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Monitoring and Evaluation Framework
Life Cycle Assessment (LCA) of Poppies – a case study applying an LCA tool for Positive Energy Districts (PEDs)

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Abbreviations and Acronyms

Acronym	Description
CLT	Cross Laminated Timber
EF	Environmental Footprint
EPD	Environmental Product Declaration
EU	European Union
EUI	European Urban Initiative
FSC	Forest Stewardship Council
GHG	Greenhouse Gas
ICT	Information and Communication Technology
JPI	Joint Programming Initiative
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMD	Nationale Milieudatabase
PED	Positive Energy District
PV	Solar Photovoltaics
SET	Strategic Energy Technology

Executive Summary

This report presents the results of a comprehensive Life Cycle Assessment (LCA) of Poppies, a demonstration Positive Energy District (PED) located in the Buiksloterham area of Amsterdam North. Developed as part of the EU Horizon 2020 ATELIER project, Poppies exemplifies a regenerative and circular urban districts that aim to achieve sustainable performance through integrated design, renewable energy, and social innovation. The LCA supports the project's broader mission of enabling cities to design and replicate PEDs as scalable solutions aligned with the broader European initiatives on sustainable urban developments.

The study applies an open-source LCA framework based on Brightway2 and evaluates the full life cycle environmental performance of the Poppies district over a 50-year time horizon (2025–2075). The assessment focuses on three key impact categories: life cycle greenhouse gas (GHG) emissions, non-renewable primary energy demand, and total environmental footprint using the EF 3.1 methodology.

Key findings:

- Total life cycle GHG emissions exceed 3 million kg CO_2-eq, with the majority coming from embodied emissions in construction materials, notably concrete and timber. Operational GHG emissions are significantly reduced due to onsite renewable electricity supply.
- Non-renewable primary energy demand is approximately 40 million MJ, mainly driven by material production and the upstream supply chain of solar PV systems.
- Environmental footprint analysis reveals land use and fossil resource depletion as dominant impact categories, highlighting the trade-offs of using wood-based construction materials and the need for sustainable material sourcing.

A core contribution of this work is the development of an open-source, transparent, reproducible LCA framework with publicly accessible data files, model code, and interactive visualizations. This framework can be adapted for assessing other urban districts and supports more advanced modelling features such as incorporating more detailed temporal and spatial aspects to the analysis in the future, as well as facilitates the better integration of life cycle thinking into urban planning.

Recommendations:

For urban planners and developers, the study emphasizes early integration of circular design, low-impact materials, and supplier-specific environmental data. Policymakers are encouraged to harmonize LCA practices with EU urban sustainability goals, and LCA practitioners are urged to build on the open-source methodology by incorporating dynamic and spatial modelling.

While the study acknowledges limitations such as static operational assumptions and reliance on generic databases due to limited data availability, it lays the groundwork for more refined, scalable, and policy-relevant LCA applications in sustainable urban Development in the future, accessible for free by a broader set of users.

1 Introduction

1.1 Background

Climate change poses significant challenges globally, with cities at the forefront due to their dense populations and concentrated resource consumption. In response, the European Union (EU) has implemented comprehensive policies aimed at mitigating environmental impacts and promoting sustainable urban development [1].

A cornerstone of the EU's strategy is the European Green Deal, introduced in 2019, which aims to transform Europe into the first climate-neutral continent by 2050 [2]. This ambitious plan emphasizes reductions in greenhouse gas (GHG) emissions, investments in green technologies, and the promotion of sustainable practices across various sectors, including urban development. The European Union (EU) demonstrates its commitment to sustainable urban development through various initiatives and resources aimed at enhancing energy efficiency and promoting circular economy principles. Notable examples include:

- **European Urban Initiative (EUI)**: An instrument of the EU's Cohesion Policy, the EUI supports cities of all sizes by funding innovative actions, building capacity, fostering knowledge exchange, and empowering urban areas for sustainable development [3].
- **Urban Agenda for the EU**: This initiative enhances the urban dimension of EU policies by fostering partnerships among the European Commission, national governments, city authorities, and other stakeholders. These collaborations aim to improve regulation, facilitate access to funding, and encourage knowledge exchange on urban issues [4].
- **URBACT Program**: A European Territorial Cooperation program that enables cities to work together to develop integrated solutions to common urban challenges. By promoting the exchange of experiences and best practices, URBACT supports cities in implementing sustainable urban development strategies [5].
- **Urban Data Platform Plus**: This platform provides comprehensive data on cities and regions, covering aspects such as population dynamics, economic development, transport, and environmental issues. It serves as a valuable resource for policymakers and urban planners, facilitating informed decision-making based on reliable data [6].

These efforts position European urban districts to reduce environmental footprints and contribute to broader climate objectives.

A pivotal tool within EU policies for environmental assessment is Life Cycle Assessment (LCA) [7]. LCA provides a comprehensive framework for evaluating environmental impacts associated with all stages of a product's or system's life cycle [8,9]. When applied to urban districts, LCA mainly encompasses activities from raw material extraction, production and the construction of buildings and infrastructure (e.g. onsite energy supply and storage systems, networks, etc.), usage phases, and end-of-life disposal and treatment. Mobility can be another key element if it is an essential part of the district. By systematically analysing factors such as energy consumption, greenhouse gas emissions, resource utilization, and waste generation, LCA offers a holistic perspective on the environmental performance of urban areas. The method is instrumental in identifying opportunities for improvement and guiding decision-making processes aimed at enhancing sustainability. Integrating LCA into urban planning enables policymakers to create more sustainable and resilient urban districts by shifting the focus from isolated interventions to a more holistic systems understanding of environmental impacts over the lifetime. Unlike conventional assessment methods that often concentrate on single stages (e.g., construction or operation phase), LCA captures the interconnected effects across the entire life cycle of buildings and infrastructure. This allows for the identification of trade-offs, long-term efficiencies, and hidden environmental costs, ultimately supporting more robust, future-proof urban development strategies. Furthermore, LCA supports monitoring and evaluating sustainability progress, ensuring that urban development strategies are effective and aligned with global sustainability targets.

1.2 Positive Energy Districts (PED): Concept and State of the Art

According to the definition of PEDs by Urban Europe [10]: "Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy." , In practice, the implementation of PEDs necessitates a comprehensive integration of diverse systems and infrastructures, fostering dynamic interactions among buildings, occupants, and regional networks encompassing energy, mobility, and information and communication technology (ICT). This holistic approach aims to ensure a reliable energy supply and enhance quality of life, aligning with the principles of social, economic, and environmental sustainability [10]. This concept emerged from European urban sustainability efforts, building on earlier ideas like "Positive Energy Blocks" and formalized under the EU's Strategic Energy Technology (SET) Plan [11]. In 2018, the SET Plan's Action 3.2 set an ambitious target of creating 100 Positive Energy Districts across Europe by 2025 [11]. The Joint Programming Initiative (JPI) Urban Europe, in collaboration with the European Commission, leads a PED Program to support planning, deployment and replication of these districts as a pathway toward climate-neutral cities. This aligns with broader EU policies such as the European Green Deal, which strives for climate neutrality by 2050. PEDs are explicitly seen as key instruments to deliver the Green Deal objectives and 2030 climate targets, by driving deep decarbonization in cities. In EU policy frameworks (e.g. the European Green Deal and the "Clean Energy for All Europeans" package), cities are recognized as critical for climate action, and initiatives like PEDs are promoted to transform urban energy systems in line with EU climate goals.

