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RESEARCH ARTICLE

Comparative Analysis of Life Cycle Assessment of Traditional and Contemporary Timber Buildings

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ABSTRACT

Wood has long been used as a primary building material, but with the Industrial Revolution and the spread of multi-story structures, its structural limitations became evident. In the 21st century, engineered timber products have reintroduced wood as a sustainable alternative, offering advantages such as lightness, rapid assembly, and recyclability. At the same time, buildings are responsible for significant environmental impacts, making assessment methods essential. Life Cycle Assessment (LCA) is one of the most widely used tools for evaluating these impacts across all stages of a building's life cycle. This study applies LCA to timber construction systems, focusing on both traditional and contemporary approaches. Using the One Click LCA software, a comparative analysis was carried out for a residential building designed with three structural systems: traditional log construction, platform frame construction, and modern cross-laminated timber (CLT) panels. The evaluation covered the production, use, and end-of-life phases, considering four impact categories: global warming potential, acidification, eutrophication, and ozone depletion. Findings show that the use phase, particularly energy consumption, accounts for the highest environmental impact. However, notable differences were observed in production and end-of-life stages: the log construction system had the lowest overall impacts, while CLT panels showed higher production impacts but offered durability and prefabrication benefits. By comparing these systems within the same LCA framework, the study contributes to the literature by highlighting their relative performance and providing guidance for sustainable timber construction.

Keywords: Sustainability, Life cycle assessment, Environmental impact assessment, Timber structures, One click LCA

1. Introduction

Building activities have evolved through different periods of history with the use of diverse materials and construction techniques. Among these, wood has historically been a preferred material due to its availability, ease of processing, and ability to span large openings [1]. However, following the Industrial Revolution, the introduction of steel and reinforced concrete significantly reduced the structural role of timber in buildings [2]. This transformation in material use coincided with the rapid growth of industrialization, which intensified environmental issues such as climate change and energy demand

[3, 4]. Today, the building sector accounts for nearly 40% of total global energy consumption, making material choice and construction methods a critical factor in sustainability debates [5, 6].

New timber technologies reduce energy use while meeting the demands of urban environments [7]. Innovative wood-based materials have replaced traditional wood products, and improvements in fire resistance and structural performance have further promoted the use of timber in high-rise construction [8]. In line with these developments, the adoption of timber as a renewable and sustainable material has accelerated, particularly in Germany and Scandinavian countries [9]. Policy frameworks also

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play an important role in this trend; for example, in the United Kingdom, the Climate Change Committee has identified increased timber use in construction as a priority [10]. To systematically evaluate the environmental implications of such material choices, Life Cycle Assessment (LCA) provides a robust methodological framework that enables the comparison of different construction systems and supports sustainability-oriented design decisions [11–13]. Sustainable construction in the civil engineering sector requires a multi-criteria approach that simultaneously considers environmental, economic, and social dimensions, while integrating practices such as energy conservation, use of eco-friendly and local materials, recycling, and renewable energy sources, in order to ensure resource efficiency, environmental protection, and long-term resilience [14–16].

Compared to reinforced concrete and steel, wood yields lower values in terms of energy consumption and greenhouse gas emissions [17–19]. Innovative timber technologies can reduce carbon emissions and energy consumption by 30–40% [20, 21]. As a result, timber construction systems are shown to support sustainability, reduce environmental impacts, and enhance energy efficiency.

This study aims to conduct a comparative evaluation of the environmental impacts of traditional and contemporary timber construction systems using Life Cycle Assessment (LCA). The general objective is to assess the role of timber in sustainable building design by analyzing its life cycle performance, while the specific objective is to compare three distinct structural systems—traditional log construction, platform frame construction, and modern cross-laminated timber (CLT) panels—within the same building context. Unlike most previous studies, which tend to focus either on single construction systems or on comparisons between timber and conventional materials such as concrete and steel, this research provides a direct comparison between traditional and contemporary timber systems under a unified methodological framework. For the analysis, a two-story detached residential building with a total floor area of 74.65 m², designed in the Mudanya district of Bursa, Türkiye, was selected as a case study. Bursa is located in the Marmara Region, which represents a temperate and humid climate zone; therefore, energy consumption patterns and environmental impacts were evaluated in this specific geographical context. Using the One Click LCA software, the study examines the production, use, and end-of-life stages of the building, focusing on key environmental impact categories: global warming potential, acidification, eutrophication, and ozone depletion potential. Through this approach, the study contributes to the

literature by addressing the research gap regarding the comparative life cycle performance of traditional and contemporary timber systems in the Turkish context, offering insights for sustainable material selection and policy development.

2. Conceptual framework

This section of the study provides an overview of traditional and contemporary timber construction materials and systems, as well as the concept of life cycle assessment.

2.1. *Traditional timber construction materials and systems*

In the earliest periods of human history, the primary struggles were for food and protection. In later periods, shelter also became a fundamental need. Since the beginning of human existence, wood has served as a source of fuel, tools, food, and shelter. As human needs evolved, the use of wood also advanced [22].

2.1.1. *Traditional timber construction materials*

Wood is a traditional construction material derived from trees. Structurally, a tree is a living organism composed of roots, a trunk, and branches. When examining a cross-section of a tree trunk, its physical structure from the center outward consists of heartwood, sapwood, cambium, inner bark, and outer bark.

Tree cells are thin, elongated, and hollow tube-like structures known as fibers. Chemically, wood is composed of approximately 40–50% cellulose, 20–30% hemicellulose, and 20–30% lignin, along with smaller amounts of albumin, essential oils, carbohydrates, mineral salts, waxes, resins, tannins, and pigments. Among these, cellulose and lignin—constituting the majority of wood—are the principal components that provide its mechanical strength [23].

Timber construction materials are generally obtained by cutting, drying, and processing trees. In nature, there are many tree species with different physical and mechanical characteristics. The structure and properties of the tree used in timber production largely determine the overall performance of the wood material [23].

Timber construction materials are typically produced through the harvesting, drying, and processing of trees. Various tree species exhibit distinct physical and mechanical properties, which largely determine the performance of the resulting wood material. For instance, Black Pine (*Pinus nigra*) has an average

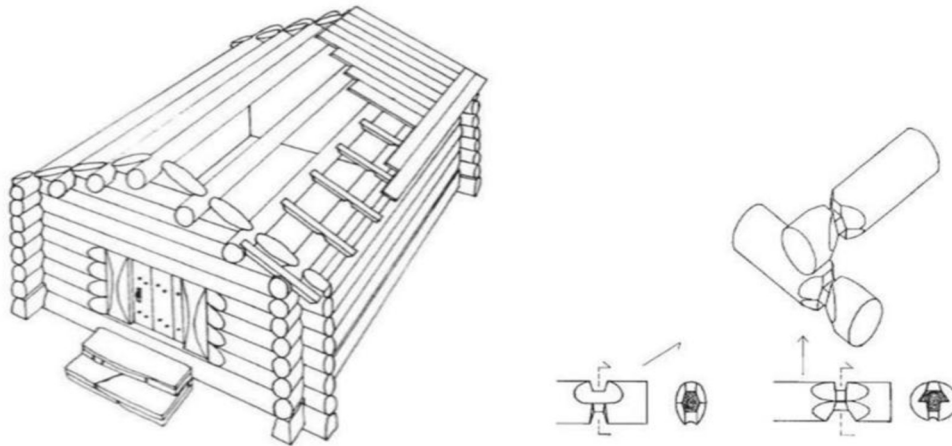


Fig. 1. Log construction system and its detail [31].

density of 0.593 g/cm^3 and a modulus of elasticity of approximately 13.46 GPa, making it suitable for structural applications [24]. Similarly, Oriental Spruce (*Picea orientalis*) exhibits a density of 0.45 g/cm^3 , a bending strength of 70 MPa, and a modulus of elasticity of 11.2 GPa, rendering it ideal for lightweight structures and interior applications [25]. The main characteristics of timber construction materials include:

- Despite being lightweight due to its fibrous and porous texture, it has high strength values [26],
- It is ideal in terms of sound absorption thanks to the air-filled cavities within its internal structure [27],
- With a relatively low thermal conductivity coefficient, it transmits heat less than many other materials and offers good thermal insulation [27],
- It is considered environmentally friendly due to its recyclability, low production energy consumption, and relatively minimal CO_2 emissions—one of the main contributors to global greenhouse effects—compared to other materials [28],
- However, unless specific fire protection measures are taken, wood is a combustible material. During fire exposure, the outer layers char and create an insulating barrier that temporarily slows heat penetration, but the reduction of the cross-section eventually decreases load-bearing capacity. For this reason, measures such as increased member dimensions or protective coatings are required to ensure fire safety in timber structures [29].

2.1.2. Traditional timber construction systems

Traditional timber structures were constructed using log (solid) and frame systems. In the log construction system, timber is used in its raw, unprocessed log form; notches are cut at the corners to allow the

logs to interlock, and they are fitted together using half-lap joints (Fig. 1) [30].

In traditional log constructions, vertical loads are transferred from the ends of stacked logs, supported one upon another, from the top down to the foundation. Consequently, an increase in building height results in greater vertical loads and deformation at the log ends. However, by applying various mechanical or chemical treatments to the logs used in the structure and reinforcing the joints with connectors, it is possible to enhance the system's resistance to lateral loads [32, 33].

The timber frame construction system consists of one-dimensional wooden elements bearing structural loads, with the spaces between posts filled with infill materials (Fig. 2). The surfaces are sometimes left exposed or finished with various cladding materials to complete the system. Compared to log systems, timber frame systems are more economical in terms of wood usage [34].

In the production of timber frame construction systems, the load-bearing components and their connections can be arranged in various ways. Frame construction methods are classified based on the arrangement of horizontal and vertical members into different types: post-and-beam frames (single- and double-story), node beam frames, rib frames (balloon and platform framing), double beam frames, and separate post frames. In these variations, beams, posts, or both can be continuous, and beams or posts may be doubled [34]. Timber frame structures can also be categorized according to infill materials and supporting elements of the load-bearing system. Based on the infill material, they are classified as wood infill, adobe (mudbrick) infill, stone infill, and brick infill. The availability of materials in the region where the structure is to be built plays a significant role in the choice of infill material.

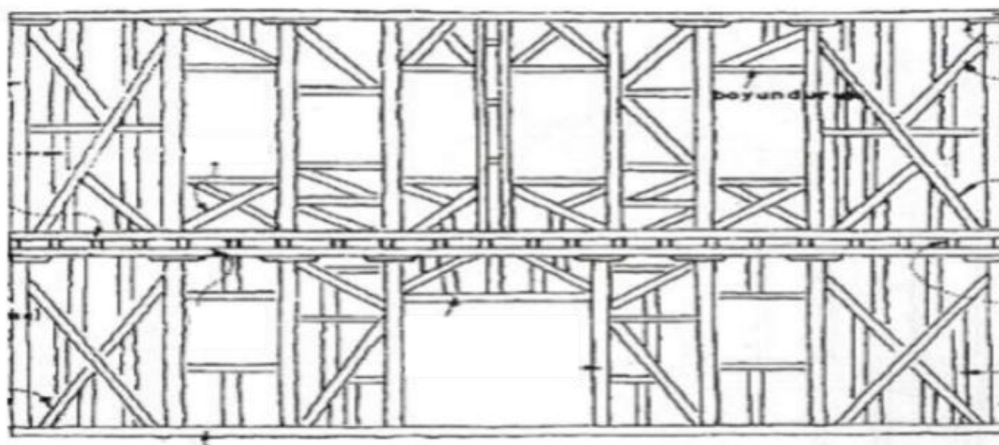


Fig. 2. Timber frame construction system configuration [34].

2.2. Contemporary timber construction materials and systems

Following the Industrial Revolution and the increasing urban concentration, wood—the most commonly used construction material of the time—could no longer meet the demands of building production and was gradually replaced by concrete and steel. However, with the rapid depletion of natural resources and the energy crisis, wood—being renewable and recyclable—reemerged as a construction material through the development of contemporary technologies.

The production of laminated wood dates back to the 16th century, with early examples attributed to Leonardo da Vinci. Due to the limited chemical technologies of the period, wooden planks were joined using finger joints. Between 1835 and 1855, laminated wood was employed in railway bridges in England and Scotland, spanning 16 to 36 meters. Its use in buildings was first recorded in 1860 in the roof beams spanning 9 meters at Southampton Registry Office (Fig. 3). In the early 1900s, Otto Hetzer patented ‘glulam,’ a structural timber product capable of spanning up to 40 meters.

