Developments in the Built Environment 21 (2025) 100622

Contents lists available at ScienceDirect

Developments in the Built Environment

journal homepage: www.sciencedirect.com/journal/developments-in-the-built-environment

Sustainability assessment of logistics halls

Alexandra Weniger[a,*], Julian Frede[b], Laura Schmidt[a], Leonie Hartmann[b], Marzia Traverso[a]

[a] Institute of Sustainability in Civil Engineering, RWTH Aachen University, 52074, Aachen, Germany
[b] Evolutiq Impact Advisory GmbH, Evolutiq Group, 50827 Cologne, Germany

ARTICLE INFO

Keywords:
Logistics halls
Sustainability assessment
LCSA
LCSA guideline

ABSTRACT

Research objective of this study is to create a framework for assessing the environmental and social sustainability of logistics halls. The goal is to determine which sustainability issues and indicators are particularly relevant for managing the best possible environmental and social balance of a logistics hall. A literature review assesses the current state of the art in Life Cycle Sustainability Assessments. Furthermore, a Social Hotspot Database screening and the Real Estate Impact Analysis Tool of the UNEP are utilized to fulfill relevant social categories. The collected data is summarized in a guideline for social and environmental life cycle assessments following the four-phase structure defined in ISO 14040/14044. To finalize the study, an exemplary case study conducting an environmental and social sustainability assessment of a logistics hall in Germany is carried out. The results provide valuable insights for future sustainability assessments of logistics halls and utilization of the developed framework.

1. Introduction

The rising pressure on the construction sector to drive sustainable development has become indispensable in recent years. With 37% of the global greenhouse gas emissions is the construction sector a major driver of climate change (UNEP, 2021a). However, especially industrial buildings also have a great influence on social as well as economic impacts (Zhang et al., 2019). Looking at the sector of logistics, for example, it plays an important role in economic development (Irtyshcheva et al., 2023), while also requires significant labor force (Jones Lang LaSalle IP and Inc, 2020) and thus provides jobs for local communities. It has, therefore, become increasingly important to include sustainability considerations in the planning of buildings in the logistics sector (Jones Lang LaSalle IP and Inc, 2020). In general, there are various assessment tools for incorporating some sustainability considerations into the planning of logistics halls. Labels and sustainability frameworks tend not to provide a complete picture, whereas a Life Cycle Sustainability Assessment (LCSA) aims to provide a holistic view, taking into account all three dimensions of sustainability throughout the assessed product life cycle (Finkbeiner et al., 2010). However, a more comprehensive assessment method also means that the application is more complex and needs more time. Although the LCSAmethodology is a well-accepted within the scientific community (Backes and Traverso, 2021), more standardization for a more structured application and easy communication of sustainability results is still necessary (Backes and Traverso, 2022; Del Rosario and Traverso, 2023).

Therefore, following the approach of other researchers in finding a common sense for sustainability assessments in the construction sector (Dong and Ng, 2016; Ayoub et al., 2022; Janjua et al., 2019; Kamali and Hewage, 2017; Jayawardana et al., 2022), this study aims to develop a guideline for sustainability assessments of logistics halls. For that, a literature review on current LCSA studies of logistics halls is performed, as well as a social risk assessment using the Social Hotspot Database to screen the relevant social risks. In addition to that is the Real Estate Impact Analysis Tool of the UNEP tool (further: UNEP fi tool) made use of, to find social impact categories with a potential positive impact. To finalize the study, two case studies providing examples for the application of the guideline are presented.

2. Theoretical background

2.1. Life Cycle Sustainability Assessment

Sustainable development in general is defined within the Brundtland Report from 1987 as a development that should meet the needs of the current generation without compromising the ones of future generations. This definition implies an environmental, economic, as well as social dimension of sustainability (United Nations, 1987). To get a

* Corresponding author.
E-mail address: alexandra.weniger@inab.rwth-aachen.de (A. Weniger).

https://doi.org/10.1016/j.dibe.2025.100622
Received 16 December 2024; Received in revised form 31 January 2025; Accepted 6 February 2025
Available online 13 February 2025

holistic view of a product's sustainability, it is vital to extend current life cycle thinking to encompass all three pillars of sustainability. By conducting an LCSA, environmental, economic, and social issues are assessed (UNEP LCI, 2011). LCSA therefore is defined as the assessment of all three dimensions of sustainability with the (environmental) Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and the Social Life Cycle Assessment (S-LCA) (Backes et al., 2024).

The first element of an LCSA, the LCA, is a method used to assess inputs and outputs, and potential environmental impacts associated with a product life cycle The potential environmental impacts include impact categories such as: Global Warming Potential or in other words the impact on climate change generated by a product life cycle from raw material extraction through production, use, waste treatment, recycling, and final disposal (International Organization for Standardization Environmentala). The principles and general framework as well as requirements and guidelines for performing an LCA are standardized in the ISO standards 14040 and 14044 (International Organization for Standardization Environmentala; International Organization for Standardization Environmentalb). Within the ISO 14040 the framework of LCA is described as being organized into four steps: 1) Goal and Scope definition, 2) Life Cycle Inventory, 3) Life Cycle Impact Assessment, and 4) Interpretation (International Organization for Standardization Environmentala). In addition to that, the ISO 14044 establishes requirements for an LCA and provides guidance for its reporting. This includes among other aspects the four phases of an LCA and its connections, reporting, and critical review and limitations of LCA (International Organization for Standardization Environmentalb). The technical report ISO/TR 14047 provides further support for conducting an LCA, as well as examples and explanations for environmental impact categories (International Standards Organization, 2012). Since this study focuses on logistics halls as products within the construction industry, the standards EN 5978 and 15804 give further insight into LCAs in construction. EN 15978 provides information about calculation rules for the assessment of the environmental performance of new and existing buildings (European Standards Organizations Sustainability ofa) while EN 15804 introduces the concept of Environmental Product Declaration and how LCAs affect the impacts of building materials including more assumptions and requirements (European Standards Organizations Sustainability ofb). For example, EN 15804 describes the life cycle of a building product in four categories: A – Production stage; B – Use stage; C – Disposal stage; D – Recycling (European Standards Organizations Sustainability ofb). The second part of a holistic sustainability assessment of a product like a logistics hall is the LCC. It is defined as the process of an economic assessment of the total costs of acquisition, ownership, and disposal and provides important data for the decision-making process in different product stages. The document standardizing LCC is the EN 60300-3-3. The procedure of an LCC is explained and defined considering the following main stages of life-cycle-costs: Concept and Definition, Design and Development, Manufacture, Installation, Operation and Maintenance, and Disposal. (International Organization for Standardization Zuverlässigkeitsmanagement) The final part of an LCSA is the assessment of positive and negative social impacts with an S-LCA. For that, the Guidelines for Social Life Cycle Assessment of Products and Organizations (UNEP, 2020) and Methodological Sheets for Subcategories (UNEP, 2021b) provide information about the execution of a S-LCA. It is strongly oriented on the LCA, whereby it is also organized into the four steps defined in ISO 14040. S-LCAs can be performed for considering different stakeholder groups such as Workers, Consumers, Local Community, Society, and Children (UNEP, 2020; UNEP, 2021b).

2.2. Sustainability assessment in construction

There are different ways in how sustainability assessment can be applied in construction. This assessment method can be used for example for certification schemes like DGNB. DGNB, in contrast to other certifications, considers the life cycle of a project instead of individual measures at least for the environmental aspects. Hereby the criteria of environmental, economic, sociocultural, functional, technical, process, as well as site quality are taken into consideration. (Deutsche Gesellschaft für Nachhaltiges Bauen) However, not all criteria necessarily include the whole life cycle of the building. Specifically, the social criteria considered only include its use stage. Another way of applying sustainability assessment in construction with a life cycle thinking approach is presented in the framework Level(s) - European framework for sustainable buildings (European Commission Level(s)). Level(s) is not a certification scheme, such as DGNB, but rather a framework that provides a common language for life sustainability assessments for buildings, strongly based on a circular approach. It is specifically intended to be useful not just for built environment and sustainability experts, but also to support Policy makers and Investors (European Commission Level(s)). Another tool by the European Commission that should lead industries towards more sustainable choices is the EU Taxonomy Regulation (2020/852) (European Commission EU taxonomy). It is a classification system that is intended to define those economic activities (such as building and construction) that substantially contribute to one or more environmental objectives of the six prioritized in the EU Taxonomy, Do Not Significantly Harm (DNSH) the other 5 objectives, and met the social aspect defined by the Social Safeguard (European Commission EU taxonomy).

However, if a product's sustainability performance needs to be holistically evaluated along its entire life cycle, a Life Cycle Sustainability Assessment needs to be performed. That way, the inclusion of all relevant aspects can be ensured throughout the entire life cycle, and all results can be retraced transparently. To obtain an overview of the extent to which such sustainability assessments are already being applied in the construction sector, a literature review is conducted of the applicability of the LCSA methodology for the sustainability assessments of various construction products. The search will be limited to the Scopus database as one of the most common databases for scientific publications. The search period covers the years 2015–2023 (May) and publications in German and English are included. The search is conducted with a combination of synonyms for LCSA (Life Cycle Sustainability Assessment, EN ISO 14040, EN ISO 14044, EN ISO 14040/44), as well as the construction industry (Building Industry, Construction Sector, Building Sector).