PEDs contribute directly to climate neutrality and GHG emissions reduction goals by drastically cutting the carbon footprint of urban districts. By generating a surplus of renewable energy and sharing it, a PED can offset more emissions than it produces – studies indicate PED implementations can cut carbon emissions by up to 85% in some urban areas. This makes PEDs powerful "building blocks" for climate-neutral and sustainable cities. The European Commission's mission for 100 Climate-Neutral Cities by 2030 and the EU's 2030 targets (e.g. >55% GHG reduction) heavily emphasize decarbonizing the urban environment, and PEDs are an actionable way to achieve this at the district scale. By integrating PEDs into city climate plans, municipalities embed renewable energy generation, efficiency measures, and smart technologies in a defined area, moving beyond individual green buildings to a holistic neighbourhood approach. For example, a PED actively manages its energy through smart grids and storage to balance supply and demand, performing techniques like peak shaving and demand response to optimize the use of local clean energy. Surplus renewable energy not used in the district can be fed into the regional grid, supporting the wider energy system's decarbonization. PEDs help turn cities into solution providers for climate change, demonstrating how urban communities can reach net-zero emissions ahead of schedule while improving local quality of life.

1.3 The Demonstration PED in Amsterdam: Poppies

Located in the redeveloping industrial area of Buiksloterham in Amsterdam North, Poppies exemplifies a new generation of circular and regenerative urban development. The district is part of a broader transformation into a resilient, sustainable mixed-use neighbourhood. It embodies a vision of a "circular micro-city," combining architectural flexibility, social cohesion, and environmental integration.

Poppies consists of four modular timber buildings arranged around a central green courtyard, with about 5098 m^2 of total floor area. Its open construction system using Forest Stewardship Council (FSC)-certified cross-laminated timber (CLT) allows for adaptability over time without demolition. Around 80% of all materials used are reusable, and the buildings can generate onsite renewable energy through solar photovoltaic panels. It is equipped with a smart grid that enables energy exchange between buildings and with systems for aquifer thermal energy storage, rainwater harvesting, greywater reuse, and biodiversity-enhancing green spaces.

Poppies blends with its post-industrial context through a distinctive grid façade inspired by warehouse structures. The modular apartment units featuring natural materials support a layered design emphasizing daylight access, acoustics, and user comfort. Residents are connected via wide planted galleries, with views over vegetated facades and roof gardens that function as social spaces and urban ecological corridors.

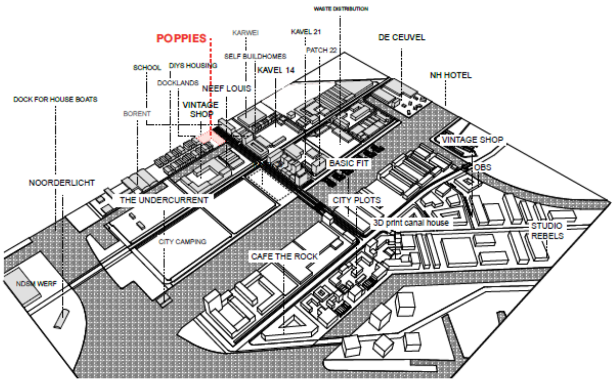

Figure 1: left: A glimpse into Poppies, Buiksloterham Amsterdam; right: location of Poppies in Buiksloterham

(photo sources: https://devreeden.nl/referenties/83/poppies-amsterdam/ & Marc Koehler Architects)

Although most of the Poppies are residential apartments, it is not just a housing complex but a social experiment in community-making. Future residents benefit from flexible rental schemes and shared facilities such as workshops, cafés, and mobility hubs. Public and semi-public ground-floor functions—including ateliers, workspaces, and meeting areas—activate the streetscape and strengthen community ties. The project's integrated design approach has become a replicable model for sustainable development elsewhere, showing how ecological, technical, and social ambitions can be fused into a coherent architectural and urban vision.

1.4 Objective and Scope of the Study

The primary objective of this study is to perform a comprehensive Life Cycle Assessment (LCA) of the Poppies urban district in Amsterdam. This assessment systematically evaluates the environmental impacts across all life cycle stages of the district over a defined 50-year temporal horizon (2025–2075). The analysis focuses on three key environmental impact categories:

1. Life Cycle Greenhouse Gas (GHG) Emissions
2. Cumulative (Primary) Energy Demand
3. Total Environmental Footprint, encompassing a broad spectrum of environmental impacts

Section 3.4 outlines detailed methodological approaches for assessing these categories. This LCA identifies the principal contributors to environmental impacts within the district, offering valuable insights into areas where targeted interventions—particularly in energy systems and construction practices—can drive significant sustainability improvements.

The secondary objective of this study is to demonstrate the application of an open-source LCA framework tailored for urban district assessments. This objective emphasizes developing a transparent, transferable, and reproducible approach that can be adapted for future evaluations of other urban districts.

In support of this, the study provides:

- A unit process Life Cycle Inventory (LCI), included in an Excel-based input file that specifies data sources, assumptions, and interlinkages between unit processes. This structure ensures transparency of the underlying datasets and enhances accessibility for stakeholders and other audiences interested in exploring the detailed foundations of the LCA.
- LCA analytical workflows for the urban district developed using Brightway2 [12], which imports the aforementioned Excel-based LCI data, ensuring full reproducibility and traceability of the results.
- A set of interactive results visualizations in .html, enabling interactive exploration of the results.

These files facilitate stakeholder communication and ensure that the assessment process is fully reproducible and easily adaptable to varying urban contexts. The complete set of files is publicly accessible through a Zenodo repository [2], supporting transparency, ongoing accessibility, and enabling future enhancements or adaptations of the framework. It should be noted that the only element subject to licensing is the background database, specifically EcoInwent cut-off v3.9.1 [13], which users must procure independently.

By combining robust environmental assessment with open-source tools and transparent data handling, this study aims to set a more accessible and reusable framework for LCA of any urban district, supporting informed decision-making and fostering scalability for broader applications.

[2] https://doi.org/10.5281/zenodo.15620566

Table 1 provides a summary of the key assumptions applied within the system and the temporal boundary of the assessment for Poppies. The following sub-sections provide a detailed description of the included life cycle phases and the key assumptions underpinning the assessment.

Table 1: System boundaries for the LCA of Poppies

	Included elements	**Key assumption of Poppies**
System boundary – product and construction phase	Construction materials consumption	- housing modules (data collected from Derix) - "skeleton" of buildings (data collected from Bouw Management Groen)
	Rooftop Solar PV	228 kWp, 40% of electricity generation for direct consumption onsite in Poppies 1 replacement after 25 years
	Aquifer thermal energy storage (ATES)	life cycle inventory (LCI) data from literature adapted to Poppies LCI for unit thermal energy supply * thermal energy consumption (based on proposal)
System boundary – operational phase	Energy use	Assumptions based on the BEST table in the ATELIER project proposal
System boundary – end-of-life disposal and treatment	Construction materials and energy supply systems	Standard end-of-life disposal and treatment processes available for corresponding materials in EcoInwent
Temporal boundary		50 years, from 2025 to 2075

1.4.1 Product and Construction Phase

This phase includes the consumption of construction materials, specifically prefabricated housing modules, with data sourced from its supplier Derix. The structural "skeleton" of buildings is based on data provided by Bouw Management Groen. Additionally, key infrastructure components such as rooftop Solar Photovoltaics (PV) systems, with an installed capacity of 228 kWp. A single replacement of the PV system is considered after 25 years. The study also considers the Aquifer Thermal Energy Storage (ATES) system, where LCI data from literature sources specific to Poppies has been adapted. The environmental impacts are calculated based on the LCI per unit of thermal energy supplied, multiplied by projected thermal energy consumption as outlined in the project proposal.

1.4.2 Operational Phase

The operational phase focuses on energy use within the district. Assumptions regarding energy consumption patterns and efficiency measures are based on data from the BEST table in the ATELIER project proposal. The analysis covers a 50-year life span, from the start year of operation in 2025 to 2075. This timeframe allows for the inclusion of key maintenance and replacement cycles, such as the mid-life replacement of the rooftop PV system, ensuring a realistic representation of long-term environmental impacts.

1.4.3 End-of-life disposal and treatment

Standard end-of-life disposal and treatment processes from the EcoInwent database are applied to the construction materials used in buildings and the materials associated with energy supply equipment, particularly, for rooftop solar PV systems and ATES installations.

2 Methodology

2.1 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a systematic methodology used to evaluate the environmental impacts of all stages of a product or system — from raw material extraction through production, use, and end-of-life disposal and treatment. In the context of buildings, LCA enables the quantification of resource, material, and energy use, as well as the emissions to the environment and their associated environmental burdens over the entire life cycle of a building or a stock of buildings.