With the recognition of the extensive application potential of laminated wood, the lengths and cross-sectional dimensions of structural timber elements increased, allowing for the production of curved and tapered components, which in turn enabled greater design flexibility. By the late 20th century, the structural advancement of timber in North America led to the construction of 4- to 5-story timber frame buildings, while cross-laminated timber products were manufactured and utilized in buildings in Germany and Austria [36]. In the 21st century, the production of timber construction products has become faster and safer. Different connection techniques and the



Fig. 3. Southampton registry office [35].

prefabrication of structural components have facilitated the development of various timber construction systems [37].

2.2.1. Contemporary timber construction materials

Due to its natural structure, wood contains defects such as knots and cracks that reduce its strength, and the material’s strength varies according to the grain direction. Natural wood is also susceptible to environmental factors. Various wood products made from softwood tend to have dimensional limitations. In contrast, industrial timber products are engineered materials designed to eliminate strength-reducing defects found in natural wood, offering enhanced resistance to environmental factors and the structural capacity to span large openings [29]. These products vary in size, shape, and assembly techniques, combining natural and manufactured wood components. Industrial wood products are classified, while their manufacturing methods and characteristics are detailed in Table 1.

Table 1. Manufacturing methods and characteristics of industrial timber products (It is derived from [7, 38–45]).

Construction Material	Manufacturing Method	Characteristics
GLULAM (Glued Laminated Timber)	Wood pieces with thicknesses of 19–50 mm and lengths of 1.5–5 m are first dried to a moisture content of 12–18%. Then, they are joined with finger joints and laminated parallel to the grain with structural adhesive.	Provides a more homogeneous structure compared to solid wood. Exhibits high mechanical properties. Resistant to moisture, temperature, and biological agents.
CLT (Cross Laminated Timber)	Solid wood layers are glued with their grain directions crossed (typically at 90°). Pressed under a minimum pressure of 0.6 N/mm ² .	High stiffness and strength; allows for prefabrication of wall and floor panels. Can be used as load-bearing or non-load-bearing elements.
LVL (Laminated Veneer Lumber)	Thin wood veneers are bonded parallel or crosswise to the grain under heat and pressure.	Provides high strength, homogeneous structure, and dimensional stability. Used as structural beams and load-bearing components.
PSL (Parallel Strand Lumber)	Long strands measuring 3.2 mm thick and 19–20 mm wide are glued and aligned longitudinally, then pressed.	Similar to LVL; more resistant to warping and bending. Suitable for beams, columns, and frame elements in residential buildings.
LSL (Laminated Strand Lumber)	Strands up to 300 mm long are placed in parallel and pressed with polyurethane adhesive.	Denser and more durable than PSL and LVL. Used in beams, headers, and joinery.
OSB (Oriented Strand Board)	Wood strands are oriented longitudinally on the outer layers and randomly inside, then pressed with resin and wax.	Durable due to its layered structure. An economical and widely used material in structural panels.
NLT (Nail Laminated Timber)	Solid wood elements are placed side by side and mechanically fastened with nails or screws.	Used in prefabricated floor and roof systems; allows for quick assembly.
DLT (Dowel Laminated Timber)	Softwood boards are fixed together with hardwood dowels to form panels.	No chemical adhesives are used; durable and environmentally friendly. Preferred for load-bearing surfaces.

2.2.2. Contemporary timber construction systems

The production of contemporary timber construction materials and systems involves the use of advanced technology and industrialized manufacturing processes, with the entire workflow—from design to production completion—being carefully planned to minimize labor and working time. The manufacturing of all materials and related processes in construction is predominantly industrial, characterized by high levels of machinery and organizational intensity [46].

Alongside advancements in the timber construction sector, contributions from academic studies and research have highlighted sustainability and renewability as key factors promoting the use of timber in buildings. As a result, contemporary timber materials have diversified and various construction systems have been developed. In European countries, contemporary timber construction systems are widely utilized; in nations such as Germany, Austria, and Norway, timber forms the load-bearing systems even in multi-story buildings [47]. Table 2 reviews various contemporary timber construction systems, examining their structural features, applications, and advantages, accompanied by system visuals.

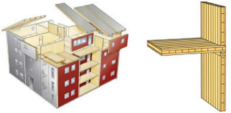
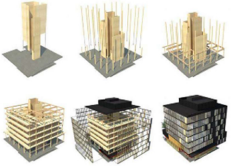
Industrial timber construction materials and contemporary timber construction systems are examined in Tables 1 and 2, respectively. Table 3 analyzes the roles of industrial timber materials within contemporary timber construction systems.

2.3. Life cycle assessment in buildings

With the rapid increase in construction activities in the 21st century, natural resources are being depleted, while agricultural lands and urban green spaces are being converted into built environments. This process has adverse effects on both ecosystems and human health. In Europe, buildings alone account for nearly 40% of total energy consumption and 32% of CO₂ emissions [60]. Reducing these impacts requires sustainable design strategies that minimize resource use and environmental damage [12]. Life Cycle Assessment (LCA) provides a systematic methodology for evaluating the environmental impacts of a building throughout all stages of its life cycle—from raw material extraction to production, use, and end-of-life processes such as recycling or disposal [61]. Since the 1990s, international standards such as the ISO 14040 series have defined its methodological framework, making LCA one of the most widely accepted tools for environmental assessment [62, 63].

Integrating social and economic dimensions into Life Cycle Assessment (LCA) is crucial for comprehensive sustainability evaluations. Social LCA (S-LCA) examines impacts on stakeholders such as workers, communities, and consumers through indicators like health, employment, and education [64–66]. Economic LCA, often conducted through Life Cycle Costing (LCC) or DEALA, enables transparent evaluations of value creation and economic contributions

Table 2. Contemporary timber construction systems: Features, applications, and advantages (It is derived from [43, 45, 47–59]).

Construction System	Structural Characteristics	Applications and Advantages
Timber Frame Construction System 	There are two types: balloon and platform framing. In the balloon system, the studs run continuously along the full height of the building, whereas in the platform system, each floor is framed separately with its own platform.	It is a lightweight system suitable for buildings up to 6–7 stories. When used with contemporary timber materials, it can span larger openings.
Timber Post-and-Beam Construction System 	It is a load-bearing system constructed using thick-section structural materials such as GLT, LVL, and PSL.	It transfers loads vertically and can span wide openings, making it suitable for tall buildings.
Timber Panel Construction System 	Load-bearing wall and floor elements are produced using prefabricated CLT panels. The panels feature simple connection details.	It provides high performance in terms of seismic resistance, fire safety, acoustics, and vibration. It enables fast assembly and offers high load-bearing capacity.
Mixed Timber Construction System 	CLT panels, GLT post-and-beam elements, and light timber frame systems are used in combination.	By combining the advantages of each system, stable and lighter structures can be created.
Hybrid Timber Construction System 	Timber is used in combination with reinforced concrete and/or steel structural systems. Composite systems are established based on span and load requirements.	Geniş açıklıklar ve yüksek taşıma kapasitesi gerektiren yapılarda uygundur.
Prefabricated Modular Timber Construction System 	Modules, each produced independently, are fabricated in the factory and assembled on site.	It provides portability, rapid assembly, and high production quality control. It is especially common in small-scale housing and temporary structures.

[67, 68]. Despite progress, challenges persist in standardization, data availability, and multidimensional integration, limiting the scalability of Life Cycle Sustainability Assessment [69, 70].

In the context of timber construction, LCA is particularly valuable because wood differs fundamentally from conventional materials: it is renewable, stores carbon during growth, and generally requires less energy to process. At the same time, its environmental performance varies depending on the structural system, durability, and end-of-life options. Therefore, LCA allows for the comparison of traditional and modern timber systems by quantifying key impact categories such as global warming potential (GWP), energy consumption, acidification, and eutrophication, thereby linking material properties directly to

sustainability outcomes. With the rapid increase in construction activities in the 21st century, natural resources are being depleted, and agricultural lands and urban green spaces are being converted into built environments. This situation has adverse effects on the natural environment and human health. In Europe, energy consumed by buildings alone accounts for 40% of the total global energy consumption and 32% of CO₂ emissions [60].

An LCA can be conducted over all processes (Fig. 4) or within the scope defined by the assessment objectives. The processes encompassing the acquisition of raw materials for building products through to the disposal of demolition waste are referred to as “cradle-to-grave.” When recycling of waste is also considered, the term “cradle-to-cradle” is used [72].

Table 3. Applications of industrial timber products in contemporary timber construction (Prepared by the author).

Industrial Timber Product	Role in Contemporary Timber Construction Systems	
	Element Level	Component Level
GLT	Structural system	Column, beam
	Roof	Components of roof truss
CLT	Wall	Wall itself in interior walls Load-bearing layer in interior wall section Load-bearing layer in exterior wall section
	Floor	Intermediate layer in floor section
LVL	Structural system	Column, beam, beam header
PSL	Structural system	Column, beam, lintel
LSL	Structural system	Wall and roof studs, beam header
	Joinery	Door and window
OSB	Wall	Intermediate layer in wall section
	Floor	Intermediate layer in floor section
	Roof	Intermediate layer in roof section
NLT	Wall	Load-bearing layer in wall section
	Floor	Load-bearing layer in floor section
	Roof	Load-bearing layer in roof section
DLT	Wall	Load-bearing layer in wall section
	Floor	Load-bearing layer in floor section
	Roof	Load-bearing layer in roof section

2.3.1. Stages of life cycle assessment

LCA consists of four stages (Fig. 5) [73]:

- **Goal and Scope Definition:** The purpose, scope, and assumptions of the study are defined, establishing the subject and limitations. This stage addresses for whom and why the study is conducted.
- **Inventory Analysis:** All inputs (resources) and outputs (solid, liquid, and gaseous wastes) throughout the life cycle are identified.
- **Impact Assessment:** Data obtained from the inventory analysis are qualitatively evaluated to calculate the magnitude of environmental impacts. The impact assessment stage consists of three steps:
 - Selection of impact categories, category indicators, and characterization models,
 - Classification of inventory results according to impact categories,
 - Calculation of category indicator results.
- **Interpretation:** This stage involves the combined evaluation of findings from the inventory analysis and impact assessment. LCA results are presented in a clear, accurate, and consistent manner in line with the study's goal and scope.

2.3.2. The impact of the selected system and material on life cycle processes in building systems

Building systems are formed by the selection of construction products and their assembly. Construction

products can have various and significant environmental impacts throughout their life cycle processes. Therefore, the impact of each life cycle stage of a product should be considered during the selection of construction materials [74]. Life cycle processes consist of several stages (Fig. 6). In this context, the main stages where a construction material causes environmental impact within its life cycle can be grouped as raw material acquisition, production, transportation, application, use, reuse, and recycling. Below, each of these stages is discussed individually, explaining the environmental impacts that should be taken into account when selecting building materials.

Raw Material Acquisition and Raw Material Production Process (A1–A3): When selecting a construction product, the raw materials used in the production of the product, the manufacturing of materials and products from these raw materials, the extraction of raw materials, and the environmental impacts of both extraction and all processes involved in production must be considered. These factors play a significant role in LCA results [73]. A material with a low environmental impact during raw material acquisition may have a high environmental impact during production. In this regard, the amount and source of energy used in production, water consumption and usage patterns, the type and quantity of waste generated, the treatment of toxic emissions, the elimination of ozone-depleting substances during production, and the management of production waste are critical factors [76].

Transportation and On-Site Process (A4–A5): The transportation of construction materials from the manufacturer to the construction site is an important factor affecting environmental impact. The use of local materials in product selection supports local companies while reducing the environmental impact associated with transportation. This is a significant consideration for LCA results [74, 76]. The application process of construction products may involve factors that negatively affect the health of workers performing the installation. Ecological materials can influence indoor air quality during the usage phase of a building, affecting criteria such as air quality, lighting, water, and energy consumption [76].