There were several studies found, focusing on the application and its challenges in the construction sector. A systematic literature review for example elaborated that from 171 reviewed studies published within 2010 and 2021, only 11% performed a full LCSA. The authors further explain that many scientific publications make use of the term LCSA in an incorrect way and the social and economic dimension tends to be neglected. It is stated, that the LCSA methodology itself however does not need to be improved, but a harmonized LCSA approach that includes a set of predefined indicators further supported by a visualization tool could provide a lower entry barrier to anchor the LCSA in the building and construction sector (Backes and Traverso, 2021). A survey from 2022 indicated that LCSA is hardly known among actual and future decision-makers in the construction sector (Backes and Traverso, 2022). There are difficulties in the final interpretation of the LCSA, the weighting, and the communication. Standardization is repeatedly called for and the majority of experts state that a set of predefined indicators and an adequate visualization tool are needed for improved implementation and support (Backes and Traverso, 2022; Del Rosario and Traverso, 2023). Furthermore, the need for more practical examples of LCSA, efficient ways of communicating LCSA results, and a need for more data and methods particularly for S-LCA indicators and comprehensive uncertainty assessment is expressed among researchers (Guinée et al., 2016). One way of communicating sustainability assessment results coherently with standardized criteria are sustainability rating tools. However, most sustainability rating tools place a preference on environmental issues and tend to place lower weight on social aspects while neglecting aspects of economic sustainability (Srivastava et al., 2022). Another solution to standardize sustainability assessment and enable transparent and simple communication while still fully assessing holistic sustainability performances is to create frameworks based on LCSA for specific product groups. In a research paper from 2016 for example, a framework to evaluate life cycle sustainability performances of residential buildings by focusing on 18 environmental impact categories, 13 social subcategories, and 10 economic indicators, was elaborated (Dong and Ng, 2016). Similar approaches trying to find a common sense for the sustainability assessment in construction exist in current literature (Ayoub et al., 2022; Janjua et al., 2019; Kamali and Hewage, 2017) Jayawardana et al. performed a literature review about the application of LCSA for modular construction, and an additionally proposed conceptual framework for future applications. They once again point out that although the necessity for LCSA application in modular construction is being identified, a lack of comprehensive LCSA studies in that sector is existent. Their proposed framework structure is based on the EN ISO 14040 standard for LCAThey are thereby being coherent with existing standards and thus enabling holistic sustainability assessments (Jayawardana et al., 2022). Following the example of Jayawardana et al., a framework to perform LCSA for logistics halls is developed. It should include recommendations for the four phases of a life cycle assessment including relevant indicators for the three pillars of sustainability.

3. State of the art

To determine which criteria in particular are of relevance in the sustainability assessment of logistics halls, a detailed literature search was carried out on existing LCA, LCC, and S-LCA studies. We focused on the databases Scopus, Web of Science, ScienceDirect as well as Google and Google Scholar. The search period again covers the years 2015–2023 (May) and a focus was placed on sustainability assessments in the English and German language. Table 1 shows the terms which were examined in combinations.

The literature review was performed in five steps: after the initial research based on synonyms for LCA, LCC, and S-LCA, 2) the search within the described databases was carried out. In step 3) a keyword analysis in title, abstract, and keywords, and step 4) a specified content review limited to the three sustainability assessment methods was conducted. Finally, in 5) the remaining studies could be reviewed in detail.

3.1. Environmental life cycle assessments of logistic halls

A detailed Literature review on existing studies of environmental life cycle assessments of logistic halls was conducted resulting in two studies performing an LCA. The first one is a diploma thesis written by Stefan Kugler in 2021 about the comparison of emissions from different construction approaches and life cycle scenarios for industrial buildings (Kugler, 2021). For that, 12 different building scenarios are defined and their global warming potential (GWP), acidification potential (AP), and

Table 1
Search combinations literature review sustainability assessment logistics halls.

Synonyms for the Sustainability Dimensions	Synonyms for Logistics Halls
LCA; E-LCA; Life Cycle Assessment; Environmental Life Cycle Assessment; Environmental Sustainability; Ökobilanz; Ökologische Nachhaltigkeit; LCC; Life Cycle Costing; Kostenbilanz; Lebenszykluskosten S-LCA; S-LCA; Social Life Cycle Assessment; Social Sustainability, Sozialbilanz; Soziale Nachhaltigkeit;	Logistikhalle; Logistics hall; Storage hall; Warehouse; Logistics sites; Distribution Center

primary energy demand from renewable and non-renewable resources (PERT, PENRT) are assessed. The database “Ökobaudat” is used for data collection for the life cycle stages A1-A3 (raw material extraction and production), C (deconstruction and disposal), and D (recycling). As functional unit either 1t of material or 1 m^2 of building component is used, depending on the part of the industrial building (Kugler, 2021). The other study was performed by Ionut Emil Iancu and Ligia Mihaela Moga in 2022 and focuses on a Cradle to Grave LCA considering industrial buildings with four different structural solutions in Rumania (Iancu and Moga, 2022). For that, the impact categories GWP, Stratospheric ozone depletion, AP, and Eutrophication potential were assessed. In addition to that, emissions of fine particles into the air, the potential for smog formation, the total primary energy incorporated, non-renewable energy, and depletion of fossil fuels were evaluated. Even though this study was not performed according to ISO 14040 and 14044, it is a life cycle assessment of potential environmental impacts using the program “Athena Impact Estimator”. There was no clear functional unit stated, but calculations were made concerning one warehouse. The authors concluded that the warehouses with the highest concrete content and the lowest content of the other materials (steel, wood) have the highest sustainability as well as durability, considering the surfaces to which they refer, as well as the energy consumption in operation, during the normal duration of their use. In addition to that industrial buildings made of prefabricated concrete elements are the most balanced and sustainable in terms of carbon and embodied energy (Iancu and Moga, 2022).

Furthermore, two studies were found during the literature review, that did not imply an LCA, however, they did give recommendations for impact categories, that are important for the environmental assessment of logistics halls. The first study focuses on the explanation of sustainability certifications and the determination of sustainability performances especially for logistics halls. They show perspectives on how logistics real estate can be made more sustainable (Jacobi et al., 2020). They recommend focusing especially on the environmental criteria biodiversity and habitat, climate change, Land contamination, energy consumption, greenhouse gas emissions, indoor environment quality, location and transportation, materials, pollution, resilience to catastrophe/disaster, renewable energy, sustainable procurement, waste management, water consumption. They were translated by us in the following LCA impact categories: GWP, Ecotoxicity, Water use, Depletion of abiotic resources, Depletion of biotic resources, PENRT, and PERT (Jacobi et al., 2020). The second study is a research paper from 2019, that assesses the economic and environmental dimensions of warehouses through interviews and the evaluation of previous studies (Bottani et al., 2019). However, it performs no LCC or LCA. If focuses solely on Emissions (CO2) from heating, cooling, and lighting within the use phase of a warehouse in northern Italy. The authors conclude that most of the expenses and emissions are held for heating and cooling the facilities. The worthiest component is the maintenance of facilities, specifically for heating and cooling (Bottani et al., 2019).

3.2. Life cycle costing of logistic halls

With regard to the economic dimension of sustainability, there were four studies found that performed Life Cycle Costing concerning logistics halls. The first study, a diploma thesis from 2021 is about an analysis of a business expansion under production- and investment-specific conditions. Within this study, three different scenarios for the expansion of a brewery were compared with regard to their expected costs. Depending on the scenario, the total costs for production, refurbishment, or demolition were taken into consideration (Reihofer, 2021). A second study performed an LCC of a spare parts distribution center in northern Chile. It aimed to assess the costs for resources consumed by the warehouse on an annual basis €/year. A life time of nine years, split into three phases (beginning, middle, and end of life) was taken into consideration (Durán et al., 2019). A study that had already been introduced in the LCA part, assessing the economic and environmental sustainability performance of a warehouse in northern Italy. From an economic perspective, the total costs of the warehouse per year (in €/year) during the use stage were calculated. Those included costs resulting from the storage of goods, heating and cooling, electricity, lighting, and mobile/fixed material handling equipment. The authors elaborated, that most expenses are held for heating and cooling (Bottani et al., 2019). The last study found was also already mentioned in the part about LCA, comparing costs resulting from different construction approaches and life cycle scenarios for industrial buildings. Costs were calculated for one specific case study within the life cycle stages A1-A3, C, and D. This included costs for building components (construction costs), investment costs for future renewals (component replacement) as well as maintenance and regular repair costs (Kugler, 2021).

In general, it became evident that the indicators considered within life cycle costing approaches in literature are not considering all aspects stated within the standardizations. When designing a logistics hall, it should be ensured that all costs are documented and calculated over the project's entire life cycle. However, as life cycle costs are usually calculated for each new construction project, the LCC of logistics halls is not further analyzed.