LCA follows a standardized approach as defined by the ISO 14040 [9] and ISO 14044 standards [8], which delineate four main phases:

1. Goal and Scope Definition: Clarifying the purpose of the study, system boundaries (e.g., cradle-to-gate or cradle-to-grave), and the functional unit (e.g., 1 m² of building area per year).
2. Life Cycle Inventory (LCI): Collecting data on energy and material inputs and environmental releases (e.g., CO_2 emissions).
3. Life Cycle Impact Assessment (LCIA): Evaluating potential environmental impacts using characterization factors (e.g., Global Warming Potential in kg CO_2-equivalents).
4. Interpretation: Analysing results concerning the goal and scope, identifying hotspots, and making recommendations for improvement.

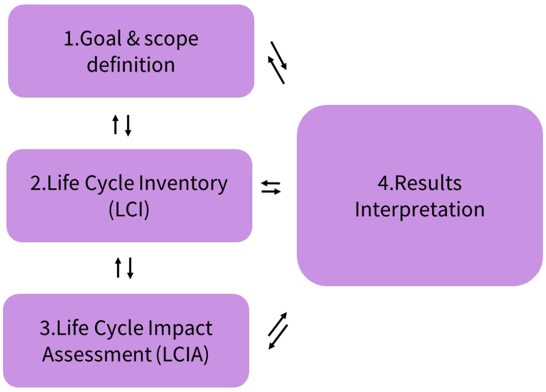

Figure 2: Steps for conducting life cycle assessment of a system

These four steps are iterative, meaning that insights gained during later phases—such as identifying data gaps or unexpected environmental hotspots during the LCI or LCIA—may require revisiting and refining earlier phases like the goal and scope definition or inventory collection. This cyclical process ensures that the assessment remains aligned with its intended purpose, improves accuracy and relevance, and ultimately supports more robust decision-making by allowing continuous refinement and validation of assumptions throughout the assessment process.

For buildings, LCA is often guided by sector-specific standards such as EN 15978:2011 [14], which outlines methods for the environmental performance assessment of buildings, and the Level(s) framework by the European Commission, which helps building professionals and public authorities measure and compare how sustainable buildings are across different projects in Europe.

LCA is increasingly applied in the life cycle environmental evaluation of buildings in practice, especially in the context of circular economy and net-zero strategies, informing decisions on materials, design, and building operation.

2.2 The Application of LCA to Urban Districts

As urban areas evolve into critical arenas for climate mitigation, the application of Life Cycle Assessment (LCA) at the district level has gained growing attention. Traditional LCA methodologies, widely used for individual buildings, face new complexities when applied to larger, more integrated urban systems such as neighbourhoods. Over the past decade, emerging concepts like Positive Energy Districts (PEDs) and Zero Emission Neighbourhoods (ZENs) have underscored the relevance of LCA for assessing sustainability performance at the district level. These frameworks emphasize the holistic nature of LCA, which aligns well with the multidimensional goals of sustainable urban development.

Lotteau et al. (2015) conducted one of the earliest and most comprehensive reviews of neighbourhood-scale LCA applications [15]. They identified significant variability across 21 case studies regarding goal and scope definitions, functional units, system boundaries, and data quality. A key takeaway from this review is the methodological inconsistency and the urgent need for context-specific approaches that align with the design stages of urban development. Expanding on this, Lausselet et al. (2020) applied an LCA model to a Norwegian ZEN, demonstrating the importance of broadening system boundaries to include buildings, mobility, and energy systems [16]. Their findings underscore that operational GHG emissions — particularly from mobility — initially dominate, but as grid electricity decarbonizes, embodied GHG emissions from building materials and construction processes take precedence. Notably, the authors argue for a shift in functional units from "per m²" of floor area to "per neighbourhood" or "per capita" to reflect shared urban dynamics more accurately. Mastrucci et al. (2020) addressed the temporal dimension of LCA by developing a spatial-temporal framework to model renovation scenarios in Luxembourg [17]. Their work highlights the importance of considering the dynamic evolution of building stocks and emissions over time, showing that the impacts of deep renovations can be overestimated if temporal aspects are ignored. Time-adjusted emission accounting revealed the increasing relative importance of embodied impacts.

Recent contributions also focus on tool development and integration. Famiglietti et al. (2022) introduced a data-driven LCA tool for assessing energy systems across 81,000 buildings in Milan, operationalizing LCA at an urban scale [18]. The study showed space heating to be the primary source of operational GHG emissions and emphasized the potential for LCA tools to support city-level policy and renovation strategies.

PED-focused studies add another layer to this discussion. Marotta et al. (2021) and Volpe et al. (2025) stress the need to integrate LCA with key performance indicators (KPIs) in PEDs, pointing out the lack of harmonized methodologies [19][20]. Sassenou et al. (2024) and Natanian et al. (2024) highlight the socio-technical complexity of PEDs and call for holistic frameworks that account for governance, energy flows, and environmental performance collectively [21][22].

Finally, Subal et al. (2024) remind us that while LCA is increasingly influential in both corporate and public decision-making, its full integration into urban planning remains limited [7]. Key institutional barriers include fragmented governance structures, limited stakeholder engagement, and the absence of mandates or clear procedural guidance [20][21][19]. Moreover, data availability and usability—especially for smaller municipalities—continue to hinder practical implementation, alongside the complexity of methods and tools not easily accessible to non-experts [18][7].

While significant progress has been made in applying LCA at the urban district scale, several methodological, operational, and institutional challenges persist. Methodological challenges include the complexity of urban systems and the need to capture spatial and temporal dynamics. Urban areas are multifaceted, with diverse functions and interactions that complicate the modelling process. Additionally, integrating dynamic data over time and space is essential to reflect the environmental impacts of urban districts accurately. Operational challenges stem from the lack of standardized, user-friendly tools and accessible data. The absence of harmonized frameworks and the difficulty in obtaining high-quality, granular data hinder the widespread adoption of LCA in urban planning. Institutional challenges are characterized by limited awareness and integration of LCA into urban planning processes.

To address these challenges, it is essential to prioritize the development of standardized yet adaptable LCA frameworks for the environmental assessment of urban districts. These frameworks should be supported by open-source tools and accessible data designed for use by both experts and non-specialists. They must effectively capture spatial and temporal dynamics, account for embodied and operational environmental impacts, and support evidence-based decision-making in urban planning and policy development.

2.3 Functional Unit and System Boundaries

This study defines two functional units: 1) the entire district of Poppies as a whole, and 2) 1 m^2 of floor area in Poppies per year. Figure 3 shows all the life cycle stages defined based on EN15978 and the stages covered in this study for the LCA of Poppies. Specifically, it covers the product stage, which includes raw material extraction, transportation, and manufacturing for the construction materials required for the buildings and energy; energy consumption during the operational phase; as well as waste processing and disposal. Transportation of construction materials from the manufacturing facility to the construction site is partly considered depending on the data availability: either as data directly collected from the project, e.g., for modular apartments from Germany to Amsterdam, or with default assumptions as part of the inventory data available in the market datasets for materials in EcoInwent version 3.9.1 database, which is used as the background database for this analysis.