Use Phase (B1–B7): The use phase covers the period during which building products are in operation, and significant environmental impacts may arise during this stage. Specifically:

- Energy consumption occurs,
- Air emissions, liquid, and solid wastes may be generated,
- Additionally, some construction materials emit indoor air pollutants during use, deteriorating

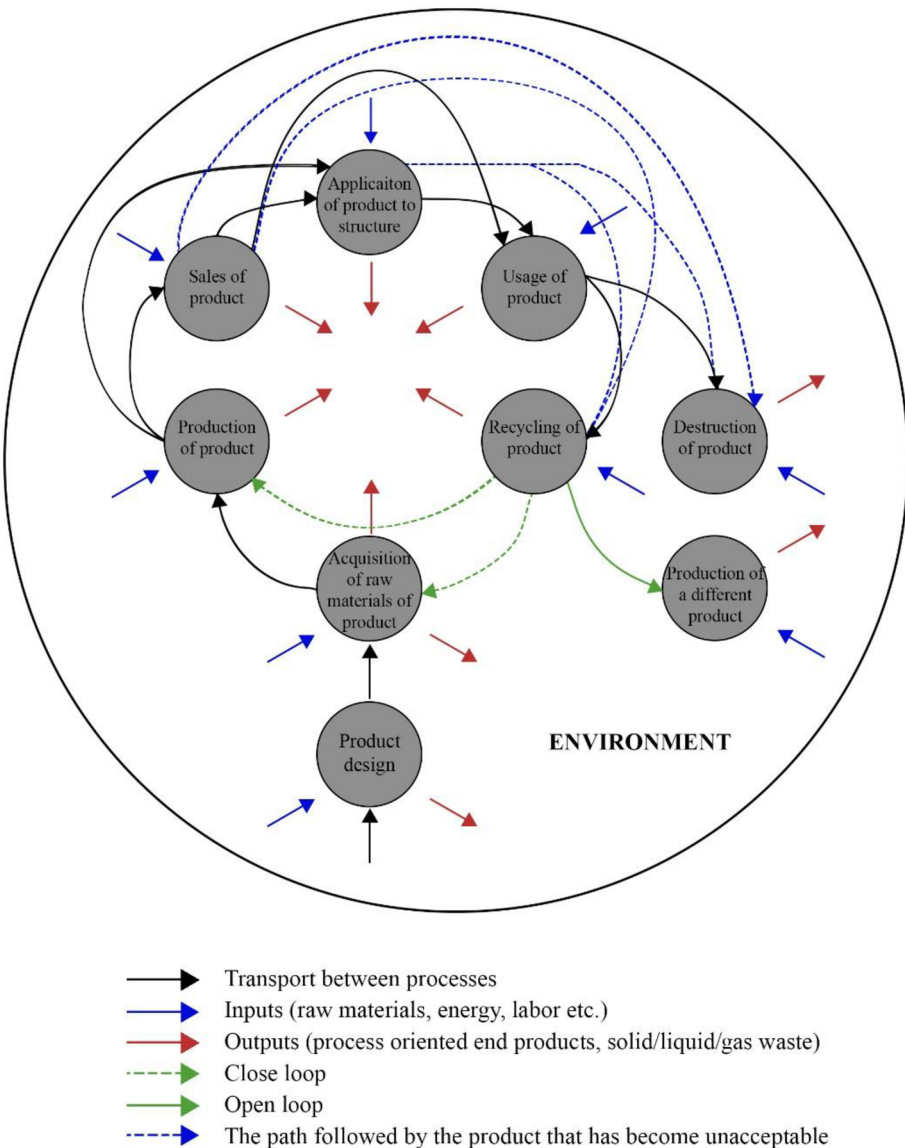


Fig. 4. Life cycle processes of a building product and their interactions with each other and the environment [71].

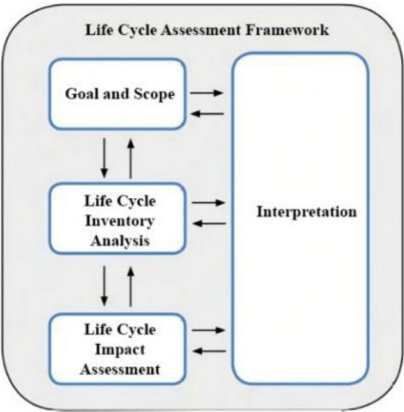


Fig. 5. LCA stages [73].

indoor air quality and negatively affecting occupant health.

These effects can vary depending on the type and composition of the product. The types of pollutants during the use phase, their originating building products, and their impacts on occupant health have been documented in various studies [71].

Reuse and Recycling Process (C1–C4): The absence of recyclability or reusability of a construction material leads to increased resource consumption and the generation of waste, which in turn causes pollution of air, water, and soil, ultimately resulting in ecosystem degradation. When a material can be recycled or reused, the environmental impacts from other life cycle stages are substantially reduced [74].

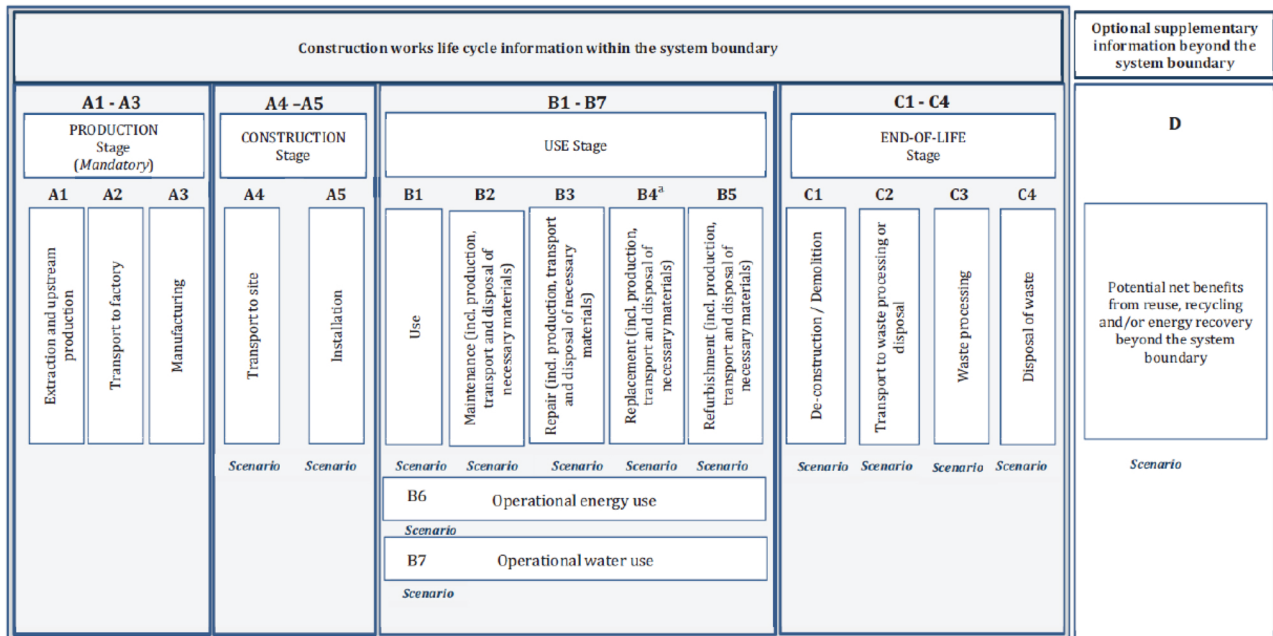


Fig. 6. LCA processes [75].

Different environmental impacts may occur at each stage of a construction material's life cycle. Therefore, in selecting a building material, it is essential to consider the influence of all life cycle stages rather than focusing on a single phase. Consequently, the quantitative and qualitative effects across all stages must be examined comprehensively to reach a well-informed conclusion.

2.3.3. Methods and tools used in life cycle assessment

Environmental assessment tools encompass a wide range of methods and software designed to evaluate the environmental performance of building materials, components, and entire buildings. These tools have been developed by various institutions for diverse purposes, including product comparison, support for design decision-making, and comprehensive building certification. Given the variety of available tools, classification frameworks have been proposed to facilitate their selection and application. Among the most widely recognized are the typology developed by the Athena Sustainable Materials Institute and the categorization presented in the International Energy Agency's (IEA) Annex 31 report, "Energy Related Environmental Impact of Buildings" [77, 78].

To provide a clear overview of the tools' functions, primary applications, and suitability for different building typologies and design decisions, the following table summarizes the main categories, representative examples, and their intended purposes (Table 4). This structured presentation enables readers to quickly identify the most appropriate

assessment tools for specific design and evaluation scenarios.

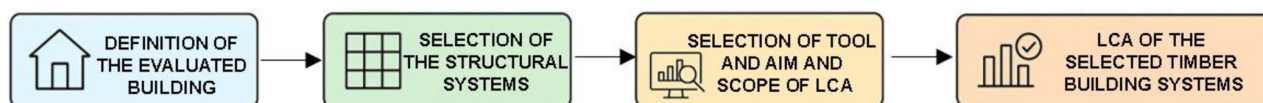
The databases utilized by these tools are highly complex and vary by region. Tools categorized under Groups 1 and 2 often rely on multiple recognized databases. In some databases, such as Envest 2 and BRE, users are allowed to add or even modify data, whereas others like ATHENA and Eco-Quantum do not permit such modifications [79, 80]. The environmental assessment results of a building can be presented in the form of graphs, tables, ratings, certifications, or reports. Group 3 tools tend to favor reports more extensively compared to those in Groups 1 and 2 [80].

3. Material and method

The LCA of a two-story residential building, designed on a selected plot in Türkiye, was conducted using different timber structural systems. Within the scope of the study, the quantities of materials and products used in each structural system and their corresponding levels of consumption and environmental impacts were evaluated separately. The assessment was carried out within the framework of the life cycle process, which includes the production of materials intended for use in the structural system, transportation of these materials to the construction site, the energy resources consumed throughout the building's lifespan, and the recycling of materials at the end of their service life. By comparing the total energy

Table 4. Classification of environmental assessment tools and their applications.

Classification Source	Group/ Category	Example Tools	Primary Purpose / Application	Suitable Building Typologies / Design Decisions
Athena Sustainable Materials Institute	Group 1: Product Comparison	BEES (USA), GaBi (Germany), SimaPro (Netherlands), UMBERTO (Germany), TEAM (France)	Compare environmental impact of construction products	Material selection, product optimization
	Group 2: Design Decision Support	ATHENA (Canada/USA), BEAT 2002 (Denmark), BeCost (Finland), EcoQuantum (Netherlands), Envest (UK), EQUER (France), LEGEP (Germany), PAPOOSE (France), OneClickLCA (Finland)	Support overall building design and decision-making	New building design, renovation planning, sustainable material choices
	Group 3: Whole Building Assessment	BREEAM (UK), EcoEffect (Sweden), EcoProfile (Norway), Environmental Status Model (Sweden), ESCALE (France), LEED (USA)	Comprehensive environmental performance assessment	Whole building evaluation, certification, regulatory compliance
IEA Annex 31: Energy Related Environmental Impact of Buildings	Energy Modeling Software	EnergyPlus (USA), TRNSYS (USA), DesignBuilder (UK), ESP-r (Scotland), eQUEST (USA), IDA ICE (Sweden)	Simulate energy performance of buildings	All building types; energy efficiency design decisions
	Environmental LCA Tools	SimaPro (Netherlands), GaBi (Germany), One Click LCA (Sweden/Finland), Tally (USA), OpenLCA (Germany)	Evaluate environmental impact of buildings and stocks	Material selection, life cycle assessment for building types
	Environmental Assessment & Rating Systems	LEED (USA), BREEAM (UK), HQE (France), CASBEE (Japan), Green Star (Australia), DGNB (Germany)	Rating and certification of building sustainability	New and existing buildings; design strategy, operational performance
	Guidelines / Checklists	Green Guide for Specification (UK), SBTool/SBP, ASHRAE Green Guide (USA), WBDG (USA), RIBA Sustainable Outcomes Guide (UK)	Support sustainable design and management	Design process guidance for multiple building typologies
	EPDs, Databases, Certifications	International EPD System (Sweden), IBU (Germany), UL Environment (USA), Green Tag (Australia), Type I Ecolabels, Cradle to Cradle Certified™ (USA)	Provide standardized product/environmental data	Material selection, product labeling, compliance verification

**Fig. 7.** Steps of method.

consumption and CO₂ emissions associated with the construction of the sample building using different timber systems, the study aims to provide guidance in the selection of traditional versus contemporary timber construction methods.

LCA was conducted using the One Click LCA tool for the selected types of traditional and contemporary timber structural systems in a sample residential building. The study consists of four main steps (Fig. 7):

- Definition of the evaluated building,
- Selection of the structural systems for comparative analysis,

- Selection of the tool and the aim and scope of LCA
- Life cycle assessment of the selected timber building systems.

3.1. Definition of the evaluated building

For the residential building subjected to LCA, parcel number 1630, located in the Bademli area of Çağrısan neighborhood, Mudanya district, Bursa province, with a size of 1170 m², was selected. The surrounding developments mainly consist of detached residential buildings. The project site and adjacent parcels are shown in Fig. 8.