3.3. Social life cycle assessments of logistic halls

There was no Social Life Cycle Assessment according to the Guidelines for S-LCA (UNEP, 2020) of Logistics halls found in the literature. However, there were three studies found regarding the social performance of logistics halls, which can give hints for further indicator selection. A first study aimed to assess the use stage of a logistics hall, by addressing health and safety issues for workers such as long-term low back injuries. After an empirical assessment of loads on employees for four typical logistics workplace settings, the authors conclude that there is indeed a potential health and safety risk existent for workers in this stage of logistics halls (Loske et al., 2021). Another study also considered the use stage, in this case aiming to determine relevant social sustainability indicators for a textile warehouse. After doing a literature review, followed by an expert revision, 12 social sustainability issues were found relevant: Workforce stability & turnover, Teamwork, Employee efficiency, Strong leadership, Ergonomics, Workforce participation, OHSAS training, Employee training and development, Employee satisfaction, Social responsibility, Continuous monitoring & Discipline management, Accidents, and physical danger (Dilaver et al., 2020). The third study is a literature review of 53 studies about social sustainability in manufacturing between 1992 and 2017. It resulted in a framework for social sustainability in manufacturing. This included workers, consumers, and the community as the most relevant stakeholder categories, and a list of ten social sustainability issues: Health and Wellness Effects, Social Justice, Operational Safety, Governance, Human Rights, Empowerment, Participation and Access, Social Capital, Social Impact, Basic Needs, Transparency (Zhang and Zhou, 2017). These issues, however, are not in accordance with the social subcategories from the UNEP Guidelines (UNEP, 2020). To ensure the same wording in the further analysis, the corresponding subcategories were assigned to the social sustainability issues from the literature.

3.4. Sustainability assessment indicators for logistic halls

To provide an overview of sustainability indicators found relevant for logistics halls in literature, Table 2 was established. Further suggestions on the basis of these results from existing literature will be provided in the following sections of the study.

Overall, it can be said that for the product category of logistics halls, there was neither a holistic LCSA study, nor an LCA, LCC, or S-LCA found in the literature assessing the entire life cycle. A gap in research was discovered particularly in the social dimension. Furthermore, it was found that none of the analyzed studies included a framework supporting the applicability of LCA and S-LCA. Furthermore, at the current time of the study, no product category rule (PCR) or social PCR exists for Environmental Product Declarations or Social Product Declarations of logistics halls. Therefore, the guideline developed in the further course of the study is an important step towards an improved applicability of holistic sustainability assessments of logistics halls.

Table 2
Results literature review: Indicators in LCA, LCC, and S-LCA.

Sustainability Dimension	Impact Category for LCA/Indicator for LCC/ Social Subcategory		Frequency
LCA	Global Warming Potential		2 (+2 non-LCA)
	Stratospheric ozone depletion		1
	Acidification Potential		2
	Eutrophication		1
	Ecotoxicity		(1 non-LCA)
	Water use		(1 non-LCA)
	Depletion of abiotic resources		(1 non-LCA)
	Depletion of biotic resources		(1 non-LCA)
	PENRT		1 (+1 non-LCA)
	PERT		1 (+1 non-LCA)
LCC	Fabrication (Work, Material etc.)		1
	Total costs manufacturing and installation		1
	non-recurring operating costs		2
	recurring operating costs		2
	non-recurring maintenance costs		1
	Replacement of life-limited parts		1
	Total costs maintenance		1
	Total costs disposal		1
S-LCA	Workers	Equal opportunities/ discrimination	(1 non-S-LCA)
		Health and Safety	(3 non-S-LCA)
		Employment relationship	(2 non-S-LCA)
	Local community	Access to material resources	(1 non-S-LCA)
		Access to immaterial resources	(1 non-S-LCA)
		Safe and healthy living conditions	(1 non-S-LCA)
		Community engagement	(1 non-S-LCA)
	Consumer	Health and Safety	(1 non-S-LCA)
		Transparency	(1 non-S-LCA)

4. Methodology

The findings from the literature research are subsequently summarized in a guideline for future applications of sustainability assessments of logistics halls. To complete the study, further methods and tools were used to analyze the social dimension of sustainability in more detail. The guideline for the sustainability assessment of logistics halls is based on the ISO 14040 and 14044 standards, which contain the principles and framework conditions as well as requirements and instructions for life cycle assessments (LCA) (International Organization for Standardization Environmentala; International Organization for Standardization Environmentalb). At the current time (May 2023), a standard for the implementation of a social life cycle assessment does not yet exist. However, the S-LCA structure follows the existing ISO 14040 standard and the UNEP Guidelines (UNEP, 2020; UNEP, 2021b). The framework includes two scenarios: A baseline-scenario, which considers a pure logistics hall, in which no special functions other than the pure storage of goods are included, and an additional scenario, with the extra function of including high bay racks (from here referred to as "baseline scenario", and a "high-bay scenario").

To address the particular lack in research in the social dimension of sustainability an additional social risk screening is carried out using the risk mapping tool of the SHDB, and the Real Estate Impact Analysis Tool by UNEP fi is utilized to identify potential positive impacts. The risk mapping tool of the SHDB can be used to identify risks associated with a sector and the countries, in which the risks are at their highest (Social Hotspot Database, 2022). Since according to the UNEP Guidelines (UNEP, 2020) an S-LCA should not only include risks for potential negative impact, but also potential beneficial positive impact, the Real Estate Impact Analysis Tool by UNEP fi is further utilized. It was developed to identify the impacts associated with real estate investments (UNEP finance initiative, 2021), such as a warehouse.

It needs to be noted that this framework should only be seen as a guideline for future LCA and S-LCA studies and it not include the life cycle costing which is the economic dimension of the LCSA. The life cycle costing has been standardized for construction sector specifically with ISO 15686-5 which is one of the reasons why the authors' focus was more on environmental and social aspects. Both LCA and S-LCA are based on the framework defined by ISO 14040 (2006) which includes: a definition for goal and scope, inventory analysis, impact assessment, and interpretation. It is important to note that this guideline is by no means intended to be globally applicable. It merely serves as an aid for the future preparation of sustainability assessments based on information from the literature, the tools used, and advice from sustainability experts. Limitations of this study include, in particular, the limited data available in the social dimension, which is aimed to be compensated for as best as possible with the SHDB risk assessment and the screening of the UNEP fi tools. Nevertheless, the underlying assumptions must be examined when a sustainability study is carried out.

5. Results

5.1. Goal and scope definition

Within the Goal and Scope phase of an LCA and S-LCA, all relevant process units should be included as well as all the assumptions necessary to develop the study. This step is crucial for all further steps within the sustainability Assessment.

Goal It is important to define a goal for the assessment as a first step, to make further decisions most suitable for the specific study. The goal itself strongly depends on the assignment received and, on the audience chosen. The following questions can help to define each goal. Does the study intended to compare different scenarios? Does the study intend to identify hotspots for decision making? Does the study aim to give an overview of the sustainability performance of the logistics hall? Which is the audience of the study (e.g. CEOs, external stakeholders, customers, etc.)?

Product System and System Boundaries The system boundaries consist of all process units which have at least an environmental and/or social relevant impact. All process units excluded from the study must be justified. What processes is the product, in our case the logistics hall, going through within its entire life cycle? Afterward, life cycle stages or processes are excluded from the study for example because of data availability reasons or because it has proven to have no relevant social and environmental impacts. For the environmental dimension of the baseline and high-bay scenarios of logistics halls, we recommend drawing the system boundaries as cradle to grave including modules C and D. That means that the production stage, as well as disposal and recycling, is assessed. The use phase can be excluded as the assessed scenarios do not make use of specific cooling, lighting, or other kind of inputs that could have a potential environmental impact, the use phase is not particularly relevant for an environmental assessment of the defined logistics halls.

For the definition of system boundaries in social life cycle assessment first, the relevant stakeholder categories need to be defined. In the literature, the stakeholder categories worker and local community, in particular, were identified by several authors as relevant categories in the construction sector (Ayassamy and Pellerin, 2023; Backes and Traverso, 2023). Within the UNEP Guidelines six potential stakeholder categories are defined: Worker, Local community, Value chain actors, Consumer, Society, Children (UNEP, 2020). Based on EN 15804, the main processes in the life cycle of logistics halls are outlined (see Table 3), from which the main stakeholder categories are drawn.

At first it becomes apparent that the stakeholder category worker is involved in many processes throughout the life cycle of a logistics hall. Not just are they the ones that produce construction materials and construct the logistics hall, perform the demolishment and recycling processes, they are also involved in the use stage. As logistics halls are not built for residential purposes, but for commercial use, it is rather the stakeholder category workers that consumers playing the major role in the use stage (Prataviera et al., 2024). Next to workers, value chain actors also play an important part in the first life cycle stages of a logistics hall (Nasiri, 2024). Furthermore, is the stakeholder category local community an important part in multiple life cycle stages. They are not only impacted by the construction works itself in their close environment, but also during the use stage. Here again, the fact, that logistics halls are used for commercial reasons, influences the economic development of the local economy, if not even on the larger society (Salim Ba Awain et al., 2021). Therefore, in the case of the baseline as well as high-bay scenario, the stakeholder categories Worker as well as Local Community are of main relevance and should be included within the study. A stakeholder analysis, however, should be performed to identify all relevant stakeholder categories. Furthermore, it is recommended that for the baseline scenario as well as the high bay scenario, system boundaries should be set as Cradle to Grave.

