17	8.0E+03
Clean concrete	2.7E+04	Concrete	0.17	4.7E+03
Clean wood	1.9E+04	Wood	0.14	2.7E+03
Clay tiles and bricks	1.7E+04	Unglazed clay tiles/bricks	0.36	6.0E+03
Mixed construction wood	1.5E+04	Wood	0.14	2.1E+03
Clean gypsum	7.1E+03	Standard gypsum	0.33	2.3E+03
Sanitary fixtures	5.7E+03	Sanitary fixtures	0.36	2.0E+03
Clean PVC	6.2E+02	PVC	4.95	3.1E+03
Mixed clay and concrete	1.6E+05	Rubble	0.227	3.5E+04
Mixed rubble	3.8E+04	Rubble	0.227	8.6E+03
Landfill waste	5.1E+03	Landfill	0.7	3.5E+03
Combustible waste	1.5E+05	Combustible waste	1.266	1.9E+05
Hard-to-recycle	4.2E+03	Landfill	0.7	2.9E+03
Mixed construction waste	1.6E+04	Mixed construction waste	0.3772	6.0E+03
Sum	**5.0E+05**	–	–	**2.73E+05**

B.4.4 BUILD method

Table B.11: Transporter waste fractions and quantities mapped to BUILD EF. Applied for *BUILD method*-scenario in Section 4.4.1.

Waste fraction	**Quantity** [kg]	**BUILD fraction**	**Fraction EF** [kgCO$_2$e/kg]	**Impact** [kgCO$_2$e]
Lightweight/aerated concrete	4.7E+04	Concrete	0.17	8.0E+03
Clean concrete	2.7E+04	Concrete	0.17	4.7E+03
Clean wood	1.9E+04	Wood	0.14	2.7E+03
Clay tiles and bricks	1.7E+04	Unglazed clay tiles/bricks	0.36	6.0E+03
Mixed construction wood	1.5E+04	Wood	0.14	2.1E+03
Clean gypsum	7.1E+03	Gypsum	0.77	5.5E+03
Sanitary fixtures	5.7E+03	Mixed	0.45	2.5E+03
Clean PVC	6.2E+02	Plastic	5.92	3.7E+03
Mixed clay and concrete	1.6E+05	Rubble	0.23	3.6E+04
Mixed rubble	3.8E+04	Rubble	0.23	8.7E+03
Landfill waste	5.1E+03	Landfill	0.66	3.3E+03
Combustible waste	1.5E+05	Combustible	1.94	2.8E+05
Hard-to-recycle	4.2E+03	Landfill	0.66	2.7E+03
Mixed construction waste	1.6E+04	Mixed	0.45	7.1E+03
Sum	**5.0E+05**	–	–	**3.77E+05**

B.5 Mixed fraction emission factors based on assumed composition

B.5.1 BUILD waste fractions

Table B.12: BUILD construction waste EFs as per the report [7], including assumed compositions. EFs are expressed in kg CO_2e/kg waste. Factors are applied in Table B.11 for all fractions.

Waste fraction	**EF** [kg CO_2e/kg]	**Composition**
Plastic	5.92	80% EPS 20% Vapour barrier
Glass	2.02	100% Window pane
Metal	1.97	90% Steel profile 10% Aluminium profile
Combustible	1.94	20% Cardboard packaging 20% OSB 20% EPS 20% Cardboard 20% Wood
Windows	1.49	67% Window pane 33% Wood
Insulation	0.69	100% Mineral wool
Landfill	0.66	80% Concrete 10% Mineral wool 10% PVC pipes
Mixed	1.94	56% Concrete 24% Clay bricks 10% Mineral wool 2% Cardboard 2% OSB 2% Bitumen roofing membrane 2% Cardboard packaging 2% Wood
Cardboard	0.44	100% Cardboard
Wood	0.14	90% Wood 10% OSB
Clay	0.36	100% Clay bricks
Rubble	0.23	70% Concrete 30% Clay bricks
Concrete	0.17	100% Concrete
Asphalt	0.07	100% Asphalt

B.5.2 Weighted average of BR fractions

Table B.13: Weighted average emission factors for mixed waste fractions based on fraction compositions from BUILD Report *Ressourceforbrug på byggepladsen*[7], and Building regulations single material emission factors. Emission factors (EF) are expressed in kg CO_2e/kg waste. Factors are applied in Table B.10 for mixed fractions.

Waste fraction	**EF** [kg CO_2e/kg]	**Composition**
Combustible waste	1.27	40% Wood 40% Cardboard packaging 20% Plastic
Windows	1.40	67% Glass 33% Wood
Landfill	0.70	80% Concrete 10% PVC 10% Stone wool
Mixed construction waste	0.38	56% Concrete 24% Unglazed clay tiles/bricks 2% Stone wool 4% Cardboard packaging 4% Wood 2% Plastic
Mixed rubble	0.23	70% Concrete 30% Unglazed clay tiles/bricks