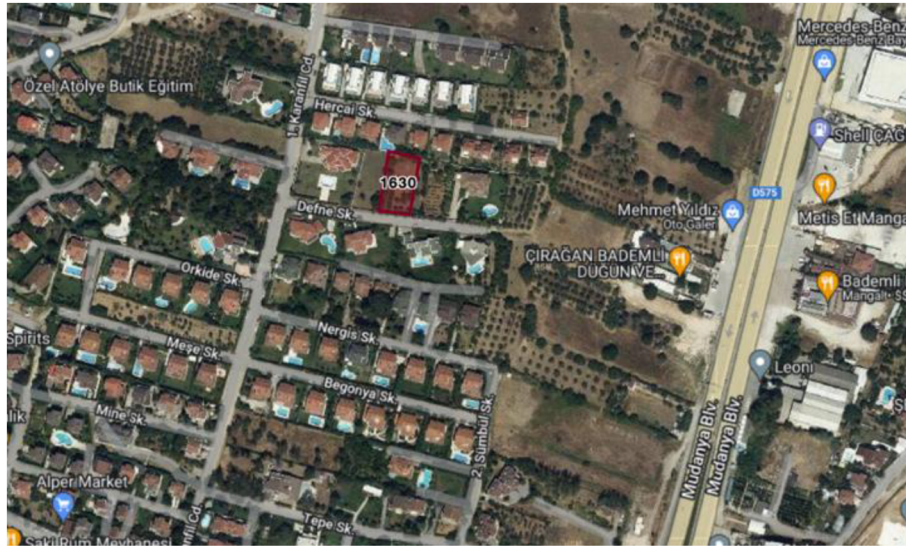


Fig. 8. Project site and surrounding area.



Fig. 9. Ground floor plan, mezzanine floor plan, section A-A, section B-B, north elevation, and south elevation of the designed residence.

The designed residence is planned to accommodate a minimum of two people and consists of a ground floor and a mezzanine. The building measures 14.00 meters in length and 5.00 meters in width. The net area of the ground floor is 61.40 m², and the mezzanine covers 13.25 m², totaling 74.65 m². The ground floor includes an entrance veranda, entrance hall, living area, kitchen, bathroom, and terrace, while the mezzanine contains a bedroom and bathroom. Wall openings are designed on all façades to ensure sunlight exposure from every direction, with dimensions suitable for application in both traditional and contemporary building systems. The plans, sections, and elevations of the designed residence are shown in Fig. 9.

3.2. Selection of the structural systems for comparative analysis

For the comparative analysis, the traditional wooden structural systems selected are the logging system and the platform-frame wooden system, while from the contemporary wooden structural systems, the CLT panel system has been chosen.

3.3. Selection of the tool and the aim and scope of life cycle assessment

The One Click LCA tool, developed by various institutions and researchers with different purposes,

life cycle stages, and databases, was selected for this study due to the following reasons:

- It includes an inventory of building materials and products specific to Turkey,
- It allows life cycle assessments at various levels such as process, system, and product through its student version,
- It is user-friendly,
- It provides clear and effective options for reporting analysis results, both in terms of information content and presentation design.

One Click LCA is a LCA software developed in 2011 by the Finnish company Bionova. It enables users to create Environmental Product Declarations (EPDs) for building materials and perform comprehensive building LCAs, as well as obtain certifications such as BREEAM and LEED for their products. The LCA tool supports data import from BIM software and models, energy performance models, Excel files, or manual entry through the system. It complies with standards including EN 15978, ISO 21931-1, ISO 21929-1, ISO 14040/44, and EN 15804. One Click LCA provides access to an extensive database covering general building materials [78].

The software includes databases from regions primarily in Europe, as well as North America, Asia, the Middle East, and South America. Its cloud database contains over 100,000 data entries sourced from various public and private entities. One Click LCA is offered under several license types: Starter, Business, Expert, and Student License. It delivers various services for construction projects, products, and operations [81].

The One Click LCA tool is applicable for LCAs of buildings with functions such as residential, cultural, industrial, educational, healthcare, hotel, office, and transportation. It can be used for newly constructed buildings, renovations of existing buildings, and the development of existing buildings or their components. The tool enables evaluation of impact categories including Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), primary energy consumption potential, and biogenic carbon storage [75].

3.3.1. Processes considered in the building's life cycle assessment

When conducting the environmental impact analysis using LCA tools, it is necessary to input information about the building products to be applied in the building, the production processes of the building, the natural resource consumption throughout the build-

ing's service life, and the outputs generated after the building's demolition.

In the analysis, the environmental impacts related to the production processes of the building products (A1–A3) were generated by One Click LCA through the system-based identification of the products used in the building. Based on the data entered within the LCA scope, the distances of the materials to be used in the building from the project site were calculated. During the distance calculation, care was taken to select the closest distribution points for each material through the system. By entering these distances into the LCA tool, the environmental impacts related to the transportation process (A4) were generated by the LCA software. The forecasts regarding products and distances are listed and explained as follows:

- The building's foundation system was selected as a raft foundation, with the concrete supplied from a concrete plant located 5.1 km away, the nearest to the project site,
- Most of the wooden structural elements used in the building were assumed to be sourced from a timber facility 10 km away, the closest to the project site,
- CLT panel products used in the structure were considered to be supplied from a wood production plant located 540 km away within Turkey, which was identified as the closest,
- General materials used throughout the building (insulation materials, cladding materials, etc.) were assumed to be procured from a building market 13 km away, the nearest to the project site.

Based on the input data for the LCA, the resource consumption of the building was determined. It was assumed that the designed building would be occupied by two people, used seven days a week, 16 hours per day (B1).

For the consumption data related to electricity use (B6), the 2020 Turkey Electricity Distribution Sector Report, published by TEDAŞ in mid-2021, was utilized. According to this report, the average per capita electricity consumption in Bursa, where the project is located, was recorded as 4,155 kWh for the year 2019. Considering that two people reside in the project, the annual electricity consumption was calculated as 8,310 kWh [82].

For the consumption data concerning natural gas (B6), the most recent 2020 Natural Gas Distribution Sector Report, published by the Turkish Natural Gas Distributors Association (GAZBİR), was used. According to the data in this report, the average household consumption in Bursa province in 2020 was 851 m³. Since the project is based on a single household, the

annual natural gas consumption was taken as 851 m³ [83].

Regarding water consumption data (B7), the report titled “Water and Wastewater Statistics 2020” published by the Turkish Statistical Institute (TÜİK) on December 16, 2021, was referenced. As this is the most current data available, water use was input according to these statistics. Since Bursa-specific values were not provided, the national average daily per capita water consumption of 228 liters was used, resulting in an annual per capita consumption of 83.22 m³. Assuming two occupants in the project, the annual water consumption was calculated as 166.44 m³ [84].

Based on the data entered within the LCA scope, the environmental impacts associated with the end-of-life phase (C1–C4) of the building materials used in the structure were calculated by the selected LCA tool, One Click LCA. Additionally, the environmental impacts related to the installation process of the building materials on the construction site (A5) were determined. However, due to the absence of fixed data regarding the duration of installation and the resource consumption during this phase for the designed building and its structural systems, no data could be generated for this stage.

3.3.2. Impact categories considered in the life cycle assessment

LCA tools perform analyses across various environmental impact categories. Environmental indicator groups used to demonstrate a building’s environmental performance throughout its service life are classified under environmental impact indicators, resource use indicators, and other environmental information indicators.

Within the scope of this study, the LCA was conducted using the following impact category indicators:

- Global Warming Potential (GWP),
- Acidification Potential (AP),
- Eutrophication Potential (EP),
- Stratospheric Ozone Depletion Potential (ODP).

3.4. Life cycle assessment of the selected timber building systems

In this section of the study, the conditions from the structural system design of the selected building systems to the environmental impact results generated by the LCA are examined. Initially, wall, floor, and roof layers were created according to the selected timber building systems, and system cross-sections were designed accordingly. These system cross-sections

were modeled in SketchUp. Through this modeling, quantity take-off data for the materials used in the buildings were obtained. The obtained quantity data were then entered into the building materials section of the One Click LCA tool.

Before entering data into the One Click LCA tool, a new design project was created specifically for this study, and data entry was performed under the listed categories. The quantity data were added to the building materials section, which is the first category in the list.

Within the building materials section of the One Click LCA tool, the following subcategories are included:

- Foundation system and substructure,
- Vertical load-bearing system and facade,
- Horizontal load-bearing system: beams, floors, and roof,
- Other load-bearing systems and materials.

The usage phase data entered into One Click LCA were kept constant across all building systems and inputted under the relevant sections. These data include the number of occupants, the annual number of usage days, daily usage hours, annual electricity consumption, annual clean water consumption, and annual natural gas consumption of the building.

3.4.1. Life cycle assessment of the log timber construction system

The first of the three building systems subjected to LCA is the traditional timber construction system known as the log timber building system. In this system, peeled logs are used for exterior walls, interior walls, floors, and roofs. Accordingly, the building materials and quantities derived from the prepared details and models are presented in Table 5.

Upon entering the data for the wooden log stacking structural system into the LCA tool, the system calculates values across various impact categories. The values corresponding to the selected processes and impact categories within the scope of this study are presented in Table 6.

The LCA report for the residential building with the wooden log stacking system, after entering all data, has been generated as graphs for the following environmental impact categories:

- According to all LCA stages for the GWP impact category (Fig. 10.a),
- According to all LCA stages excluding B6 and B7 for the GWP impact category (Fig. 10.b),
- According to all LCA stages for the AP impact category (Fig. 10.c),

Table 5. Building materials used in the log timber construction system.

Area in the Building	Material Used	Quantity Used	Density	Source
Foundation	Ready-mixed concrete	21 m ³	2394.0 kg/m ³	C35/45 (5000/6500 PSI)
Exterior Wall	Sawn logs	143.26 m ² × 200 mm	740.0 kg/ m ³	EGGER Sägewerk Brilon GmbH
Interior Wall	Sawn logs	16.17 m ² × 200 mm	740.0 kg/ m ³	EGGER Sägewerk Brilon GmbH
Floor	Sawn logs	16.71 m ² × 200 mm	740.0 kg/ m ³	EGGER Sägewerk Brilon GmbH
Roof	Slate roofing	62.38 m ²	39.0 kg/m ²	DAPcons.c-004.105
	OSB roof sheathing	62.38 m ² × 100 mm	610.0 kg/m ³	TR EPD
	Sawn logs	6.98 m ³	740.0 kg/ m ³	EGGER Sägewerk Brilon GmbH
Doors and Windows	Wooden exterior doors and windows	23.22 m ²	41.26 kg/m ²	PCR Fenster und Türen
	Wooden interior doors	5.8 m ²	41.26 kg/m ²	PCR Fenster und Türen

Table 6. Values of the log timber construction system according to processes and impact categories.

Process	Process Category	GWP (kg CO ₂)	AP (kg SO ₂)	EP (kg PO ₄)	ODP (kg CFC-11)
A1-A3	Building Materials	7,84E+03	3,10E+01	1,20E+01	3,60E-04
A4	Transportation	4,68E+01	1,10E-01	2,40E-02	8,30E-06
A5	Construction	–	–	–	–
B1-B5	Use Stage	1,63E+03	9,75E+00	1,54E+00	6,90E-05
B6	Energy Use	3,72E+05	2,30E+03	4,94E+02	1,50E-02
B7	Water Use	2,50E+03	1,35E+01	6,84E+00	2,70E-04
C1-C4	End of Life	4,21E+03	6,72E+00	1,55E+00	4,00E-07
C1-C4	Deconstruction	4,21E+03	6,72E+00	1,55E+00	4,00E-07
D	External Influences	–1,60E+04	–1,84E+01	–3,46E+00	–3,30E-05
D	Installed Materials	–1,60E+04	–1,84E+01	–3,46E+00	–3,30E-05
D2	Energy recovery	–	–	–	–
	Total	3,89E+05	2,36E+03	5,16E+02	1,62E-02

- According to all LCA stages excluding B6 and B7 for the AP impact category (Fig. 10.d),
- According to all LCA stages for the EP impact category (Fig. 10.e),
- According to all LCA stages excluding B6 and B7 for the EP impact category (Fig. 10.f),
- According to all LCA stages for the ODP impact category (Fig. 10.g),
- According to all LCA stages excluding B6 and B7 for the ODP impact category (Fig. 10.h).

3.4.2. Life cycle assessment of the timber platform frame construction system

The second of the three building systems assessed through LCA is the timber platform frame construction system, which is one of the traditional timber structural systems. In this system, standard use of timber platform framing composed of lumber is envisaged for exterior walls, interior walls, floors, and the roof. A three-dimensional model of the structure, designed according to the proposed building and system section, was created using the SketchUp software. Based on this, the building materials and their quantities derived from the prepared details and models are presented in Table 7.