Functional Unit The functional unit is the quantified value of a product system for the use as a reference unit. It determines what is to be analyzed. All subsequent analyses are then related to this functional unit, since all inputs and outputs in the life cycle inventory and consequently, also the impact assessment profiles are related to the functional unit. For the case of logistic halls, that are solely used as storage warehouses, we recommend a functional unit of $1m^3$ storage space with all characteristics representative of the specific logistics hall (e.g. with a specific lifetime). This includes the baseline as well as the high-bay scenario, which makes the results of the sustainability assessments comparable with each other.

Reference Flow The reference flow is calculated after having set the functional unit. It describes the measure of the outputs of processes of an existing product system that are required to perform the function, expressed by the functional unit (International Organization for Standardization Environmentala; International Organization for Standardization Environmentalb). An example of that is presented in a research paper from 2019, in which the functional unit is set as: 1 m^2 of material that fulfills the Eurocodes' requirements for strength, serviceability, durability, and fire resistance. The LCA study aimed to compare the potential environmental impacts of different types of aggregate

Table 3
Life cycle stages of logistics halls (own illustration based on (UNEP, 2020; European Standards Organizations Sustainability ofb)).

Life Cycle Stage	Processes
A1-A3: Production	• Raw material extraction • Transport • Production of building components
A4-A5: Construction	• Transport • Construction of logistics hall
B1-B7: Usage and Maintenance	• Repairing and maintenance of building Components • Usage of the building: In case of logistics halls, workers storing and collecting products
C1-C4: Disposal	• Transport • Waste disposal
D: Recycling	• Recycling process

concrete. This meant, that for the two materials, differences in thickness were needed to fulfill the same functional unit (Marinković and Carević, 2019). A comparison of potential environmental impacts using reference flows therefore ensures that the actual function of the product is compared.

Impact Assessment Method As there were no consistent impact categories used in the literature evaluated, it is recommended to use the midpoint indicators of the CML methodology for both scenarios to assess their potential environmental impact. The CML methodology aims to assess most relevant midpoint indicators for environmental life cycle assessment (European Commission-Joint Research Centre - Institute for Environment and Sustainability, 2011), and provides therefore a valuable solution to holistically assess a logistics hall's potential environmental impact. Midpoint impacts allow a comparison of environmental interventions at a level of the cause-effect chain between emissions/-resource consumption and the endpoint level. Endpoint impacts, on the other hand, are farther in the cause-effect chain at a level of areas of protection, such as the natural environment's ecosystems, human health, and resource availability (European Commission-Joint Research Centre - Institute for Environment and Sustainability, 2011). Accordingly, these include the following impact categories.

- Abiotic Deplition (ADP elements)
- Abiotic Deplition (ADP fossil)
- Acidification Potential
- Eutrophication Potential
- Freshwater Aquatic Ecotoxicity
- Climate Change (GWP)
- Climate change (GWP) excl. biogenic carbon
- Human Toxicity Potential
- Marine Aquatic Ecotoxicity Potential
- Ozone Layer Depletion Potential
- Photochem. Ozone Creation Potential
- Terrestric Ecotoxicity Potential

For the assessment of the social sustainability of logistics halls, specific subcategories for the relevant stakeholder groups from the UNEP, 2020 Guidelines (UNEP, 2020) as well as the identification of a reference scale is of importance. To identify, which subcategories are of relevance, a social hotspot analysis has been developed for a basic logistics hall. Those aspects include the processes of construction and transport as well as the mineral and metal product production. Aspects, that are of high or very high risk need to be included in an S-LCA, while aspects of medium risk can be included, and the ones of low risk can be excluded. All social subcategories that showed a low risk for Germany in all assessed products/services and a predominant low risk in the other European countries are excluded from the summary of potential risks for the baseline as well as high-bay scenario (see Table 4). Here again, it must also be checked on a case-by-case basis whether a country with a high or very high risk in one of the subcategories is involved in the production chain. If this is the case, the corresponding subcategory must be included in the S-LCA. Since this social hotspot assessment only considers risks of potential negative impact, the Real Estate Impact Analysis Tool of UNEP fi was taken into consideration for potential positive impacts. A social subcategory, that was stated with a potential positive impact for logistics halls should therefore also be included in an S-LCA study. The overall results are shown in Table 4.

For both the Baseline as well as the high bay scenario the Reference Scale approach (Type I S-LCA) as a Social Impact Assessment approach can be applied.

Data Collection Strategy For environmental data collection all input and output flows for each process of the product system within the defined system boundaries need to be collected. This can be done by collecting primary data and/or using secondary data from databases. Here it is advisable to make use of modeling software such as Gabi, Simapro, or OpenLCA, which can be linked directly to databases such as Ecoinvent. To collect data for social life cycle assessment, site specific data should be collected by performing a questionnaire with the relevant stakeholder groups. Generic data should only be used where site specific data is not available.

Table 4
Potential positive and negative social risks of logistics halls based on (UNEP fi, 2021; Social Hotspot Database, 2022).

Stakeholder Group	Social Subcategory	Potential negative Impact (SHDB)	Potential positive Impact (UNEP)
Workers	Freedom of association and collective bargaining	X	
	Child labour		
	Fair salary		
	Working hours	X	
	Forced Labour	X	
	Equal opportunities/ Discrimination	X	
	Health and Safety	X	X
	Social benefits/Social security	X	
	Employment relationship	X	
	Sexual harassment	X	
	Smallholders including farmers	X	
Local Community	Access to material resources		X
	Access to immaterial resources	X	X
	Delocalization and migration	X	
	Cultural heritage	X	X
	Safe and healthy living conditions	X	X
	Respect of indigenous rights		
	Community engagement	X	
	Local employment	X	X
	Secure living conditions	X	X

5.2. Inventory

In the Inventory phase of a life cycle assessment, all relevant data according to the goal and scope of the study is collected. For an environmental life cycle assessment of both defined scenarios of logistics halls, that means that all input flows (Energy and Materials) and output flows (E.g.: Emissions and Product) of each process within the product system need to be documented. In the ISO 14044 standard, there are exemplary tables with which the data collection can be carried out.

To collect data for the assessment of the social sustainability performance of the defined logistics halls, a questionnaire needs to be developed, to collect site specific data according to the relevant social subcategories. If the collection of site-specific data is not possible, generic data from databases like PSILCA can be used.

5.3. Impact assessment

For the impact assessment of potential environmental impact within an LCA, it should be performed according to ISO 14040 and 14044. According to those standards, impact assessment is the phase of the LCA that aims to assess the significance of potential environmental impacts using the results of the Life Cycle Inventory. Generally, in this step, life cycle inventory data are allocated to specific impact categories and characterized by calculating impact indicator values in an attempt to identify the resulting potential impacts. (International Organization for Standardization Environmentala; International Organization for Standardization Environmentalb) Potential environmental impact should be calculated for the product system defined in the goal and scope phase for the 11 impact categories in the CML method. If software like GaBi or SimaPro is used, impact assessment can be calculated there.

Calculation of potential or actual social impacts can be done using two types of impact assessment methods. Type I is the "Reference Scale Approach" which aims to describe a product system with a focus on its social performance or social risk. Using the reference scale approach, the social performance of activities of organizations in the product system is assessed based on specific reference points of expected activity. Type II S-LCA is the so-called "Impact Pathway Approach", which aims is to predict the consequences of the product system, with an emphasis on characterizing potential. With this approach, potential or actual social impacts are calculated using causal or correlation/regression-based directional relationships between the product system and the resulting potential social impact (UNEP, 2020). The impact pathway approach is less used because few methodologies with characterization factors have been developed yet.

5.4. Interpretation

The Interpretation phase on an LCA or S-LCA again, should be performed according to ISO 14040/44 as well as the UNEP, 2020 Guidelines (UNEP, 2020). It should be done along the goals scope defined early on in the study, to sufficiently answer the research question. However, it is important to consider at this stage of the assessment all assumptions made and limitations of the study. The results should therefore be critically discussed along these limitations.

6. Case study

To illustrate the application of the developed guideline, the following section gives an example of how the implementation of an environmental life cycle assessment as well as a social sustainability assessment could look like. The execution of a life cycle costing is not explained in more detail here, as it is assumed that a cost assessment is carried out for every construction project and that a project that is not economically worthwhile is not carried out. For both assessments, the same specific case study of a logistic hall in Germany is used.

6.1. Life cycle assessment

6.1.1. Goal and scope definition

Goal: Assessment of the environmental sustainability performance for the production stage of a specific storage warehouse without special equipment. Within the scope definition Table 5 summarizes the determined frame for the study.

For this case study, the functional unit was not defined as m^3 of storage capacity, as recommended in the guideline. This is due to a limited data availability, and since this study does not follow the purpose of comparison. As this case study is only intended to provide an exemplary application of an LCA for logistics halls, the functional unit of one basic logistics hall for storage located in Germany was found sufficient for its purpose. To define the system boundaries cut-offs had to be made due to limited data availability. Fig. 1 shows the system boundaries and cut-offs taken.

6.1.2. Inventory

Data collection was carried out using primary data from a specific case study in Germany. The data included the construction description and quantities of certain building materials for the logistics hall. Due to limited data availability expert-lead assumptions, such as the type of concrete and steel had to be made. The inventory can be seen in Table 6.