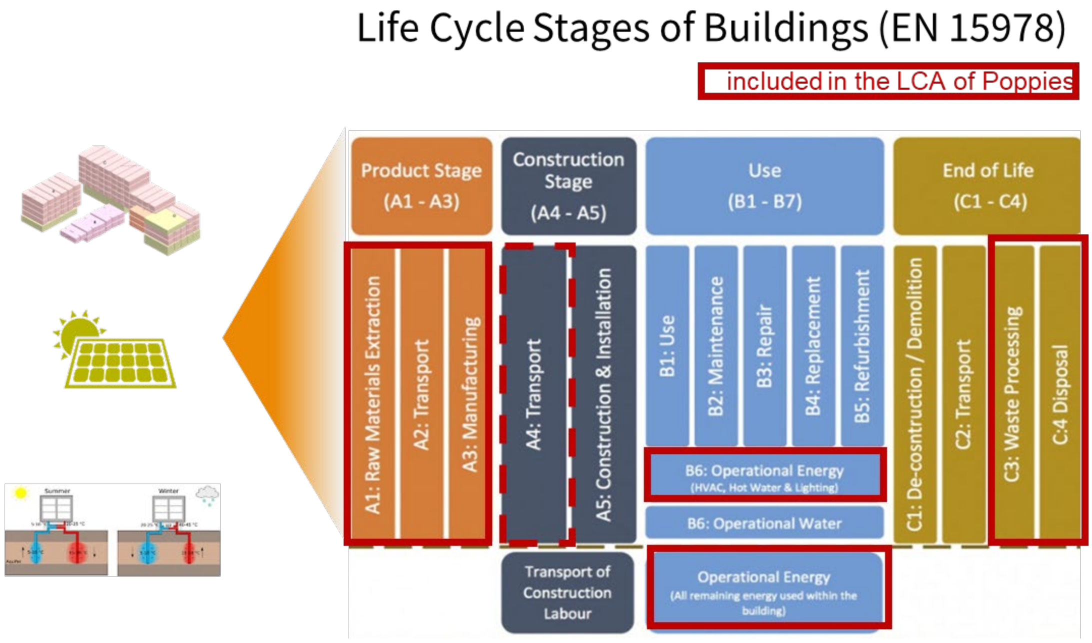

Figure 3: Life cycle stages of buildings according to EN 15978 and included life cycle stages for the LCA of Poppies - a case study applying LCA to a PED demonstration site in ATELIER

2.4 Life Cycle Impact Assessment (LCIA) Methods

In assessing the environmental performance and sustainability of systems, processes, and products, specific Life Cycle Impact Assessment (LCIA) methodologies are employed to provide robust, consistent, and scientifically sound insights.

2.4.1 Life Cycle Greenhouse Gas (GHG) Emissions – IPCC 2021

The quantification of greenhouse gas emissions follows the Intergovernmental Panel on Climate Change (IPCC) 2021 methodology, recognized globally as a scientific standard for climate change assessment. This approach characterizes emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other GHGs by converting them into CO_2-equivalents (CO_2-eq) using scientifically determined Global Warming Potentials (GWPs) over a 100-year horizon [23]. This LCIA method assumes the uptake of biogenic carbon dioxide is balanced with its emissions at the end-of-life treatment process (e.g., when the wood material is incinerated), and does not account for the temporary storage of carbon in wood-based materials.

2.4.2 Non-Renewable Primary Energy Demand

Assessment of non-renewable primary energy demand quantifies the cumulative amount of energy sourced from fossil fuels (e.g., coal, oil, natural gas) and nuclear resources throughout a product's or system's life cycle. In other words, it includes both direct energy use (e.g., fossil fuels burned for heating) and indirect energy use (e.g., energy embedded in materials and manufacturing processes), and provides insight into the product's dependency on non-renewable resources. It is quantified in the unit of megajoules (MJ) of non-renewable primary energy and is an essential indicator in understanding long-term sustainability, helping stakeholders make informed decisions towards reducing reliance on non-renewable energy sources and transitioning to more renewable alternatives [26].

2.4.3 Total Environmental Footprint – EF 3.1

The Environmental Footprint (EF) v3.1 method, developed under the auspices of the European Commission, offers a comprehensive approach for quantifying the overall environmental impact across multiple environmental impact categories [27]. EF v3.1 incorporates a harmonized set of midpoint impact indicators, including climate change, resource depletion, eutrophication, acidification, and ecotoxicity, among others. By consolidating diverse environmental indicators into a standardized framework, EF v3.1 facilitates holistic environmental decision-making and comparability across sectors and regions. The normalization and weighting factors used in calculating the total environmental footprint can be found in Annex 1 & Annex 2, respectively.

3 Results

3.1 Material consumption

Figure 4 provides a comparative bar chart illustrating the total weight of primary building materials grouped by their application: housing modules and building “skeleton”. These material weights were obtained directly from inventory data collected during the construction phase of the urban district project. Material categorization was based on their primary usage within the construction: either consumed as materials for manufacturing housing modules or as structural elements – the so-called building “skeleton.” The materials considered include gypsum fibreboard, gypsum plasterboard, cross-laminated timber, glued laminated timber, concrete, reinforcing steel, wood board, wood beam, and limestone.

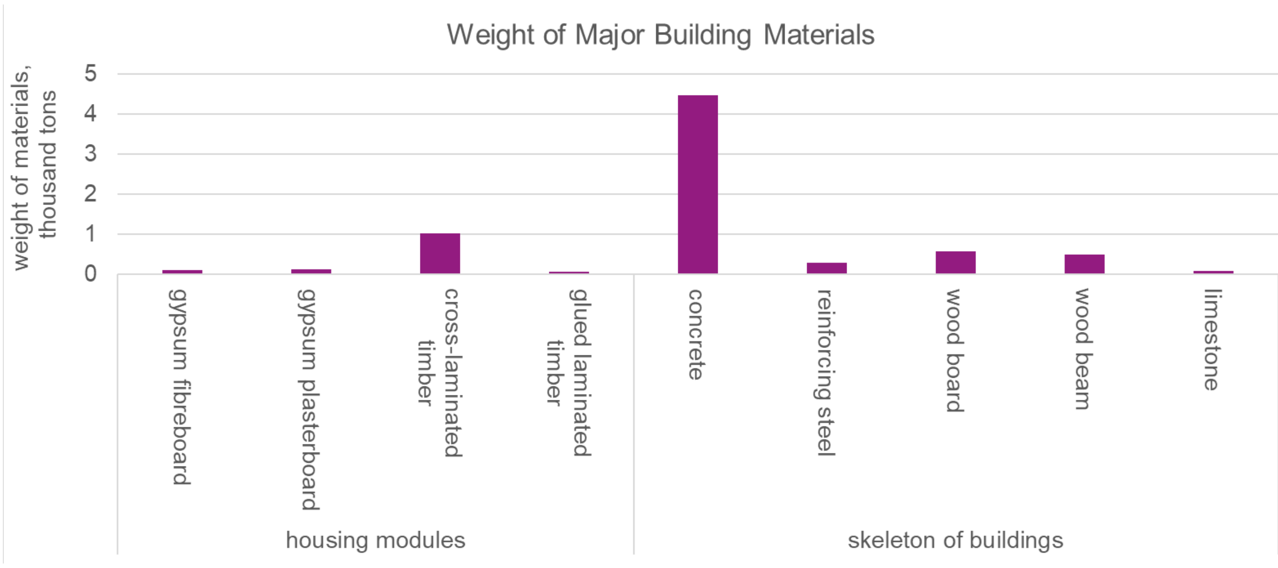

Figure 4: Weight of major building materials consumed in Poppies, Amsterdam

Concrete used in the “skeleton” of buildings clearly emerges as the predominant material by weight, accounting for approximately 4500 tons, significantly exceeding the other materials. Cross-laminated timber (CLT), the second most prominent material, has an approximate weight of 1000 thousand tons, primarily utilized within housing modules. Wood boards and beams are the third most consumed materials, each around 500 tons. Other materials such as gypsum fibreboard, gypsum plasterboard, glued laminated timber, reinforcing steel, and limestone each weigh significantly less, all under 300 tons individually.