With the input of data related to the timber platform frame construction system into the LCA tool, the system calculates values based on various impact

categories. In accordance with the selected processes and impact categories within the scope of the study, the results are presented in Table 8.

As a result of entering all data, the LCA report for the residential building constructed with the timber platform frame system was generated with graphical representations for the following environmental impact categories:

- According to the GWP (Global Warming Potential) impact category across all life cycle stages (Fig. 11.a),
- According to the GWP impact category excluding B6 and B7 life cycle stages (Fig. 11.b),
- According to the AP (Acidification Potential) impact category across all life cycle stages (Fig. 11.c),
- According to the AP impact category excluding B6 and B7 life cycle stages (Fig. 11.d),
- According to the EP (Eutrophication Potential) impact category across all life cycle stages (Fig. 11.e),
- According to the EP impact category excluding B6 and B7 life cycle stages (Fig. 11.f),
- According to the ODP (Ozone Depletion Potential) impact category across all life cycle stages (Fig. 11.g),
- According to the ODP impact category excluding B6 and B7 life cycle stages (Fig. 11.h).

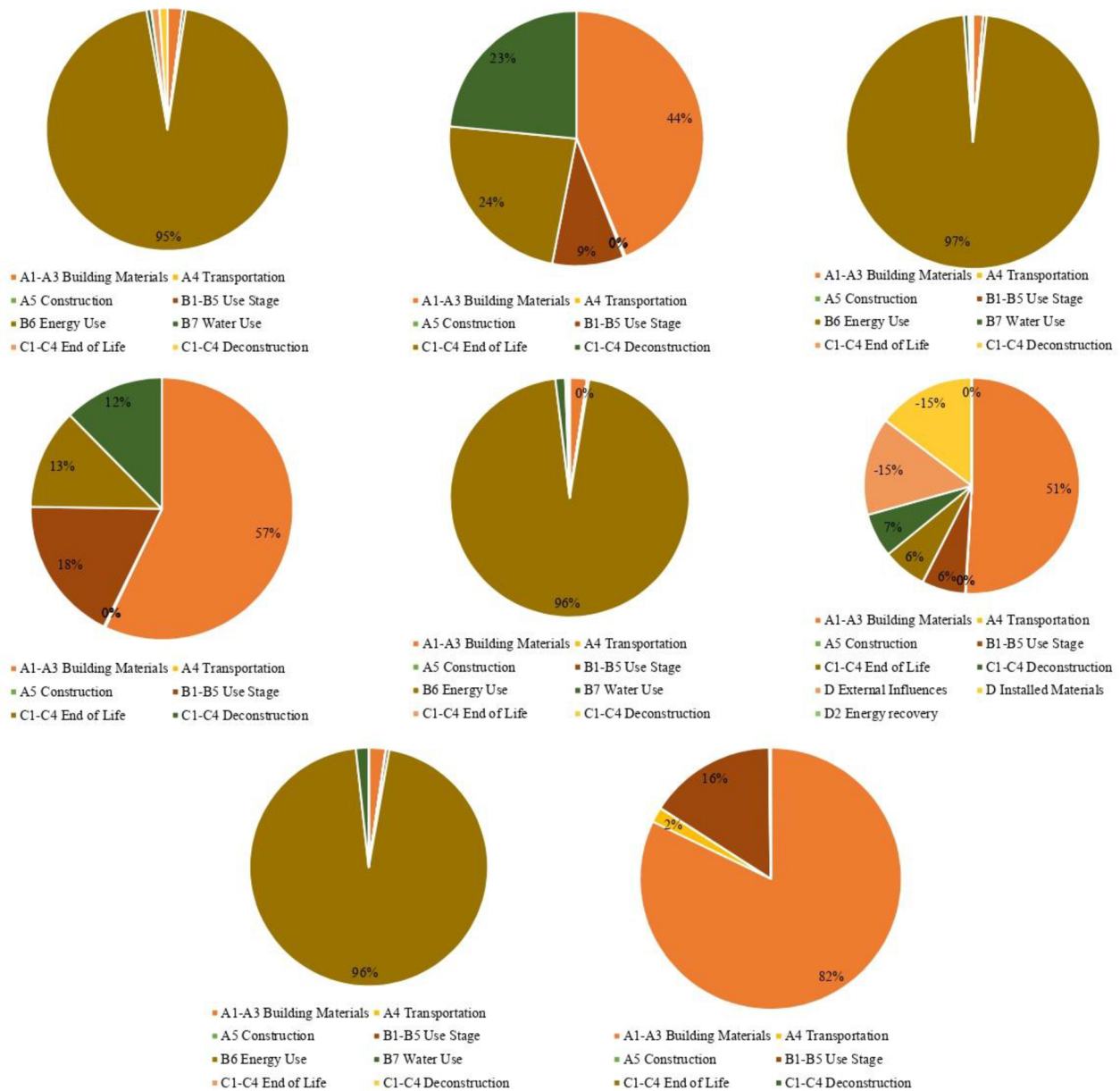


Fig. 10. (a) According to all LCA stages for the GWP impact category, (b) according to LCA stages excluding B6 and B7 for the GWP impact category, (c) according to all LCA stages for the AP impact category, (d) according to LCA stages excluding B6 and B7 for the AP impact category, (e) according to all LCA stages for the EP impact category, (f) according to LCA stages excluding B6 and B7 for the EP impact category, (g) according to all LCA stages for the ODP impact category, (h) according to LCA stages excluding B6 and B7 for the ODP impact category.

3.4.3. Life cycle assessment of the cross-laminated timber (CLT) panel construction system

The third of the three building systems assessed through LCA is the CLT panel construction system, which is one of the contemporary timber structural systems. In this system, prefabricated CLT panels are envisaged for use in exterior walls, interior walls, floors, and the roof. A three-dimensional model of the structure, designed according to the

proposed building and system section, was created using the SketchUp software. Based on this, the building materials and their quantities derived from the prepared details and models are presented in Table 9.

By inputting the data of the CLT panel construction system into the LCA tool, values were calculated for various impact categories. According to the selected processes and impact categories within the

Table 7. Building materials used in the timber platform frame construction system.

Designed Building Component	Material Used	Quantity Used	Density	Standart Type
Foundation	Ready-mixed concrete	21 m ³	2394.0 kg/m ³	C35/45 (5000/6500 PSI)
Exterior Wall	Timber exterior cladding	143.26 m ² × 10 mm	525.0 kg/m ³	BS 8605-1:2014
	Moisture barrier	143.26 m ² × 3 mm	0.14 kg/m ²	TR EPD
	Thermal insulation (XPS)	143.26 m ² × 50 mm	24.2 kg/m ³	TSE - ODE Yalitım Sanayi
	OSB sheathing	143.26 m ² × 10 mm	610.0 kg/m ³	TR EPD
	Sawn and planed timber	2.8 m ³	460.0 kg/m ³	EPD Planed Timber by Stora Enso
Interior Wall	Gypsum board interior wall cladding	143.26 m ² × 10 mm	680.0 kg/m ³	TR EPD
	Sawn and planed timber	0.396 m ³	460.0 kg/m ³	EPD Planed Timber by Stora Enso
	Gypsum board interior wall cladding	32.24 m ²	680.0 kg/m ³	TR EPD
Floor	Sawn and planed timber	0.62 m ³	460.0 kg/m ³	EPD Planed Timber by Stora Enso
	Floor covering (OSB)	16.71 m ² × 10 mm	610.0 kg/m ³	TR EPD
Roof	Slate roof cladding	62.38 m ²	39.0 kg/m ²	DAPcons.c-004.105
	Moisture barrier	62.38 m ² × 10 mm	0.14 kg/m ²	TR EPD
	Roof sheathing (OSB)	62.38 m ² × 10 mm	610.0 kg/m ³	TR EPD
	Thermal insulation (XPS)	62.38 m ² × 50 mm	24.2 kg/m ³	TR EPD - ODE Yalitım Sanayi
	Sawn and planed timber	1.164 m ³	460.0 kg/m ³	EPD Planed Timber by Stora Enso
	Gypsum board interior ceiling cladding	62.38 m ²	680.0 kg/m ³	TR EPD
	Timber exterior doors and windows	23.22 m ²	41.26 kg/m ²	PCR Fenster und Türen
Doors and Windows	Timber interior doors	5.8 m ²	41.26 kg/m ²	PCR Fenster und Türen

Table 8. Environmental impact values of the timber platform frame construction system by life cycle.

Process	Process Category	GWP (kg CO ₂)	AP (kg SO ₂)	EP (kg PO ₄)	ODP (kg CFC-11)
A1-A3	Building Materials	1,17E+04	4,98E+01	2,15E+01	7,00E-04
A4	Transportation	3,81E+01	7,30E-02	1,50E-02	6,60E-06
A5	Construction	–	–	–	–
B1-B5	Use Stage	2,35E+03	1,34E+01	3,34E+00	2,70E-04
B6	Energy Use	3,72E+05	2,30E+03	4,94E+02	1,50E-02
B7	Water Use	2,50E+03	1,35E+01	6,84E+00	2,70E-04
C1-C4	End of Life	7,50E+02	2,31E+00	8,70E-01	6,80E-06
C1-C4	Deconstruction	7,50E+02	2,31E+00	8,70E-01	6,80E-06
D	External Influences	–3,42E+03	–5,00E+00	–1,31E+00	–3,30E-05
D	Installed Materials	–3,42E+03	–5,00E+00	–1,31E+00	–3,30E-05
D2	Energy recovery	–	–	–	–
	Total	3,90E+05	2,38E+03	5,26E+02	1,67E-02

scope of the study, the results are presented in Table 10.

As a result of entering all data, the LCA report for the residential building with the timber platform frame system was generated with graphs illustrating the following environmental impact categories:

- GWP across all life cycle stages (Fig. 12.a),
- GWP excluding life cycle stages B6 and B7 (Fig. 12.b),
- AP across all life cycle stages (Fig. 12.c),
- AP excluding life cycle stages B6 and B7 (Fig. 12.d),
- EP across all life cycle stages (Fig. 12.e),
- EP excluding life cycle stages B6 and B7 (Fig. 12.f),
- ODP across all life cycle stages (Fig. 12.g),
- ODP excluding life cycle stages B6 and B7 (Fig. 12.h).

4. Findings and discussion

According to the LCA results obtained using the One Click LCA tool, the selected building systems were evaluated comparatively. In this section, all selected building systems are grouped under environmental impact categories, and the GWP, AP, EP, and ODP results are compared. The comparisons were conducted for all life cycle stages as well as for all stages excluding B6 and B7, where similar data inputs were used for the selected building systems. Initially, the comparisons were analyzed according to individual impact categories, followed by an overall comparison based on the total sum of all environmental impact values.