Table 5
Scope parameters of the LCA-study.

System boundaries	Cradle-to-Gate (A1-A5)
Functional Unit	One basic logistics hall for storage located in Germany
Reference Flow	Calculated for each material for the case study (see Inventory)
Data Collection Method:	Primary Data + and various Databases within the software GaBi ts (especially useful: XIV Construction materials)
Assumptions made:	Several assumptions and cut-offs had to be made due to limited data availability (see Inventory)
Impact Assessment Method:	CML methodology used with the software GaBi ts

6.1.3. Impact assessment

For the impact assessment, the CML method was used with the software Gabi ts (see Table 5). A scenario analysis was performed with two different concrete types for the in-situ concrete as well as the concrete for outdoor use: C25/30 (scenario 1) and C30/37 (scenario 2). It can be seen that the elements of the product system made of concrete have the highest potential environmental impacts. This is the case for both scenarios, the one with C25/30 and C30/37 concrete (see Figs. 2 and 3).

Looking at the GWP emissions more in detail, it becomes clear that the production process of the materials has a much higher potential impact than the transportation processes (see Figs. 4 and 5).

The results do not seem to be very different for the two concrete types. Yet, elements made of concrete are the main drivers of potential environmental impact, whereby a close look at the differences between the two scenarios is taken (see Fig. 6). The results show that the potential environmental impact on climate change for this product system is more than 20% higher when using C30/37 concrete instead of C25/30 concrete. However, C30/37 concrete has a greater mechanical strength classification, and in some cases, it may be necessary to use the stronger type of concrete.

6.2. An exemplary social life cycle assessment: health and safety subcategory

6.2.1. Goal and scope definition

Concerning social sustainability assessment, there is no complete social life cycle assessment performed. However, to represent the application of the Framework of Sustainability Assessment for Logistics halls, the proceeding is shown exemplary. As the goal of the study, it is defined: An assessment of the social sustainability performance for the use stage of a specific storage warehouse without special equipment. Within the scope definition Table 7 illustrates the determined frame for the study.

According to the goal and scope defined before, only the impact subcategory health and safety within the stakeholder category workers in the use stage of the logistics hall is included. The decision as to why this social impact subcategory was selected for this exemplary case study is based on the preceding literature review in this study (see sections 3.3. and 3.4.). Based on the literature reviewed, it has been found that most studies consider workers health and safety to be a relevant social impact subcategory for logistic halls.

6.2.2. Inventory

Data collection within the life cycle inventory was carried out using primary data. At first relevant indicators within the social impact subcategory were defined. As there is no standardization for that yet, it has to be decided on a case-by-case basis which indicators should be assessed within the framework of the study. For our case study, the choice of indicators was based on the standards of the International Labour Organization (ILO), as these list the most important aspects of occupational health and safety (Guide to international labour standards, 2014). This resulted in the following list of indicators, which are assessed in the following section of the impact assessment.

• Availability of toilets	• Measures existent in case of emergencies
• Provision of personal protective equipment	• Existence of emergency plans
• Safe condition of the workplace	• Information about health and safety measures provided to employees
• Compliance with health and safety regulations in Germany	• Health and safety training provided
• Existence of a health and safety commission	• Health and safety checks provided
	• Opportunity for reporting of risks

(*continued on next page*)

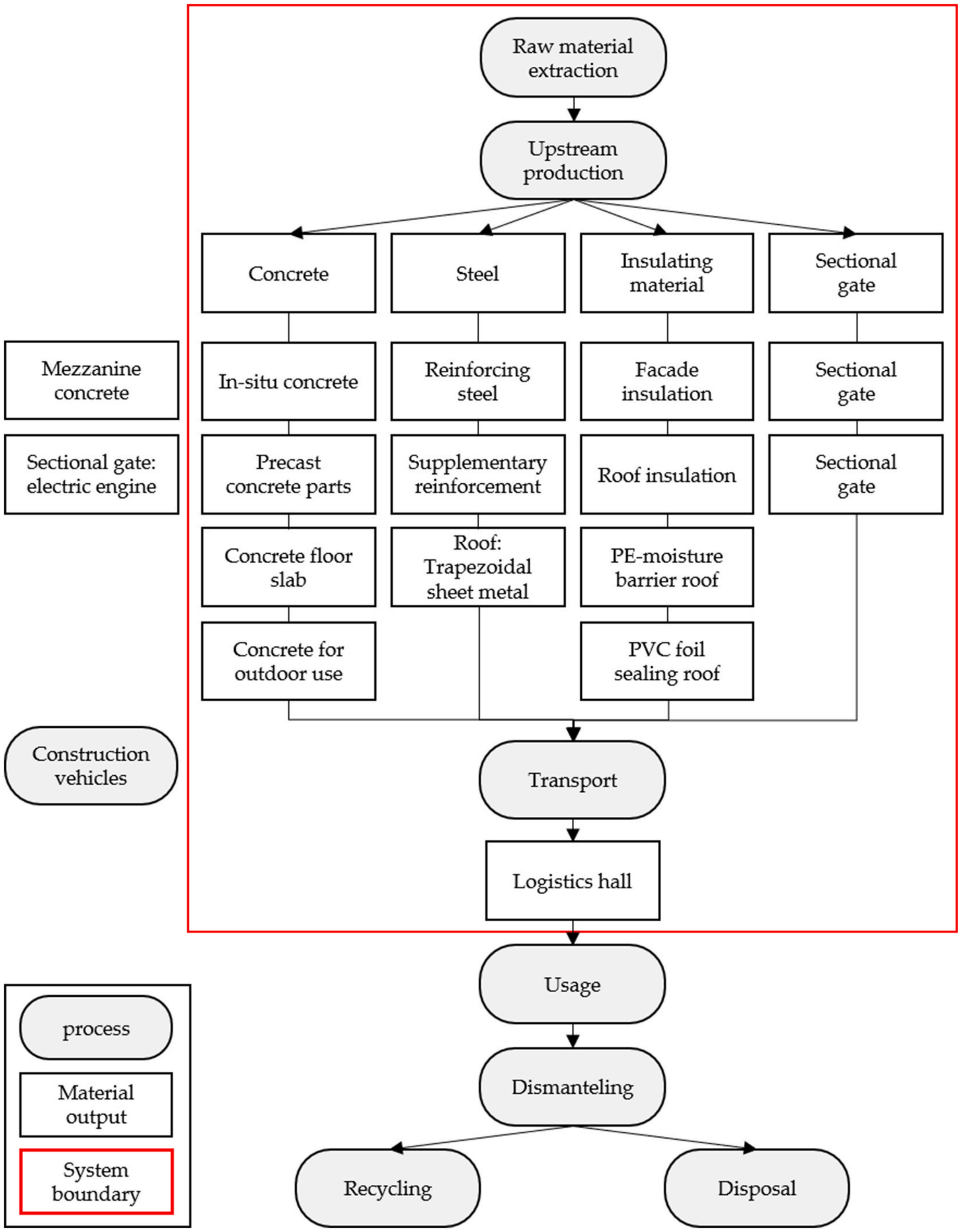

Fig. 1. System boundaries LCA case study logistics hall.

(*continued*)

• Measures taken to protect the health and safety of workers

Primary data was collected with official documents and certifications such as the annual risk assessment report (GBU) and the official site plan.

6.2.3. Data evaluation

Using primary data such as official documents and documentation did not leave the possibility to assess an impact using the reference scale approach. However, it could be assessed whether negative impacts either are existent if the risks are not sufficiently counteracted with appropriate measures, or not existent. Table 8 summarizes if the indicators defined are fulfilled, whereby according to the primary data received no risk of a negative social impact exists.

It becomes clear from the information available, that the organization fulfills all assessed indicators regarding the health and safety of workers in the use stage of the case study. The only aspect that is not clear from the data as to whether personal protective equipment is provided by the organization and/or whether the organization ensures the use of them among its workers. It is stated in several aspects of the risk assessment report, that the organization ensures that employees wear personal protective equipment to protect their occupational health and safety.

Table 6
Life Cycle Inventory LCA Case Study Logistics hall.