3.2 Life Cycle GHG Emissions

Figure 5 presents a detailed breakdown of the total life cycle GHG emissions for the entire Poppies district. Emissions are further dissected by life cycle stages, specifically the product stages, construction stage (mainly by transport of the housing modules), operational electricity use, and end-of-life stages. The product stage is further split into contributions from buildings, solar PV, and ATES

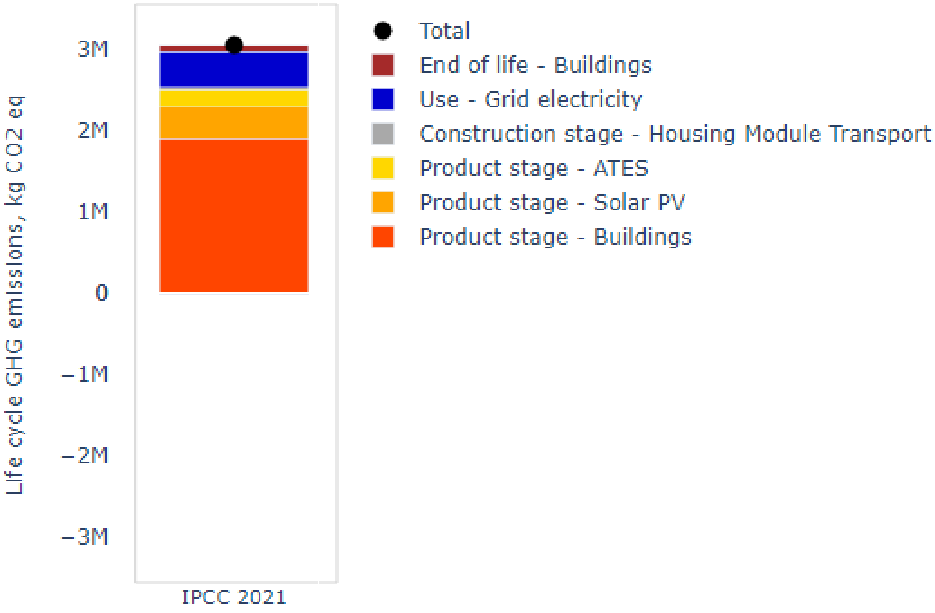

Figure 5: Life cycle GHG emissions of Poppies, with breakdown into different life cycle stage and key contributors.

An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4

The total life cycle GHG emissions of Poppies exceed 3 million kg CO_2-eq. The product stage, in particular, the materials used for building construction, remains the largest contributor to embodied GHG emissions, reflecting the substantial carbon footprint of construction materials. Additional contributors include solar PV production, the ATES system, and grid electricity use, while the end-of-life stage and transport play comparatively minor roles.

Based on the total floor area of Poppies, the normalized life cycle greenhouse gas (GHG) emissions were calculated at approximately 12 kg CO_2-equivalent per square meter per year (kg CO_2-eq/m²/year) for the entire district. This value is relatively low compared to the average for European residential buildings, which can reach up to 80 kg CO_2-eq/m²/year [28]. Of the total emissions, 7.5 kg CO_2-eq/m²/year is attributed to embodied GHG emissions. While this is also lower than the European average for embodied emissions—up to 15 kg CO_2-eq/m²/year [28]—the margin is less significant than when considering total life cycle emissions. Therefore, although Poppies performs well in both categories, its advantage is more pronounced when evaluating overall life cycle GHG emissions, mainly thanks to the low-carbon energy supply during the operational phase.

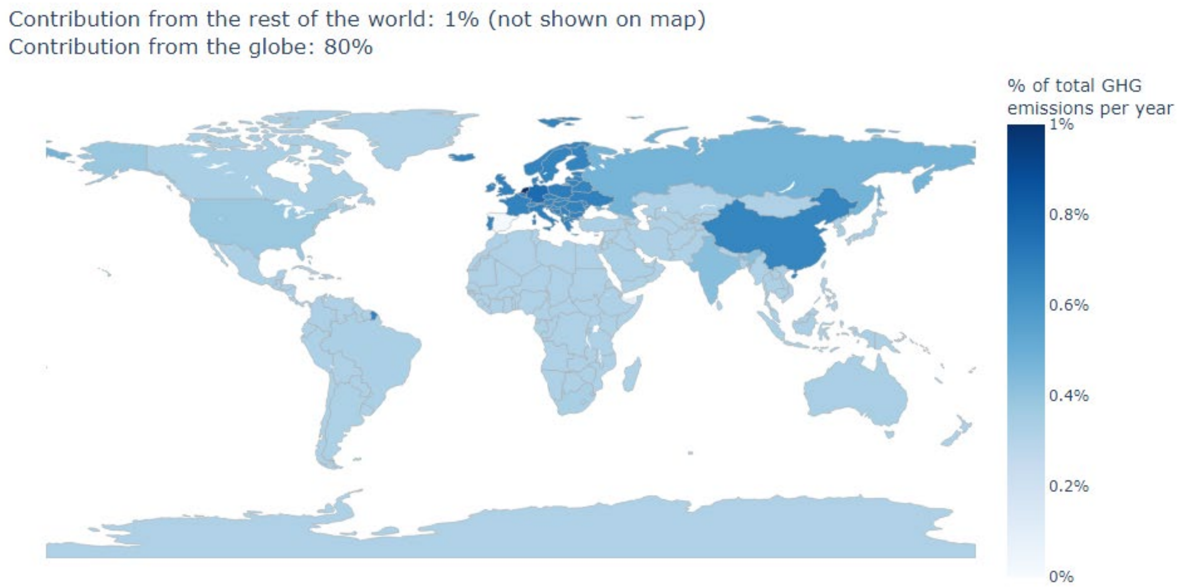

Figure 6: Global distribution of life cycle GHG emissions caused by the Poppies district;

method adopted from Zhang et al. [29] *. An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4*

The global distribution of life cycle GHG emissions associated with the Poppies district shows a distinct concentration in a few key regions. As illustrated in the map, approximately 80% of the total GHG emissions are from global market activities. In comparison, an additional 1% originates from the “Rest of the World” regions not represented on the map (reasons for this are explained in Zhang et al. [29]). The largest shares of GHG emissions are attributed to China and European countries, reflecting the globalized nature of construction material supply chains and manufacturing processes. China stands out prominently, likely due to its dominance in the production of energy-intensive materials, such as steel, and the upstream products for other industrial components used in the district, such as the solar photovoltaic system. European countries contribute significantly as well, likely linked to the sourcing of specialized products, such as timber products and adhesives. The concentration of GHG emissions in these regions highlights the embedded carbon footprint that extends far beyond the physical boundaries of the district itself. These findings underscore the critical importance of considering global supply chain GHG emissions in LCA of urban developments, and they reinforce the need for sustainable procurement strategies that prioritize low-carbon materials from a life cycle perspective.