4.1. Global warming potential findings

When examining the GWP results, according to all assessed life cycle stages (Fig. 13), all building

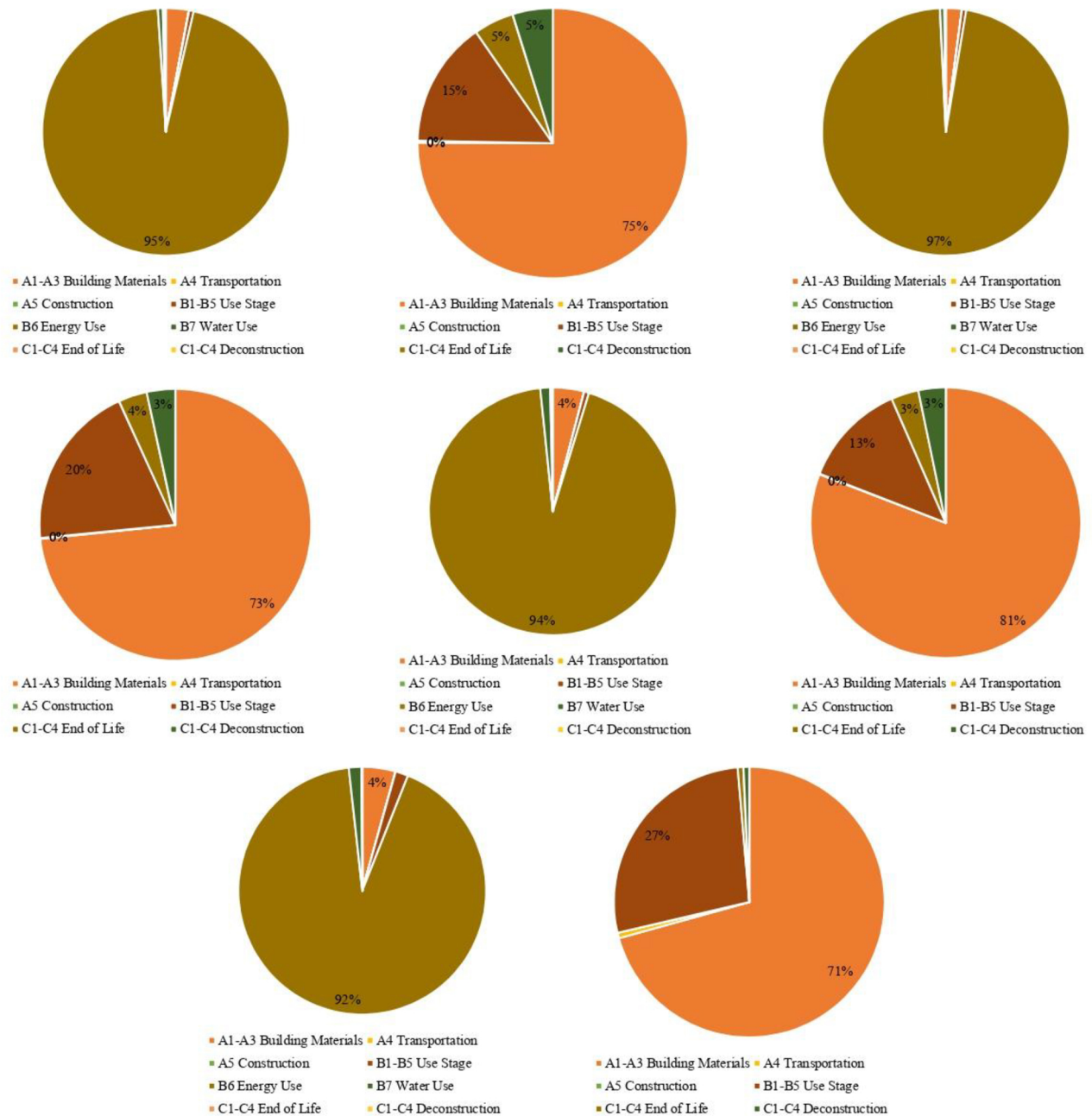


Fig. 11. (a) According to the GWP impact category across all life cycle stages, (b) according to the GWP impact category excluding B6 and B7 stages, (c) according to the AP impact category across all life cycle stages, (d) according to the AP impact category excluding B6 and B7 stages, (e) according to the EP impact category across all life cycle stages, (f) according to the EP impact category excluding B6 and B7 stages, (g) according to the ODP impact category across all life cycle stages, (h) according to the ODP impact category excluding B6 and B7 stages.

systems exhibit approximately 400,000 kg CO₂ equivalent. The energy consumption stage (B6) is identified as the most impactful process within the buildings.

When the systems are ranked from lowest to highest based on GWP impact, the timber log construction system ranks first, followed by the platform frame system and the CLT panel system. The difference between the highest and lowest values in this

ranking is approximately 10,000 kg CO₂. When evaluating the selected building systems excluding life cycle stages B6 and B7—where similar data inputs were applied—differences in impact values among the systems become apparent (Fig. 14). The ranking of the systems' impact values is similar to the previous graph. In this comparison, the greatest differences are observed in the building materials stage.

Table 9. Building materials used in the CLT panel construction system.

Designed Building Component	Material Used	Quantity Used	Density	Standart Type
Foundation	Ready-mixed concrete	21 m ³	2394.0 kg/m ³	C35/45 (5000/6500 PSI)
Exterior Wall	Timber exterior cladding	143.26 m ² × 10 mm	525.0 kg/m ³	BS 8605-1:2014
	Moisture barrier	143.26 m ² × 3 mm	0.14 kg/m ²	TR EPD
	Thermal insulation (XPS)	143.26 m ² × 50 mm	24.2 kg/m ³	TSE - ODE Yalitım Sanayi
	CLT wall panel	143.26 m ² × 150 mm	481.0 kg/m ³	TR EPD
Interior Wall	Gypsum board interior wall cladding	143.26 m ² × 10 mm	680.0 kg/m ³	TR EPD
	CLT wall panel	16.17 m ² × 150 mm	481.0 kg/m ³	TR EPD
	Gypsum board interior wall cladding	32.24 m ²	680.0 kg/m ³	TR EPD
Floor	CLT floor panel	16.71 m ² × 150 mm	481.0 kg/m ³	TR EPD
	Floor covering (OSB)	16.71 m ² × 10 mm	610.0 kg/m ³	TR EPD
Roof	Slate roof cladding	62.38 m ²	39.0 kg/m ²	DAPcons.c-004.105
	Moisture barrier	62.38 m ² × 10 mm	0.14 kg/m ²	TR EPD
	Thermal insulation (XPS)	62.38 m ² × 50 mm	24.2 kg/m ³	TR EPD - ODE Yalitım Sanayi
	CLT roof panel	62.38 m ² × 150 mm	481.0 kg/m ³	TR EPD
	Gypsum board interior ceiling cladding	62.38 m ²	680.0 kg/m ³	TR EPD
Doors and Windows	Timber exterior doors and windows	23.22 m ²	41.26 kg/m ²	PCR Fenster und Türen
	Timber interior doors	5.8 m ²	41.26 kg/m ²	PCR Fenster und Türen

Table 10. Impact values of the CLT panel construction system by life cycle stages and impact categories.

Process	Process Category	GWP (kg CO ₂)	AP (kg SO ₂)	EP (kg PO ₄)	ODP (kg CFC-11)
A1-A3	Building Materials	1,80E+04	7,97E+01	3,62E+01	1,20E-03
A4	Transportation	3,62E+02	1,56E+00	3,40E-01	7,10E-05
A5	Construction	0	0	0	0
B1-B5	Use Stage	2,81E+03	1,59E+01	4,58E+00	4,00E-04
B6	Energy Use	3,72E+05	2,30E+03	4,94E+02	1,50E-02
B7	Water Use	2,50E+03	1,35E+01	6,84E+00	2,70E-04
C1-C4	End of Life	2,43E+03	4,30E+00	9,70E-01	5,40E-06
C1-C4	Deconstruction	2,43E+03	4,30E+00	9,70E-01	5,40E-06
D	External Influences	-1,39E+04	-1,62E+01	-3,10E+00	-3,30E-05
D	Installed Materials	-1,39E+04	-1,62E+01	-3,10E+00	-3,30E-05
D2	Energy recovery	-	-	-	-
	Total	3,99E+05	2,41E+03	5,43E+02	1,74E-02

Regarding the impact of building materials, the timber log construction system shows the lowest impact value, whereas the CLT panel system has the highest. Another notable difference appears in the end-of-life stage (C1–C4). At this stage, the timber platform frame system has the lowest impact value, while the timber log construction system has the highest. Although the CLT panel system involves significantly longer transportation distances compared to the other systems, this does not result in substantial differences in the impact values.

When compared based on their GWPs, the most environmentally impactful stage for all buildings is energy consumption. Ranking the systems from highest to lowest environmental impact during production processes, the order is as follows: CLT panel, timber platform frame, and timber log construction.

4.2. Acidification potential findings

When examining the AP results across all assessed life cycle stages (Fig. 15), all building systems exhibit

approximately 24,000 kg SO₂ equivalent. The energy consumption stage (B6) is identified as the most impactful process within the buildings.

When ranked from lowest to highest based on AP impact, the systems are ordered as follows: timber log construction, platform frame construction, and CLT panel construction. When evaluating the systems excluding life cycle stages B6 and B7—where similar data inputs were applied—differences in impact values are observed (Fig. 16). The ranking of impact values among the systems is similar to that of the previous graph. As with the GWP comparison, the greatest differences are found in the building materials stage. Regarding the impact of building materials, the timber log construction system shows the lowest impact value, whereas the CLT panel system has the highest.

When compared based on their AP, energy consumption is the most environmentally impactful stage for all buildings. Ranking the systems from highest to lowest environmental impact during production processes, the order is: CLT panel, timber platform frame, and timber log construction.

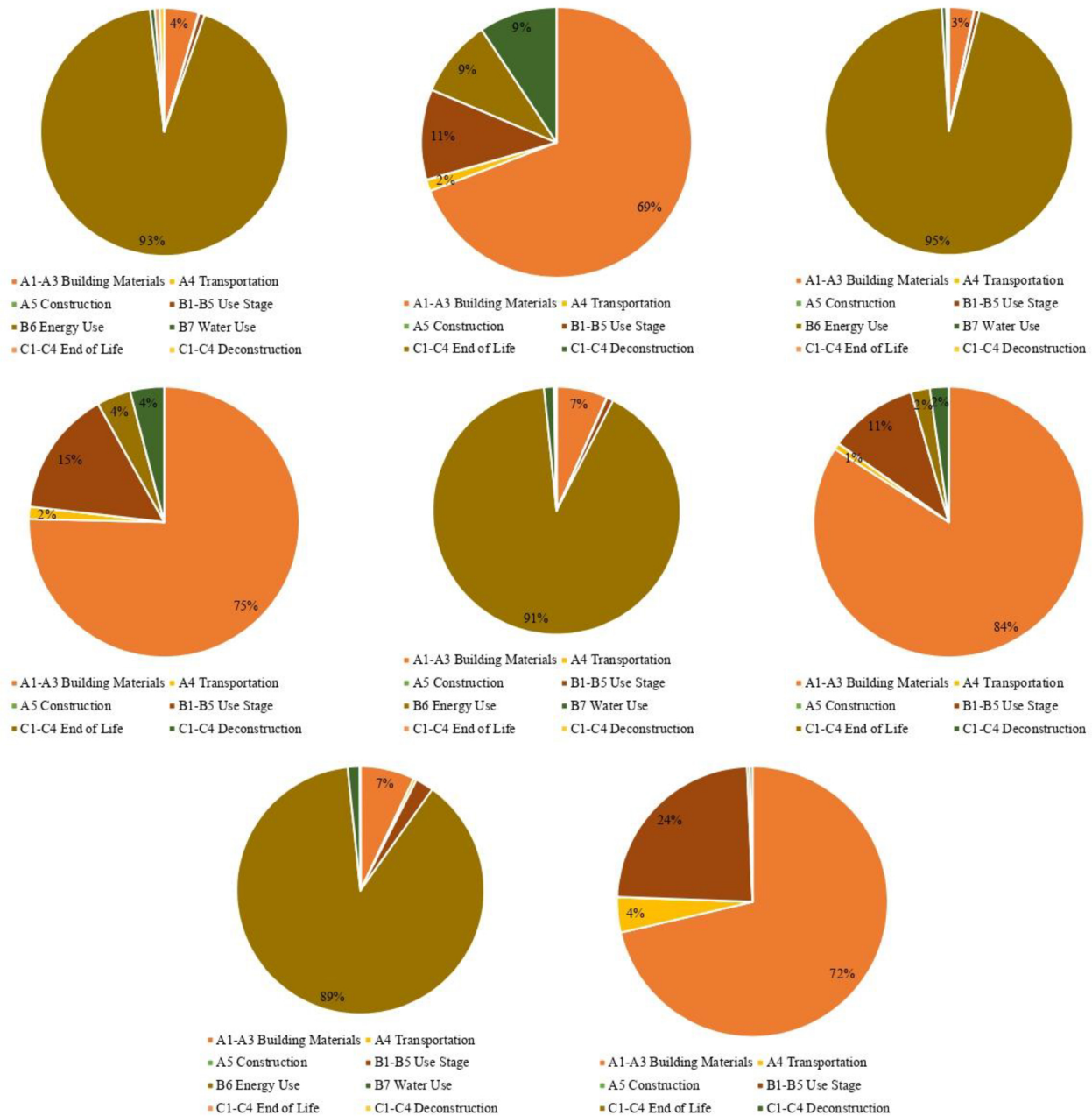


Fig. 12. (a) GWP across all life cycle stages, (b) GWP excluding life cycle stages B6 and B7, (c) AP across all life cycle stages, (d) AP excluding life cycle stages B6 and B7, (e) EP across all life cycle stages, (f) EP excluding life cycle stages B6 and B7, (g) ODP across all life cycle stages, (h) ODP excluding life cycle stages B6 and B7.

4.3. Eutrophication potential findings

When examining the EP results across all assessed life cycle stages (Fig. 17), all building systems exhibit approximately 500–550 kg PO₄ equivalent. As in other comparisons, the energy consumption stage (B6) is identified as the most impactful process within the buildings.