	Input	Unit	GaBi Process	Assumptions
Material				
In-situ concrete	5963,98	t	EU-28: Concrete C25/30 (Ready-mix concrete) (EN15804 A1-A3) Sphera EU-28: Concrete C30/37 (Ready-mix concrete) (EN15804 A1-A3) Sphera	C25/30 concrete C30/37 concrete
Precast concrete parts	10027,50	t	EU-28: Pre-cast concrete Sphera	Precast concrete elements without consideration of formwork
Concrete floor slab	13333,50	t	EU-28: Pre-cast concrete Sphera	Precast concrete elements without consideration of formwork
Concrete for outdoor use	3175,20	t	EU-28: Concrete C25/30 (Ready-mix concrete) (EN15804 A1-A3) Sphera EU-28: Concrete C30/37 (Ready-mix concrete) (EN15804 A1-A3) Sphera	C25/30 concrete C30/37 concrete
Steel reinforcement	853	t	EU-28: Steel sections (EN15804 A1-A3) Sphera <t-agg>	
Supplementary steel reinforcement	10	t	EU-28: Steel sections (EN15804 A1-A3) Sphera <t-agg>	
Roof: Trapezoidal sheet metal	5021,74	m^2	EU-28: Aluminium profile (trapezoidal 35/207) - IFBS (A1-A3) Sphera-EPD	Aluminium profile Gabi: weight 2.3 kg/m^2, thickness 0.7 mm, height 35 mm; PVC foil sealing included in the process
Façade insulation	38,60	t	EU-28: Polyisocyanurate (PIR high-density foam) Sphera	Same insulation material as roof insulation
Roof insulation	137,86	t	EU-28: Polyisocyanurate (PIR high-density foam) Sphera	
PE-moisture barrier (roof)	475	kg	EU-28: Damp insulation PE (EN15804 A1-A3) Sphera	
Sectional gate steel double wall	2826	kg	EU: Steel electrogalvanized worldsteel	Thickness steel per wall: 20 mm
Sectional gate insulation	10,8	kg	Polyethylene foam (EN15804 A1-A3)	
Transportation				
Truck to construction site (per material)	100	km	GLO: Truck-trailer, Euro 4, 34 - 40t gross weight/27t payload capacity Sphera <e-ep>	Assumed distance from building material to construction site process step. Driven by diesel (GaBi DE process) - amount on fuel (diesel) depending of weight.

6.3. Interpretation and discussion

In the following, the results of the two case studies for sustainability assessments of a logistics hall located in Germany are discussed. At first limitations of the studies such as limited data availability have to be mentioned. Especially for the environmental life cycle assessment, multiple assumptions regarding material specifications had to be made. On the social impact, it is not possible to summarize conclusions on the data availability because the S-LCA is not complete in this phase. In addition to that, cut-offs were made such as excluding construction vehicles and the corresponding emissions and the energy demand on the construction site due to a lack of information. Furthermore, it must clearly be stated that only certain life cycle stages were assessed in both studies. The reason for that was, that this should only provide an overview about how sustainability assessments according to the previously established framework are to be conducted. Therefore, the guideline is not applied in its entirety within the case studies; instead, they are intended to serve as an exemplary illustration of the guideline application. To holistically understand the sustainability performance of logistics halls, a full LCSA study needs to be conducted.

Nevertheless, these results still give valuable insights not just into how sustainability assessments are performed, but for LCA also what aspects to set a greater focus on. For that it became clear, that concrete is the major driver of the potential environmental impacts of the case study. For that, it could be advantageous to further investigate if different, less environmentally damaging concrete mixtures that still fulfill the functions needed. The scenario analysis confirmed this by showing, that the material choice with a greater strength in the case of concrete had a significantly higher potential impact on climate change. This raises an interesting question as to whether materials with better structural performance are automatically less sustainable from an environmental point of view. Further research is needed on materials used in structural engineering, for example, with optimized concrete composition or increased recycled content. Based on the results of this exemplary case study, it is important for users of the guideline to think about material choices, and what functions such as strength and fire resistance are needed at what part of the building, which can open the possibility design a more optimized building – including the environmental aspect as one key criterium. In addition to that, using recycled material as well as providing the possibility to easily recycle materials later on, could further improve the environmental performance. As within this case study, only the production stage was included in the system boundaries, this aspect is not yet represented in the results.

As mentioned before, it needs to be emphasized that this is not a complete S-LCA. However, here again, the application of the guidelines is shown for future decision makers to easier implement the methodology. When looking at this case study, it is interesting to note that there was no survey or analysis of secondary data, as is the case in many S-LCAs. Instead, the decision was made to initially scan certificates and official documents. While the previous research showed that health and safety can be a potential risk for workers in the use stage of logistics halls, the analysis of the case study showed that this is not a hotspot according to the available data. However, it must be noted at this point that this only applies to the indicators considered in the system boundaries of this study. Generally, it is worthwhile to scan such documents beforehand to avoid time-consuming data acquisition. This case study has shown that the use of such secondary site-specific data sources can also represent a reasonable first approach. Particularly because the availability of social data has proven to be a considerable challenge in past studies. Yet one aspect that cannot be examined with this data source is the identification of different scales of performances, as it would be the case with the reference scale approach. With this approach, it is soely possible to detect a potential negative impact or to identify that this is not present for the indicator being tested. The assessment of social issues using official documents and reports is thus an important first foundation for the inclusion of the social dimension in sustainability assessments. However, this case study also shows that further work is needed to enable a larger database and more standardization in the data collection of social aspects for a more comprehensive assessment of social sustainability. Examples of this could be standardized data

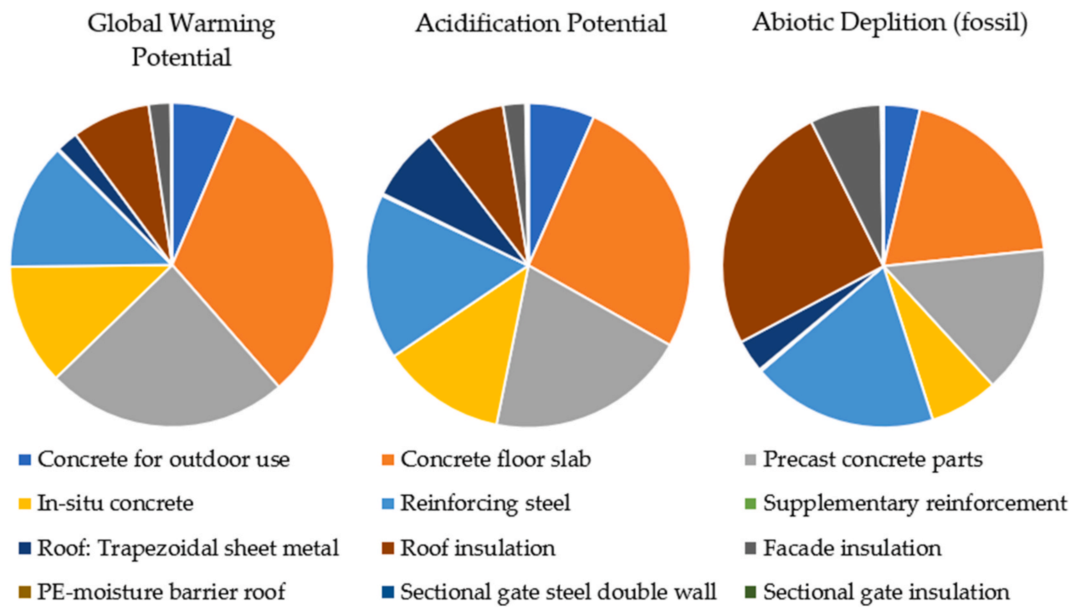

Fig. 2. GWP, AP and ADf distribution of scenario 1 (C25/30 concrete).

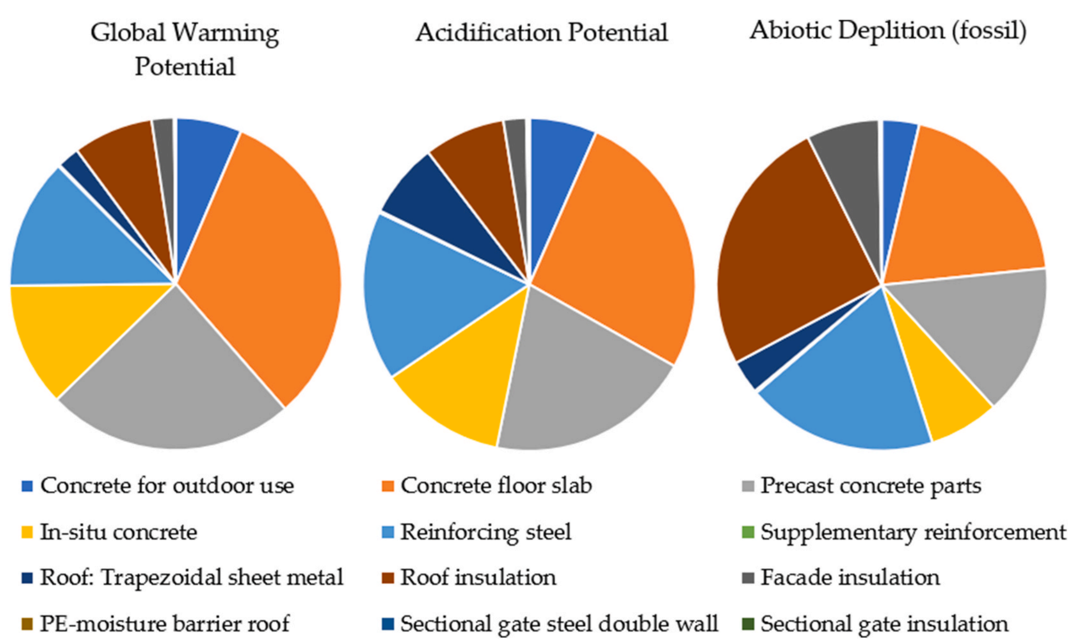

Fig. 3. GWP, AP and ADf distribution of scenario 2 (C30/37 concrete).

collection tools (Chabrawi et al., 2024) and product category rules for S-LCAs (The international EPD system, 2023).