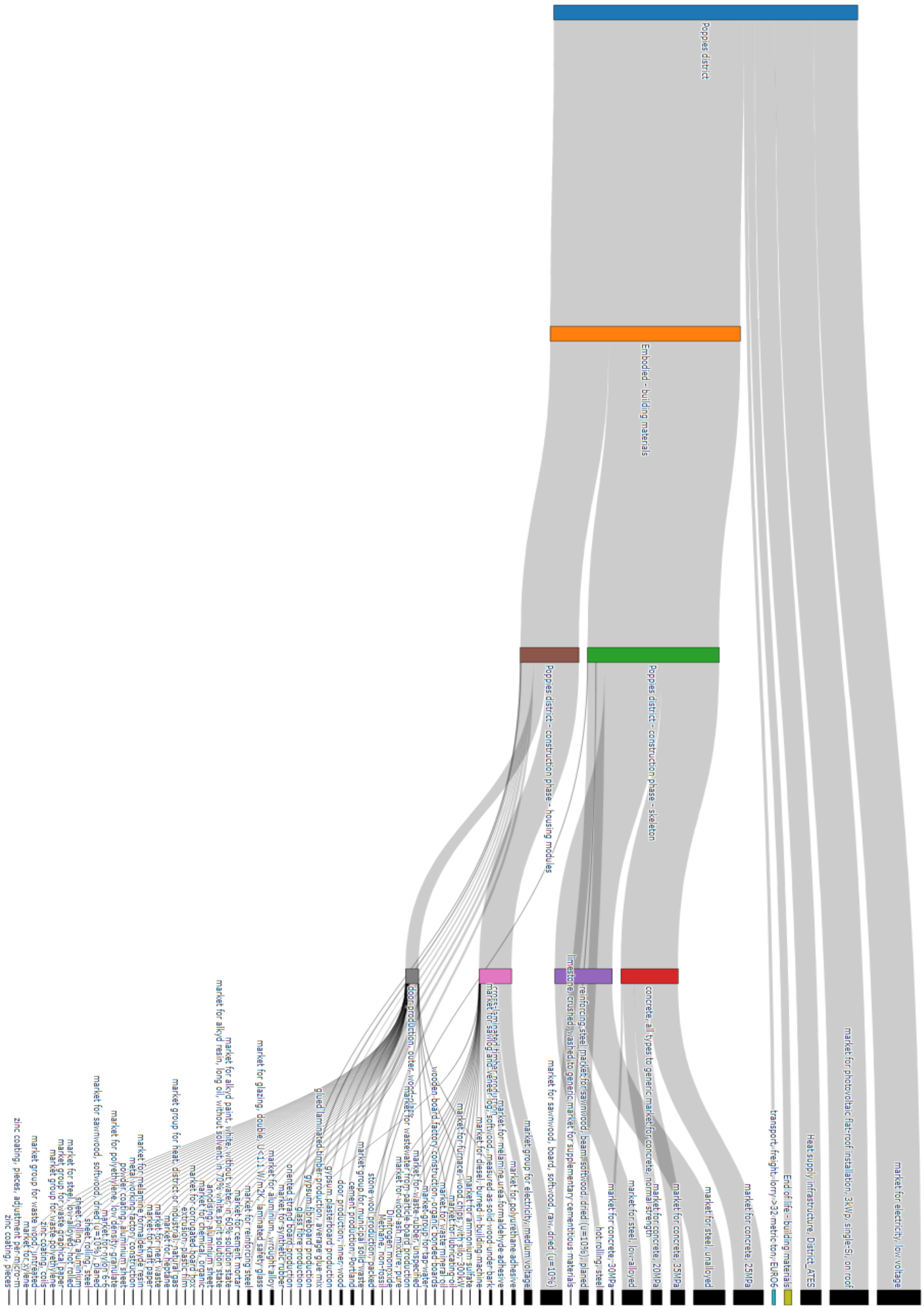

Figure 7: Sankey diagram of life cycle GHG emissions of Poppies based on IPCC 2021.

An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4

Figure 7 provides a more detailed visualization of the life cycle GHG emissions of the Poppies district based on the LCIA method of IPCC 2021 by extending the contribution analysis deeper into the upstream processes. Within the construction phase, emissions are further divided between two main components: the skeleton construction and the housing modules. The skeleton, largely composed of concrete and steel elements, accounts for a considerable portion of emissions due to the inherently carbon-intensive nature of these materials. In contrast, the housing modules display a more diversified emission profile, with contributions from wood-based materials, insulation, glazing, and finishing elements. Despite the use of timber, which is generally considered a lower-carbon option, the variety of materials still results in notable embodied emissions.

The diagram underscores the critical importance of material selection and construction practices in reducing the carbon footprint of urban districts. Strategies such as sufficiency measures to reduce material consumption, substituting high-carbon materials with lower-impact alternatives, incorporating recycled or bio-based materials, and promoting circularity could offer substantial mitigation potential. The analysis highlights that for such urban districts that are energy-efficient during the operational phase, addressing embodied GHG emissions, particularly in the early design of the structural framework of buildings, is essential for achieving low-carbon districts from a life cycle perspective like Poppies.

3.3 Primary Energy Demand

Figure 8 illustrates the life cycle cumulative non-renewable energy demand for the assessed system, totalling approximately 40 million megajoules (MJ), which is much greater than the grid electricity consumption (about 3.2 million MJ for an operation of 50 years for the entire district). This highlights once again that the energy embodied in materials and upstream supply chain is enormous. The breakdown across life cycle stages highlights key contributors to non-renewable energy use.

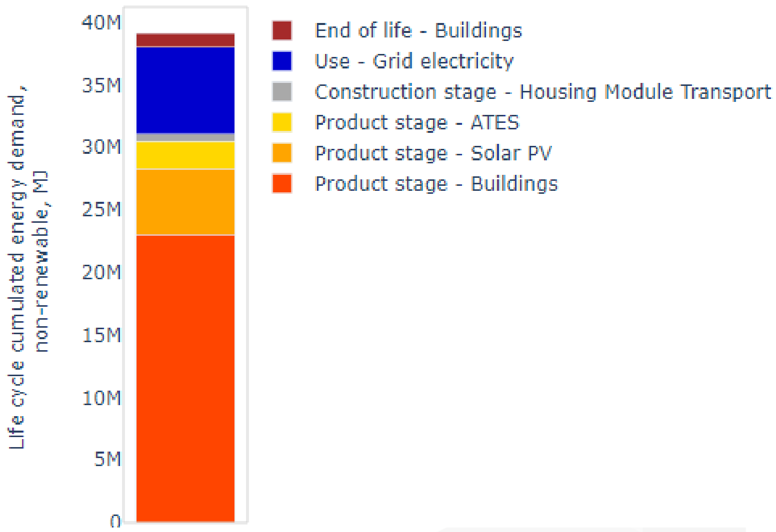

Figure 8: Life cycle non-renewable primary energy demand for Poppies.

An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4

Building materials are by far the largest contributors, accounting for more than half of the primary energy demand. This emphasizes the substantial energy intensity associated with the production of construction materials, such as concrete, steel, and other conventional building components. The significant impact at this stage underlines the importance of material selection and sourcing strategies when aiming to reduce embodied energy.

Another significant contributor is the primary energy demand associated with the grid electricity consumption during the operational phase, this indicates that operational energy consumption still plays a critical role in the overall non-renewable energy footprint, especially if the grid mix is dominated by fossil fuels.

The solar PV system also accounts for a significant share of the primary energy demand. Although PV systems support operational decarbonization, their manufacturing is highly energy-intensive and predominantly occurs in regions where electricity generation relies heavily on fossil fuels, such as China [30]. While leading solar manufacturers are increasingly integrating renewable energy into their production processes [30], detailed supplier-specific data is lacking in the Poppies project. As a result, it is not possible to apply a supplier-specific LCI for the solar PV systems, leading to reliance on generic datasets that may overestimate the associated energy demand.

On the other hand, the ATES system, transport of housing modules from the manufacturing site to the construction site, and end-of-life stage contribute relatively minor shares to the primary energy demand. This suggests that, while important, these stages offer more limited opportunities for reducing non-renewable energy demand in their supply chains compared to the material production for buildings, electricity use during the operational phase, and the solar PV system.

Overall, the results highlight that effective strategies to reduce non-renewable energy demand should prioritize lowering embodied energy in building materials, sustainably sourcing renewable electricity supply systems like solar PV, and improving operational energy efficiency—ideally in conjunction with grid decarbonization.

3.4 *Environmental* Footprint (EF 3.1)

Figure 9 illustrates the total Environmental Footprint (EF) points for Poppies. The most prominent impact is observed in land use, which overwhelmingly dominates the overall footprint. Substantial contributions are also seen in categories such as climate change, freshwater ecotoxicity, fossil resource depletion, and water use. These results suggest that emissions of air pollutants, greenhouse gases, water use, and resource consumption caused by material production are critical environmental hotspots for the district. In particular, the high score in climate change emphasizes the particular importance of addressing not only the operational GHG emissions within urban developments but the life cycle GHG emissions, including the embodied GHG emissions. This is especially important for sustainable urban districts like Poppies that are ambitious in achieving net-zero energy balance during the operational phase, as environmental burdens might shift from the operational phase to the product and construction phase.

Additionally, contributions from the solar PV system are visible in categories such as resource depletion (fossils and minerals), ozone depletion, non-cancer human toxicity and water use, reflecting the energy- and resource-intensive nature as well as considerable amount of pollutants emitted during PV manufacturing processes despite its operational benefits.

Meanwhile, transport during construction, grid electricity uses during operational phase and end-of-life stages show minimal contributions across most categories.