When the systems are ranked from lowest to highest based on EP impact, the timber log construction

system ranks first, followed by the platform frame system and the CLT panel system. The difference between the highest and lowest values in this ranking is approximately 27 kg PO₄. When evaluating the selected building systems excluding life cycle stages B6 and B7—where similar data inputs were applied—differences in impact values among the systems are observed (Fig. 18). The ranking of the systems' impact values is similar to that of the previous graph.

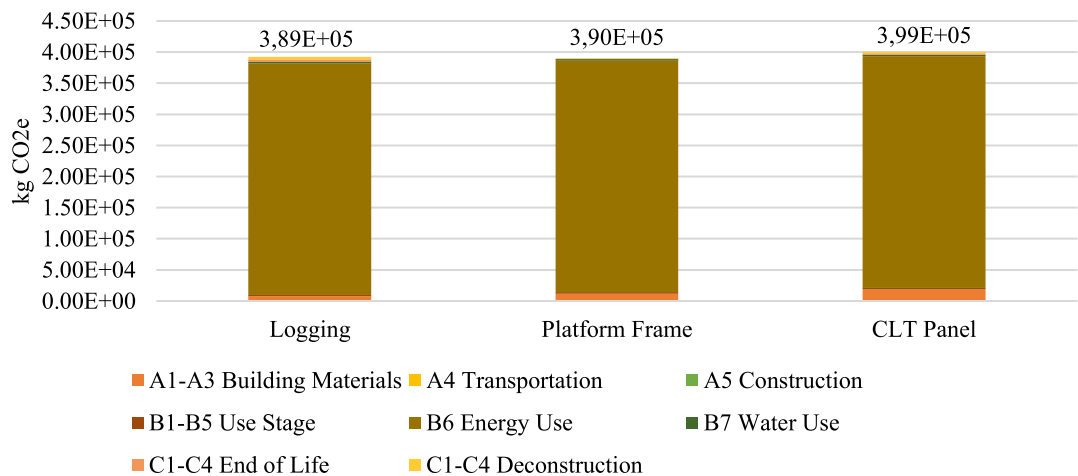


Fig. 13. Comparison of GWP of the systems across all life cycle stages.

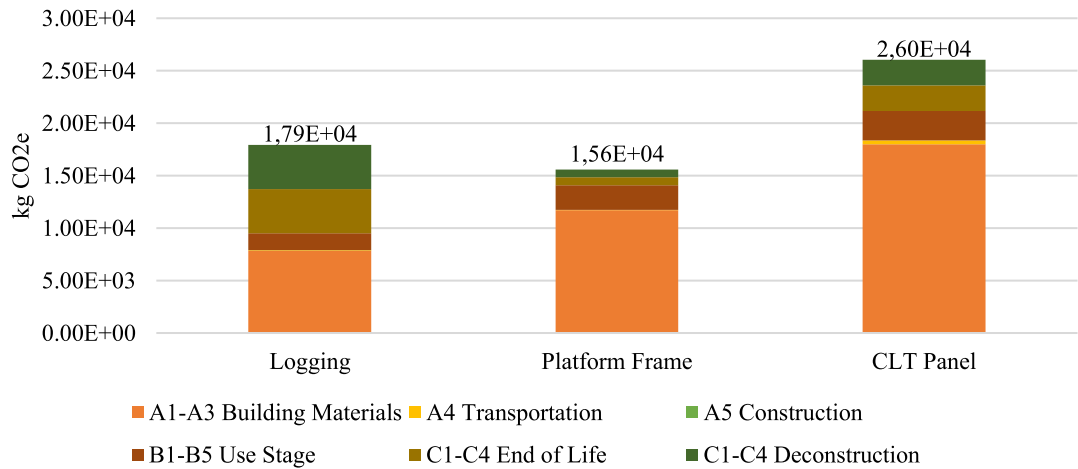


Fig. 14. Comparison of GWP of the systems according to selected LCA stages.

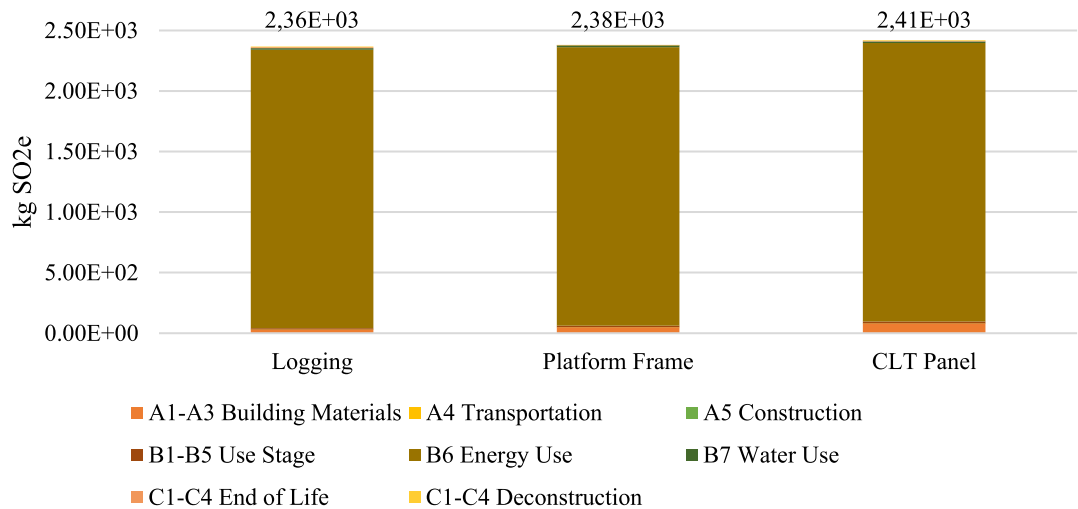


Fig. 15. Comparison of AP of the systems across all life cycle stages.

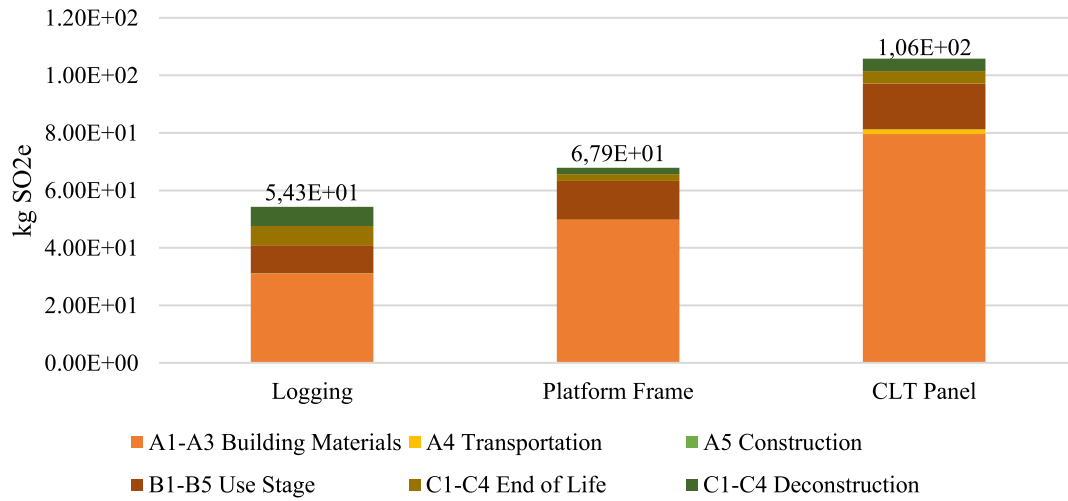


Fig. 16. Comparison of AP of the systems according to selected LCA stages.

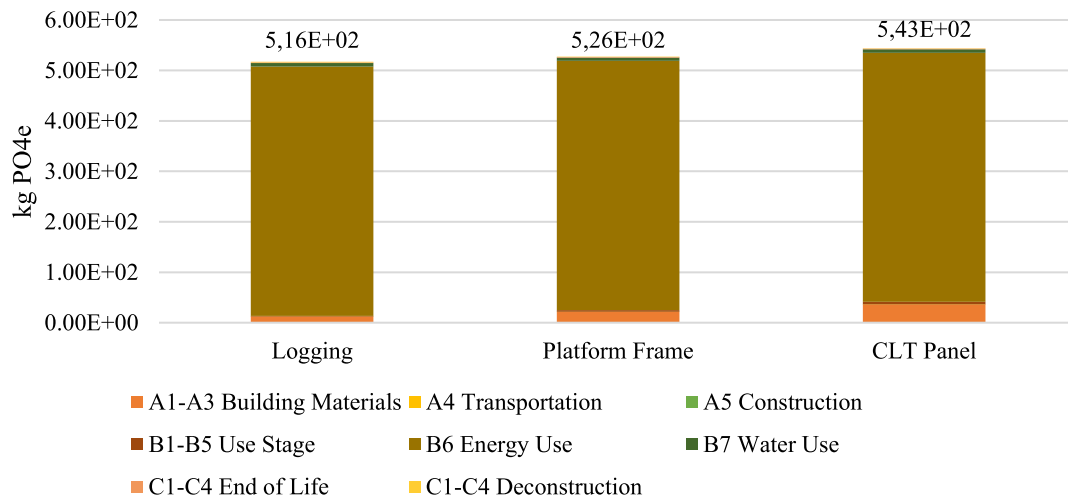


Fig. 17. Comparison of EP of the systems across all life cycle stages.

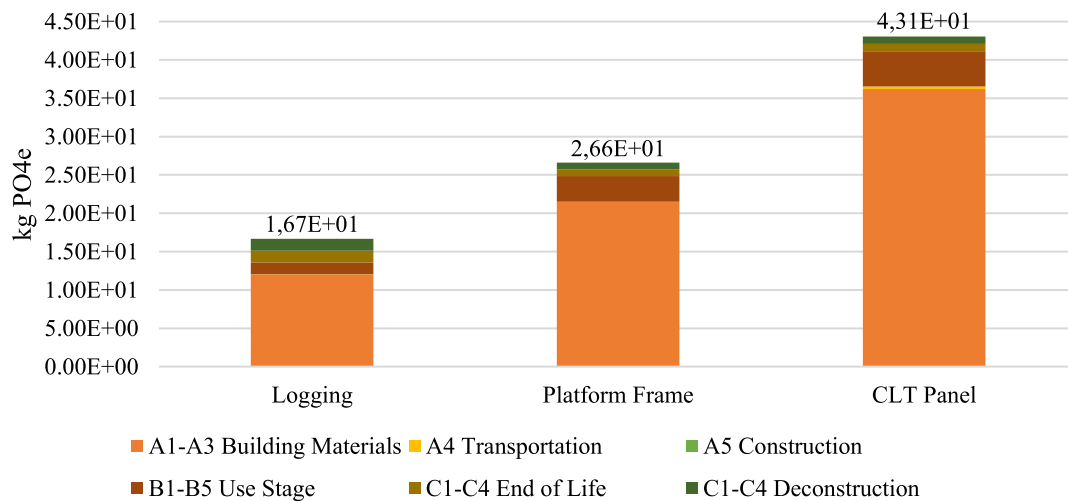


Fig. 18. Comparison of EP of the systems according to selected LCA stages.

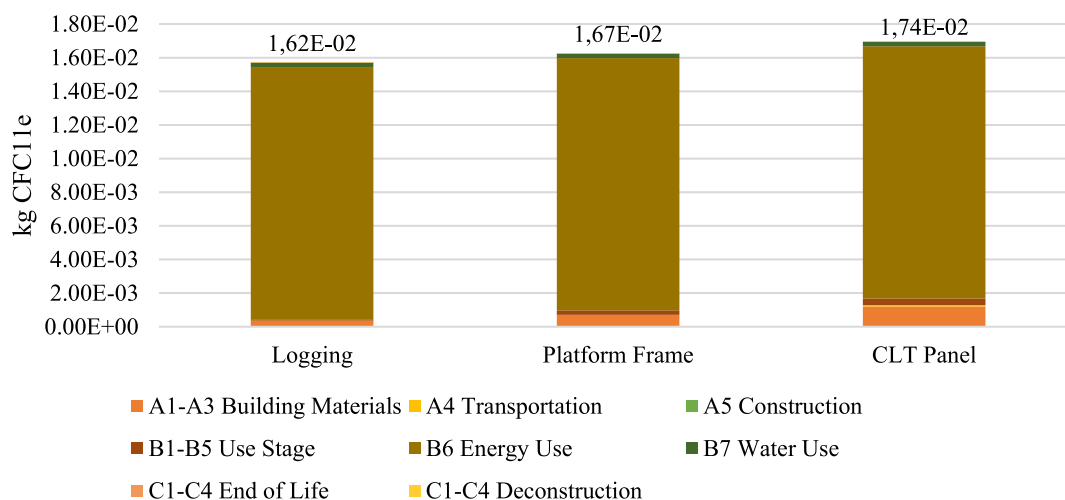


Fig. 19. Comparison of ODP of the systems across all life cycle stages.