Overall, it can be concluded that these case studies round off this project well in an attempt to improve sustainability assessments for logistics halls. Important insights can be gained, which should be further deepened in subsequent studies. For further sustainability assessments of logistics halls and the implementation of sustainability criteria in decision-making processes in the early planning phase, the developed guideline offers an important foundation and support. Thus, it is now up to companies in the construction industry that are in a position to make such important decisions to implement the holistic sustainability consideration as a decisive criterion to drive sustainable development. When applying the guideline in industry, the assumptions and limitations outlined in the study must be taken into consideration. As expressed beforehand, these should continue to be evaluated on a case-by-case basis. For further studies, it could be an interesting step to consider expanding the guideline to other contexts, such as other types of industrial buildings.

7. Conclusion

To conclude, a guideline was developed in this study to simplify holistic sustainability assessments of logistics halls. The purpose of this is to promote sustainability performance in decisions in the construction sector. For the guideline, a literature review of existing sustainability assessments (LCA, LCC, and S-LCA) of logistics buildings was conducted. In addition, a social risk assessment and a screening of the UNEP fi tool for potential positive impacts were carried out. Furthermore, the knowledge of sustainability experts was utilized for the development of the guideline. Finally, two case studies were prepared to present the

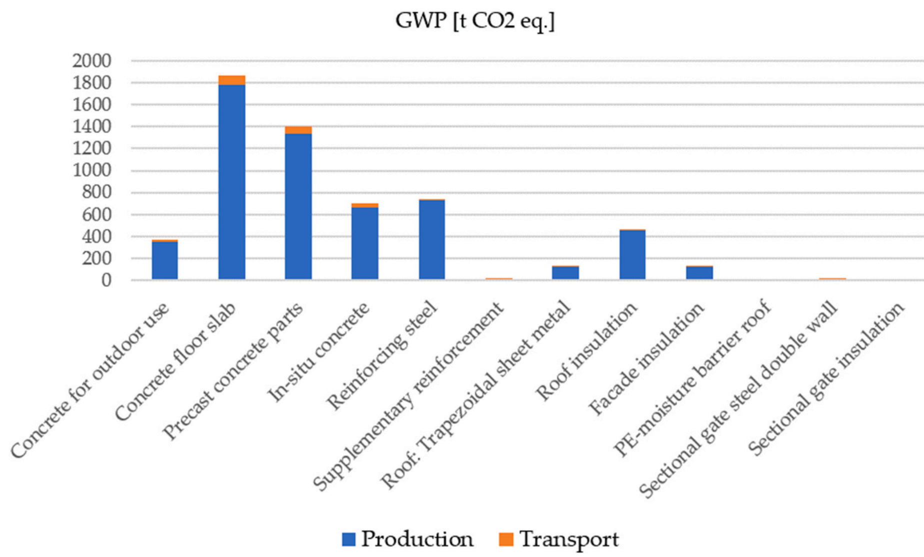

Fig. 4. GWP for the product system, scenario 1 (C25/30 concrete).

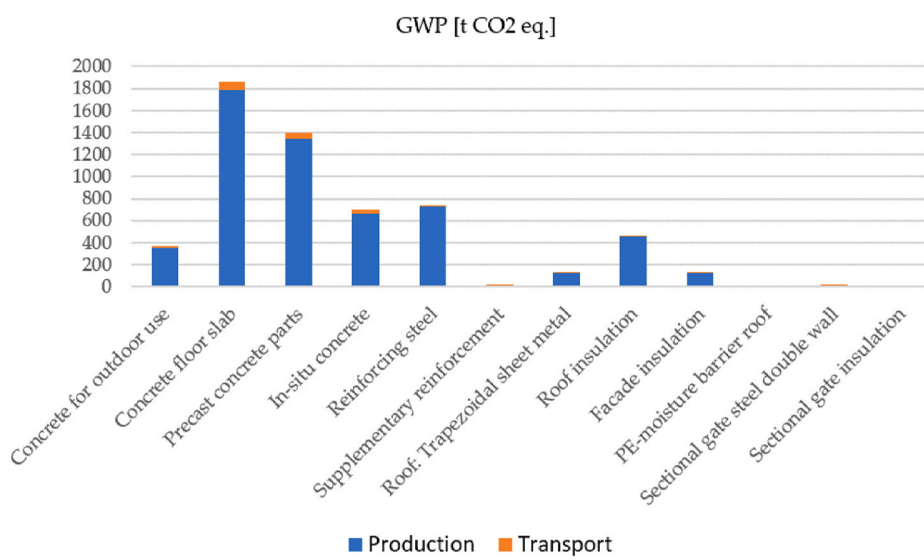

Fig. 5. GWP for the product system, scenario 2 (C30/37 concrete).

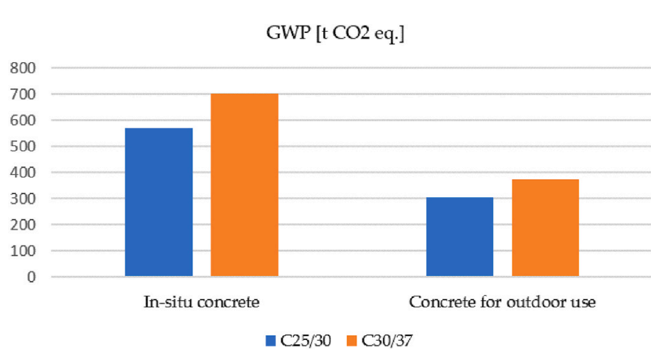

Fig. 6. GWP scenario anaylsis

application of the guideline.

The study contains limitations, such as assumptions made both in the guideline and in the case studies due to a lack of sufficient data. Furthermore, it is important to emphasize that this study only provides an initial foundation as support for sustainability assessments of logistics halls. For generally valid statements, it would be necessary to create a comprehensive LCSA study verified by third-party experts. Nonetheless, this initial guideline is an important basis for incorporating sustainability assessments in the early planning phase of logistics buildings. Furthermore, the following key findings emerged from the study.

Table 7
Scope parameters of the S-LCA-study.

System boundaries	Use stage
Stakeholder category	Worker
Functional Unit	One basic logistics hall for storage located in Germany
Data Collection Method:	Primary Data from official documents and certifications
Assumptions made:	–
Impact Assessment:	Qualitative evaluation of the data received for the social impact subcategory health and safety

Table 8
Workers health and safety evaluation.

Indicator	Fulfilled?	Data source	Comment
Compliance with health and safety regulations in Germany	Yes	GBU 2023	General report signed as okay for 2023
Availability of toilets	Yes	GBU 2023 (1.8)	
Provision of personal protective equipment	?		
Safe condition of the workplace (including equipment and machinery)	Yes	GBU 2023 (1.11)	
Existence of a health and safety commission	Yes	GBU 2023 (1.9)	Specialist for occupational health and safety and health and safety coordinator
Measures taken to protect the health and safety of workers	Yes	GBU 2023 (2.1, 2.2, 2.4)	
Existence of emergency plans	Yes	GBU 2023 (7.1)	
Information about health and safety measures provided	Yes	GBU 2023 (1.10)	
Training provided	Yes	GBU 2023 (1.1)	
Regular health and safety checks	Yes	GBU 2021/ 2022/ 2023	Annual risk assessment and effectiveness check through the regular safety inspections by the occupational safety specialist. The documentation is done using the visit reports.
Opportunity for reporting of risks	Yes	GBU 2023 (1.10)	

- Social sustainability assessments remain less frequently applied for logistics halls
- Concrete components represent the main drivers of potential environmental impacts of the assessed case study
- Relevance of material selection → Conscious decisions for/against building material selection for the components necessary in the planning stage
- Include recycling: The use of recycled materials and possible recycling of the materials at the end of its lifetime can potentially improve the environmental sustainability performance
- A social sustainability assessment could also be prepared with the help of site-specific secondary data in the form of e.g. the annual risk assessment report

It is important to follow up on these initial endeavors and to further advance sustainability assessments of logistics halls. To this end, it is essential to carry out a holistic, third-party verified LCSA study using primary data as the next step.

CRediT authorship contribution statement

Alexandra Weniger: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Julian Frede:** Writing – review & editing, Supervision, Conceptualization. **Laura Schmidt:** Writing – review & editing, Formal analysis. **Leonie Hartmann:** Writing – review & editing. **Marzia Traverso:** Writing – review & editing, Supervision.

Funding

This research received no external funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was initiated and supported by the evolutiq GmbH (evolutiq). Their support is gratefully acknowledged.

Data availability

The authors do not have permission to share data.