In general, it shows that while operational efficiency and renewable energy integration are important, the environmental impacts embedded in construction materials and life cycle land use dominate the district's life cycle footprint. This underscores the need for strategies focusing on sustainable material choices, lowering consumption, and improving supply chain sustainability to mitigate the environmental burden of urban developments like Poppies.

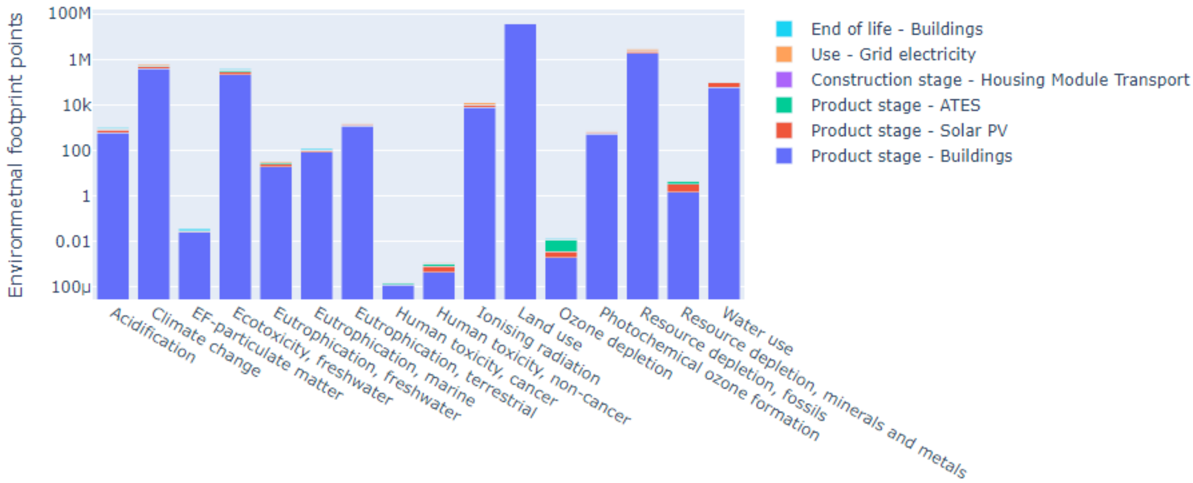

Figure 9: Total environmental footprint of Poppies.

An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4

Since land use and fossil resource depletion are the two leading contributors to the total environmental footprint, the following section provides an in-depth analysis of these impact categories.

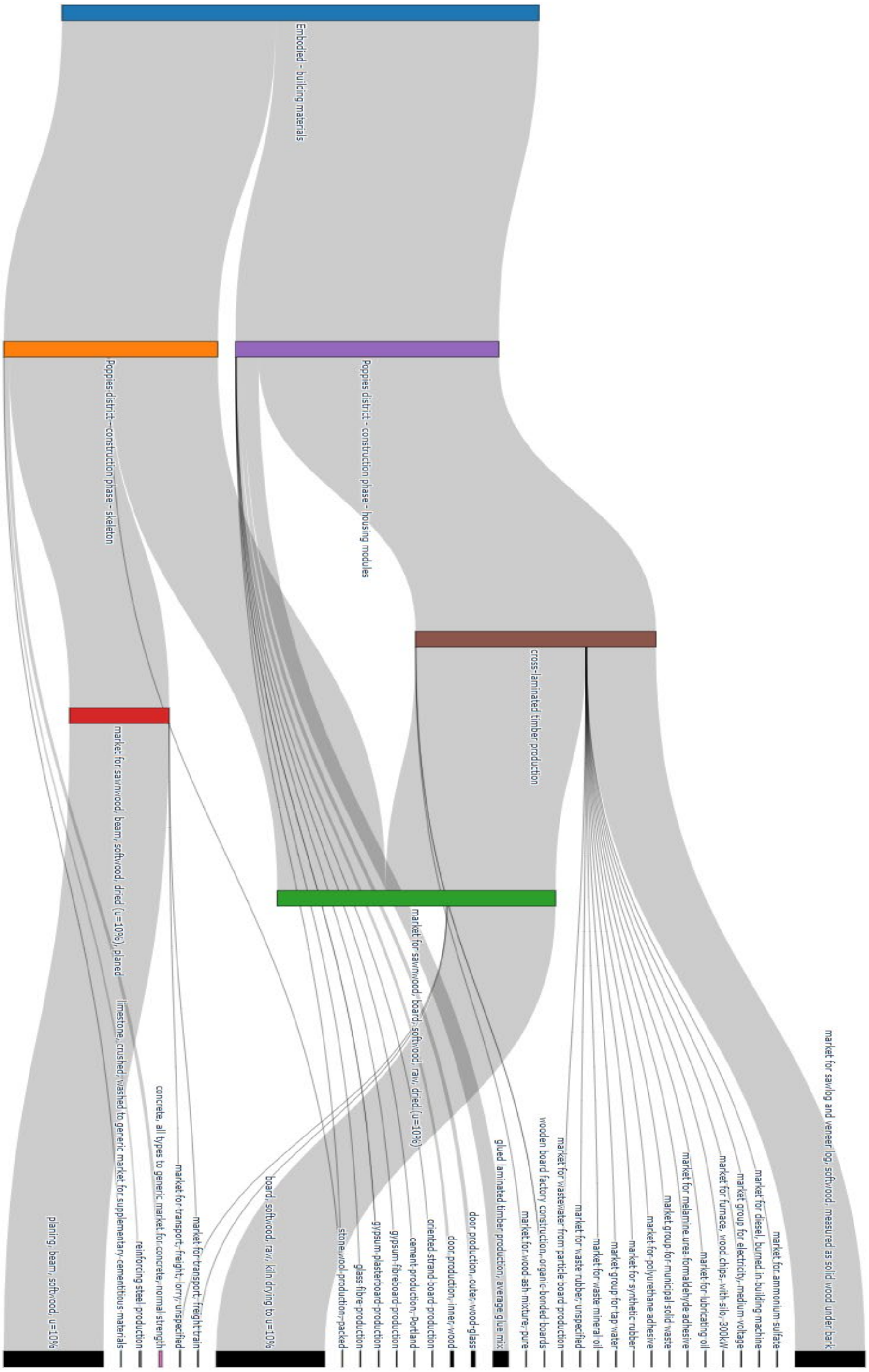

Figure 10: Sankey diagram for the life cycle land use impact of Poppies (unit: soil quality index, dimensionless).

An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4

Figure 10 shows the life cycle land use impact of the Poppies district. It highlights that the primary contribution stems from the embodied impacts of building materials during the construction phase. Both the housing modules and the structural skeleton are major contributors, with a particularly strong reliance on CLT production. This confirms that the use of timber-based construction materials, while offering clear benefits in terms of temporal carbon storage, shifts a considerable share of environmental pressure towards land use impact.

A detailed examination of material flows reveals that forestry-related activities dominate the upstream land use profile. The production of CLT heavily depends on the market for saw logs, sawn wood, and board products, emphasizing the critical importance of sustainable forest management practices. The diagram further illustrates the complexity of supply chains in the district's construction. Smaller yet noticeable flows link the land use impacts to various auxiliary materials and processes, such as adhesives. This underlines that the broader material ecosystem still carries considerable environmental significance in certain impact categories, even in a district emphasizing renewable materials.

Figure 11 shows the life cycle fossil resource depletion of the Poppies district. It reveals that most impacts originate from the embodied materials used during the construction phase. Like land use impact, both the structural skeleton and the housing modules contribute substantially to fossil resource depletion, albeit through different material pathways.

For the structural skeleton, reinforcing steel production emerges as a significant hotspot. The production of unalloyed and low-alloyed steel, along with associated processes such as hot rolling, heavily relies on fossil fuels for energy-intensive extraction, processing, and manufacturing. Similarly, the concrete supply chain, including various strength grades, also shows notable contributions to fossil depletion, primarily due to the energy demands of cement production.