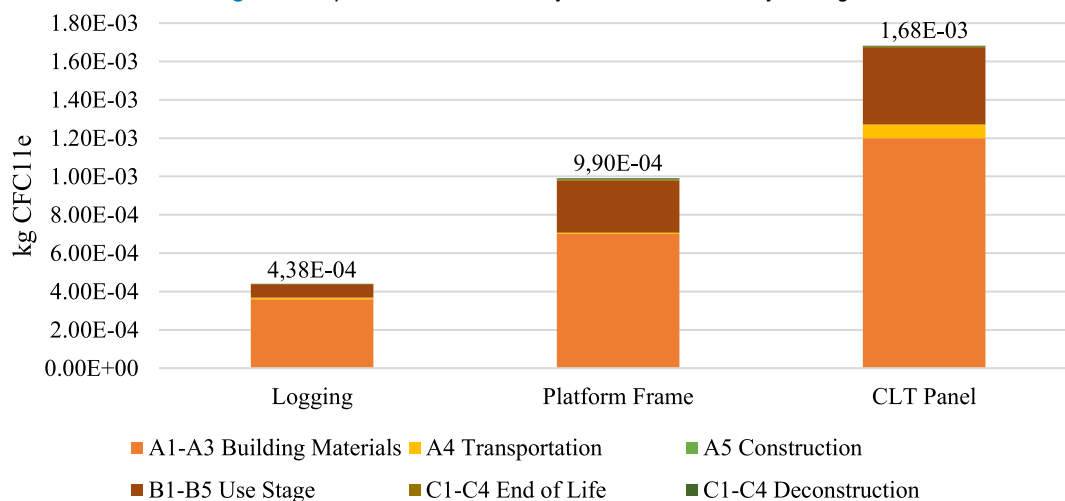


Fig. 20. Comparison of ODP of the systems according to selected LCA stages.

When compared based on their EP, energy consumption is the most environmentally impactful stage for all buildings, as observed in other comparisons. Ranking the systems from highest to lowest environmental impact during production processes, the order is: CLT panel, timber platform frame, and timber log construction.

4.4. Ozone depletion potential findings

When examining the ODP results across all assessed life cycle stages (Fig. 19), all building systems exhibit approximately 0.015–0.0175 kg CFC-11 equivalent. As in other comparisons, the energy consumption stage (B6) is identified as the most impactful process within the buildings.

When ranked from lowest to highest based on ODP impact, the timber log construction system ranks first, followed by the platform frame system and the CLT panel system. The difference between the highest and

lowest values in this ranking is approximately 10.1%. When evaluating the selected building systems excluding life cycle stages B6 and B7—where similar data inputs were applied—differences in impact values among the systems are observed (Fig. 20). The ranking of the systems' impact values is similar to that of the previous graph.

When compared based on their ODP, energy consumption is the most environmentally impactful stage for all buildings, as seen in other comparisons. Ranking the systems from highest to lowest environmental impact during production processes, the order is: CLT panel, timber platform frame, and timber log construction.

4.5. General evaluation of findings related to impact categories

Within the scope of this study, the environmental impacts during production, use, and end-of-life phases of three different timber construction systems

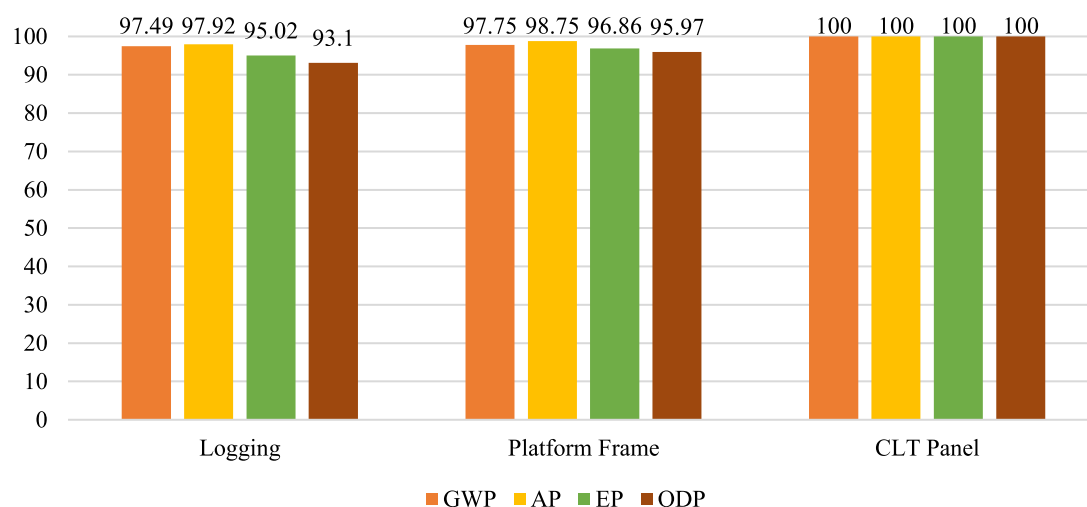


Fig. 21. Comparative environmental impacts of three timber construction systems (log construction, platform frame, CLT panel) across the categories of GWP, AP, EP, and ODP (Results are presented as normalized percentages, where the highest value in each category is set to 100%).

Table 11. LCA EN 15978 values of the compared systems.

	Timber Log Construction System	Timber Platform Frame Construction System	Timber CLT Panel Construction System
LCA, EN-15978 (kg CO ₂)	388 654	389 809	398 565

(log construction, platform frame, and CLT panel) proposed for the structural system of a two-story residential building designed in Bursa were evaluated. These building systems were compared based on relative percentage values, normalized by setting the highest value in each category to 100%, derived from data obtained through the One Click LCA tool, according to the impact categories of GWP, AP, EP, and ODP. The comparative results are presented in Fig. 21. Among the systems compared, the timber CLT panel construction system exhibits the highest

values across all impact categories, while the timber log construction system has the lowest values in all categories.

The LCA CO₂-equivalent values of the compared systems, calculated according to EN 15978, are presented in Table 11. The comparison of these values, derived from data obtained through One Click LCA and expressed as percentages according to EN 15978, is illustrated in Fig. 22. When comparing the systems based on total impact categories, the ranking from lowest to highest environmental impact is as

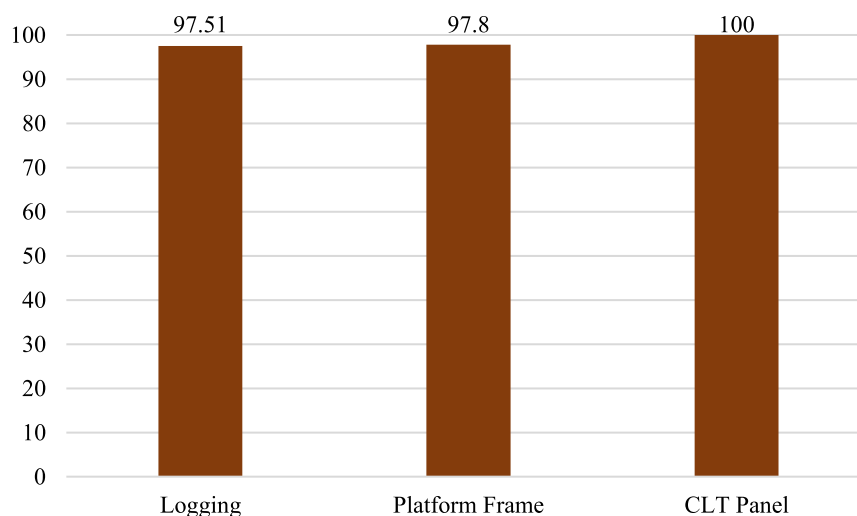


Fig. 22. Percentage comparison of systems based on LCA EN 15978.

follows: timber log construction system, timber platform frame system, and timber CLT panel system.

5. Results and discussion

This study presents a comparative analysis of the environmental performance of traditional (timber log construction and timber platform frame) and contemporary (CLT panel) timber building systems using the LCA method. The production, transportation, use, and end-of-life phases of these three different systems applied to the same residential design in the Bursa/Mudanya region were evaluated using the One Click LCA tool. Quantitative results were obtained for impact categories including Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Ozone Depletion Potential (ODP).

The analyses revealed that the highest environmental impacts across all building systems stem from energy consumption during the use phase, particularly the B6 stage. This finding indicates that, regardless of the choice of building materials, user habits and the type of energy source are critical determinants of the overall environmental impact. However, apart from this common impact, significant differences were observed among the building systems in the production (A1–A3), transportation (A4), and end-of-life (C1–C4) phases.

The timber log construction system exhibited relatively low GWP values due to lower energy consumption in raw material production processes, attributed to its low level of processing. Nonetheless, its architectural limitations, low thermal insulation capacity, and insufficient detailing to meet modern building requirements suggest that this system may remain limited in widespread and contemporary applications.

The timber platform frame system demonstrated balanced performance in both production processes and energy efficiency during use. Its relative flexibility in material procurement and workmanship makes it a viable option, especially for single- or two-story residential buildings. However, its inability to provide a significant advantage in environmental impacts over the building's lifecycle necessitates selective application in specific contexts.

The CLT panel system resulted in higher environmental impacts during production compared to the other systems, particularly in GWP and AP categories. However, its durability, prefabrication benefits, and structural capacity highlight it as a high-performance alternative. The industrial manufacturing of CLT load-bearing elements and the necessity of long-distance transportation led to increased environmental impacts during the transportation (A4) phase

compared to other systems. Nevertheless, the rigidity, prefabrication advantages, and recyclability of CLT panels provide a potential to offset these environmental drawbacks over the long term.

In this study, the end-of-life (C1–C4) scenarios were modeled according to the default options provided by the One Click LCA database. For timber components, it was assumed that approximately 50% of the material is directed to energy recovery through incineration with energy substitution benefits, 30% is mechanically recycled into secondary wood products, and 20% is disposed of in landfill. These proportions reflect typical European practice and are aligned with the EN 15978 framework, but they may vary in local contexts. The sensitivity of the results to different end-of-life pathways highlights the importance of reuse and recycling strategies, as increasing the share of material reuse or cascading recycling could further reduce life cycle impacts. Future studies may focus on developing more context-specific scenarios for Türkiye to capture regional waste management capacities and timber reuse potentials.

Biogenic carbon calculations performed under the D (external influences) module for all building systems emphasize the role of timber structures in mitigating environmental impact. This supports the confirmation that the use of carbon-storing materials such as timber is significantly more environmentally friendly compared to fossil fuel-based building materials.

In conclusion, all three building systems offer a more environmentally sustainable approach compared to traditional reinforced concrete or steel constructions. However, when compared among themselves;

- The timber log construction system, with its low technology requirements and use of natural materials, may be particularly suitable for local, low-density rural applications.
- The timber platform frame system, due to its cost-effectiveness and ease of assembly, stands out as a viable option for small-scale residential projects.
- The CLT panel system is preferable for multi-story and fast-track construction projects; however, optimizing its environmental benefits requires localization of production and logistics processes.

Despite these distinctions, the results confirm that the overall environmental impacts of the three timber systems are fundamentally similar, as the dominant contribution of the use phase (B6) largely outweighs differences in production, transportation, and end-of-life processes.

From a policy and practical perspective, promoting the wider adoption of timber construction requires

supportive incentive mechanisms, revisions in regulatory frameworks to accommodate contemporary timber technologies such as CLT, and the integration of timber-specific criteria into existing green building certification systems. Such measures could encourage both the construction sector and local authorities to prioritize timber as a sustainable alternative to conventional materials.

In future studies, conducting analyses that consider not only environmental but also economic and social sustainability dimensions will be crucial for developing holistic design approaches and solutions. Furthermore, the widespread adoption of CLT production in Turkey and the mitigation of its adverse environmental impacts can contribute to the efficient use of local and fundamental resources within the country.

Conflict of interest statement

The authors declare that there is no conflict of interest.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Author contributions

Conceptualization, S.A., G.T.; methodology, S.A., G.T.; fieldwork, S.A., G.T.; software, S.A., G.T.; title, S.A., G.T.; validation, S.A., G.T.; formal analysis, S.A., G.T.; research, S.A., G.T.; sources, S.A., G.T.; data curation, S.A., G.T.; manuscript-original draft, S.A., G.T.; manuscript-review and editing, S.A., G.T.; visualization, S.A., G.T.; supervision, S.A., G.T. All authors have read and legally accepted the final version of the article published in the journal.

Ethics

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