References

Ayassamy, P., Pellerin, R., 2023. Social life-cycle assessment in the construction industry: a review of characteristics, limitations, and challenges of S-LCA through case studies. Sustainability 15, 14569. https://doi.org/10.3390/su151914569.
Ayoub, H., Sweis, G., Abu-Khader, W., et al., 2022. A framework to evaluate sustainable construction principles in government building projects: the case of Jordan. ECAM. https://doi.org/10.1108/ECAM-01-2022-0040.
Backes, J.G., Traverso, M., 2021. Application of life cycle sustainability assessment in the construction sector: a systematic literature review. Processes 9, 1248. https://doi.org/10.3390/pr9071248.
Backes, J.G., Traverso, M., 2022. Life Cycle Sustainability Assessment in the construction sector – actual application and future outlook. E3S Web Conf 349, 4007. https://doi.org/10.1051/e3sconf/202234904007.
Backes, J.G., Traverso, M., 2023. Social life cycle assessment in the construction industry: systematic literature review and identification of relevant social indicators for carbon Reinforced concrete. Environ. Dev. Sustain. https://doi.org/10.1007/s10668-023-03005-6.
Backes, J.G., Mankaa, R.N., Traverso, M., 2024. Drei Säulen der Nachhaltigkeit und Bewertungsansätze. In: Kampker, A., Heimes, H.H. (Eds.), Elektromobilität. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 629–642.
Bottani, E., Tebaldi, L., Lazzari, I., et al., 2019. A model for assessing economic and environmental sustainability dimensions of a fashion supply chain and a case study. IFAC-PapersOnLine 52, 361–366. https://doi.org/10.1016/j.ifacol.2019.11.147.
Chabrawi, A.M.R.O., de Andrade, J.M., Ugaya, C.M.L., Traverso, M., 2024. Towards reliable primary data collection and harmonized set of indicators in S-LCA on the stakeholder worker Assessment. Int. J. Life Cycle Assess. 1–19. https://doi.org/10.1007/s11367-024-02400-z.
Del Rosario, P., Traverso, M., 2023. Towards sustainable roads: a systematic review of triple-bottom-line-based assessment methods. Sustainability 15, 15654. https://doi.org/10.3390/su152115654.
Deutsche Gesellschaft für Nachhaltiges Bauen - DGNB e.V. Aboout the DGNB system: The "Global Benchmark for Sustainability" among certification systems for sustainable buildings and districts. https://www.dgnb.de/en/certification/important-facts-about-dgnb-certification/about-the-dgnb-system. Accessed 19 October 2023.
Dilaver, B., Çokoğlu, H.T., Yamanlar, M., et al., 2020. Sustainability evaluation of textile warehouses from social and environmental perspective. In: Durakbasa, N.M., Gençyılmaz, M.G. (Eds.), Proceedings of the International Symposium for Production Research 2019. Springer International Publishing, Cham, pp. 791–810.
Dong, Y.H., Ng, S.T., 2016. A modeling framework to evaluate sustainability of building construction based on LCSA. Int. J. Life Cycle Assess. 21, 555–568. https://doi.org/10.1007/s11367-016-1044-6.
Durán, O., Afonso, P., Durán, P., 2019. Spare parts cost management for long-term economic sustainability: using fuzzy activity based LCC. Sustainability 11, 1835. https://doi.org/10.3390/su11071835.
European Commission EU taxonomy for sustainable activities. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en. Accessed 19 October 2023.
European Commission Level(s): European framework for sustainable buildings. https://environment.ec.europa.eu/topics/circular-economy/levels_en. Accessed 19 October 2023.
European Commission-Joint Research Centre - Institute for Environment and Sustainability, 2011. Handbook- Recommendations for Life Cycle Impact Assessment in the European Context. Publications Office of the European Union, Luxemburg.
European Standards Organizations Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method; German Version EN 15978:2011.
European Standards Organizations Sustainability of Construction Works – Environmental Product Declarations – Core Rules for the Product Category of Construction Products; German Version EN 15804:2012+A2:2019 + AC:2021.

Finkbeiner, M., Schau, E.M., Lehmann, A., et al., 2010. Towards life cycle sustainability assessment. Sustainability 2, 3309–3322. https://doi.org/10.3390/su2103309.
Guide to International Labour Standards, second ed., 2014. ITC, Turin.
Guinée, J., 2016. Life cycle sustainability assessment: what is it and what are its challenges? In: Clift, R., Druckman, A. (Eds.), Taking Stock of Industrial Ecology. Springer International Publishing, Cham, pp. 45–68.
Iancu, I.E., Moga, L.M., 2022. Life cycle analysis of warehouse-type constructions. In: CLIMA 2022 Conference, 2022: CLIMA 2022 the 14th REHVA HVAC World Congress. https://doi.org/10.34641/clima.2022.329.
International Organization for Standardization Environmentala International Organization for Standardization Environmental Management — Life Cycle Assessment — Principles and Framework.
International Organization for Standardization Environmental Management — Life Cycle Assessment — Requirements and Guidelines.
International Organization for Standardization Zuverlässigkeitsmanagement – Teil 3-3: Anwendungsleitfaden – Lebenszykluskosten (IEC 60300-3-3:2004); Deutsche Fassung EN 60300-3-3:2004. Dependability Management – Part 3-3: Application Guide - Life Cycle Costing (IEC 60300-3-3:2004); German Version EN 60300-3-3: 2004.
International Standards Organization, 2012. ISO/TR 14047, Environmental Management - Life Cycle Assessment - Illustrative Examples on How to Apply ISO 14044 to Impact Assessment Situations. Technical report, Swizerland.
Irtyshcheva, I., Nosar, A., Boiko, Y., et al., 2023. The multiplier effect of investment and innovation support for the development of transport and logistics systems: Foreign experience and practice for Ukraine. J. Hyg. Eng. Des. 211–219.
Jacobi, C., Kruschina, D., Nehm, A., et al., 2020. Klimabilanz - Impulse für die Logistikimmobilienwirtschaft.
Janjua, S.Y., Sarker, P.K., Biswas, W.K., 2019. Sustainability assessment of a residential building using a life cycle assessment approach. Chem. Eng. Trans. 72. https://doi.org/10.3303/CET1972004.
Jayawardana, J., Zhang, G., Kulatunga, A.K., et al., 2022. Life cycle sustainability assessment for modular construction – a proposed conceptual framework. IOP Conf. Ser. Earth Environ. Sci. 1101, 42039. https://doi.org/10.1088/1755-1315/1101/4/042039.
Jones Lang LaSalle IP, Inc, 2020. Logistics Buildings of Tomorrow: the Impact of Demographics, Technology, Urbanisation and Sustainability on Future Buildings and Locations.
Kamali, M., Hewage, K. (Eds.), 2017. Sustainability Performance Assessment: A Life Cycle Based Framework for Modular Buildings.
Kugler, S., 2021. Decision Support Tool for Ecological and Economical Optimization of Flexible Industrial Buildings via Parametric Modelling. Technische Universität Wien. Diploma thesis.
Loske, D., Klumpp, M., Keil, M., et al., 2021. Logistics work, Ergonomics and social sustainability: empirical musculoskeletal system strain assessment in retail intralogistics. Logistics 5, 89. https://doi.org/10.3390/logistics5040089.
Marinković, S., Carević, V., 2019. Comparative studies of the life cycle analysis between conventional and recycled aggregate concrete. In: New Trends in Eco-Efficient and Recycled Concrete. Elsevier, pp. 257–291.
Nasiri, Hamid (Ed.), 2024. Building a Sustainable Future: the Imperative of Sustainable Construction.
Prataviera, L.B., Creazza, A., Perotti, S., 2024. A call to action: a stakeholder analysis of green logistics practices. IJLM 35, 979–1008. https://doi.org/10.1108/IJLM-09-2022-0381.
Reihofer, V., 2021. Analyse einer Betriebserweiterung unter produktions- und investitionsspezifischen Rahmenbedingungen. Technische Universität Wien.
Salim Ba Awain, A.M., Jantan, M.D., Sukati, I., 2021. Assessing the effect of integration in logistics sector on economic growth: evidence from sultanate of Oman. IBR (Indian Bot. Rep.) 15, 35. https://doi.org/10.5539/ibr.v15n1p35.
Social Hotspot Database, 2022. Risk Mapping Tool. http://www.socialhotspot.org/tools.html. (Accessed 15 September 2024).
Srivastava, S., Raniga, U.I., Misra, S., 2022. A methodological framework for life cycle sustainability assessment of construction projects incorporating TBL and decoupling principles. Sustainability 14, 197. https://doi.org/10.3390/su14010197.
The international EPD system, 2023. SPD-PCR 2023:01: Rolling Stock, VERSION 1.0.0.
UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products and Organizations 2020.
UNEP, 2021a. 2021 Global Status Report for Buildings and Construction. United Nations Environment Programme, Nairobi.
UNEP, 2021b. Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA) 2021.
UNEP fi, 2021. Real Estate Impact Analysis Tool. https://www.unepfi.org/impact/unep-fi-impact-analysis-tools/real-estate-impact-analysis-tool/. (Accessed 15 September 2023).
UNEP finance initiative, 2021. Real Estate Impact Analysis Tool. https://www.unepfi.org/impact/unep-fi-impact-analysis-tools/real-estate-impact-analysis-tool/.
UNEP LCI, 2011. Towards a Life Cycle Sustainability Assessment: Making Informed Choices on Products.
United Nations, 1987. Report of the World Commission on Environment and Development: Our Common Future.
Zhang, Y., Zhou, T., 2017. Social Sustainability in Manufacturing. Politecnico di Milano.
Zhang, Q., Oo, B.L., Lim, B.T.H., 2019. Drivers, motivations, and barriers to the implementation of corporate social responsibility practices by construction enterprises: a review. J. Clean. Prod. 210, 563–584. https://doi.org/10.1016/j.jclepro.2018.11.050.