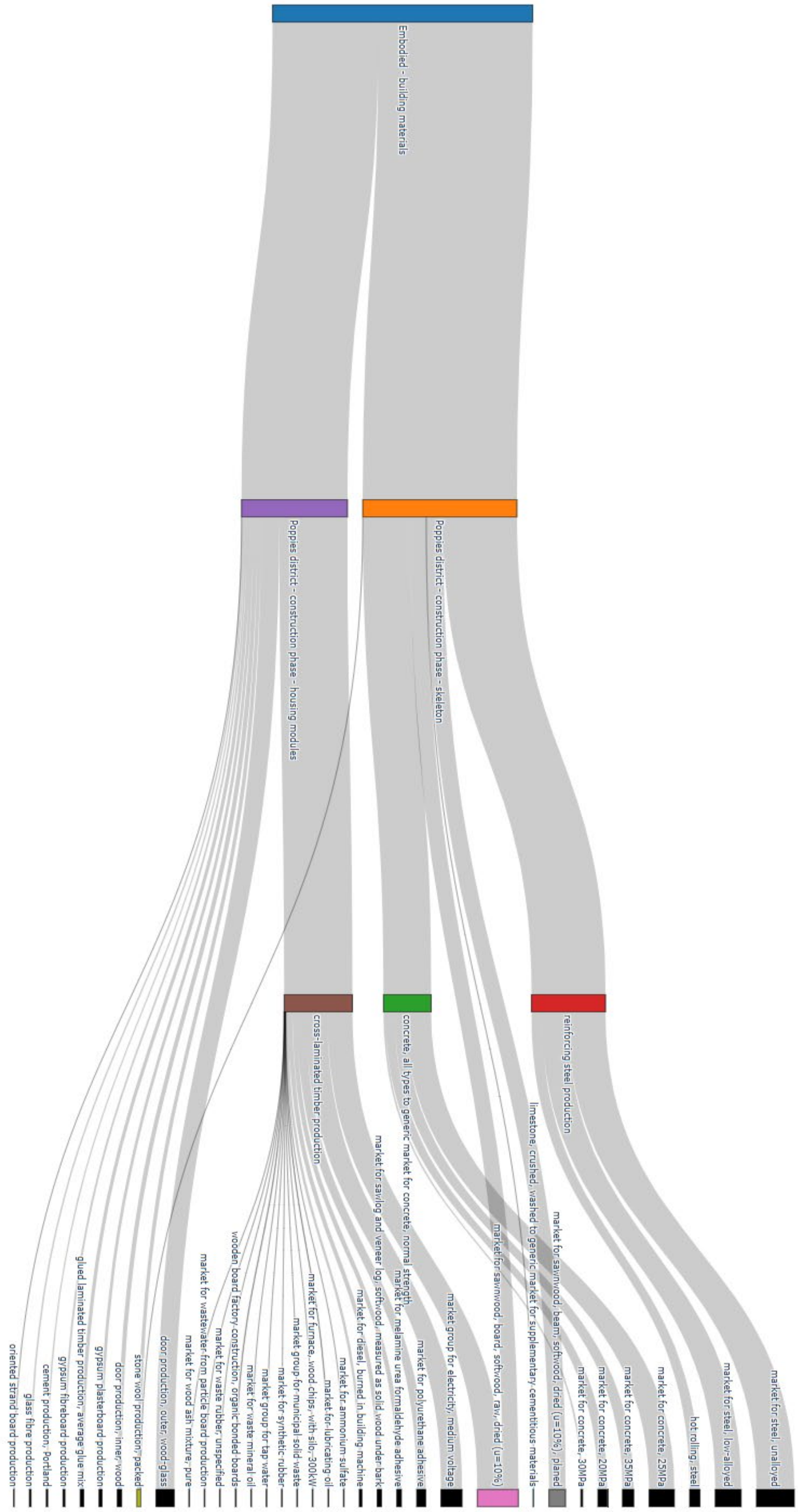

Figure 11: Sankey diagram for life cycle fossil resource depletion of Poppies.

An interactive version of this result, in HTML format, is available in the Zenodo repository referenced in Section 1.4

In contrast, the largest contributor to fossil resource depletion for the housing modules is CLT production. Although timber itself is a renewable material, the upstream processes required for CLT manufacturing—such as kiln drying of timber, production of adhesives (e.g., melamine-urea-formaldehyde and polyurethane adhesives), and wood panel manufacturing—are energy-intensive and predominantly reliant on fossil-based energy sources. Additionally, auxiliary material production further adds to the burden of fossil resource depletion.

In general, the results suggest that material choice alone is insufficient to minimize fossil resource depletion in urban construction. Instead, a combined strategy is needed, including adopting alternative manufacturing technologies, renewable energy sourcing for material production, and a strategy throughout the supply chain to reduce fossil fuel dependency across all life cycle stages.

4 Discussions

4.1 Generic vs. specific unit process data and results

More specific unit process data and results are available for certain elements of the Poppies district. For instance, the cross-laminated timber (CLT) used in the construction of the housing modules supplied by Derix is documented with a specific Environmental Product Declaration (EPD). Additionally, unit process data for several construction materials relevant to the Dutch market, such as concrete and steel, are accessible through the NMD process database[3]. However, these data sources were not incorporated into this study for two main reasons. First, there was a mismatch in the background database versions: this study relies on the EcoInwent cut-off v3.9.1 database, whereas the Nationale Milieu database, at the time of analysis, was linked to earlier EcoInwent versions. Second, as in the case of the CLT EPD, only cumulative life cycle impact assessment (LCIA) results were available (e.g. without the LCA model based on unit processes), and these results were produced using EcoInwent cut-off v3.4.

Using generic instead of specific unit process data compromises the accuracy of the results. For reference, the life cycle global warming potential result for CLT from the EPD provided by Derix is 104 kg/m^3 of unit product, whereas, in this study, the generic process producing CLT has a life cycle global warming potential of 140 kg/m^3 of unit product. However, mixing different background database versions in one system must be avoided because it introduces inconsistencies and affects the reliability of the results. On the other hand, it should be noted that Derix also offers CLT products with a "take-back guarantee," promoting the reuse of materials after their end-of-life in buildings [4]. This initiative aligns with circular construction principles and can potentially reduce environmental impacts. The cumulative environmental impact data for these CLT products is accessible through the Nationale Milieu database (NMD) viewer [5]. It's important to note that the EPD result referenced in this section pertains to CLT without this take-back guarantee. Incorporating CLT into future studies could provide insights into further environmental benefits.

To extend the discussion on integrating Dutch-specific datasets into this study, it's important to note recent developments in the NMD. The latest NMD process database (as of writing is NMD v3.9) offers integration with EcoInwent v3.9.1, specifically utilizing the "Allocation, cut-off, EN15804" system model from EcoInwent. This model aligns with the EN15804+A2 standard, which is essential for EPDs in the European construction sector. However, this differs from the "Allocation, cut-off by classification" system model employed in this study. Therefore, incorporating Dutch-specific datasets from the NMD would necessitate migrating the background database from EcoInwent v3.9.1 "Allocation, cut-off by classification" to EcoInwent v3.9.1 "Allocation, cut-off, EN15804" to maintain methodological consistency.

Furthermore, integrating EPDs for specific materials requires access to the underlying LCA models composed of unit processes upon which these EPDs are based. Often, EPD reports provide only aggregated life cycle impact assessment (LCIA) results without detailed unit process data. Without access to these detailed models, it's challenging to harmonize the EPD

[3] https://milieudatabase.nl/en/database/process-database/
[4] https://derix.de/en/services-engineered-timber-construction/lexicon/ruecknahmeverpflichtung/
[5] https://milieudatabase.nl/nl/database/over-de-viewer/

data with the existing LCA framework, potentially compromising the accuracy and reliability of the assessment.

In summary, while the inclusion of Dutch-specific datasets and EPDs could enhance the specificity of the LCA, it would require careful consideration of methodological alignment and access to detailed unit process data to ensure the integrity of the results.

4.2 Scaling PED LCA to City-level

As discussed in Sections 2.2 and 3.2, Positive Energy Districts (PEDs) are emerging as a central concept in sustainable urban development initiatives within the EU. Life Cycle Assessment (LCA) offers a robust framework to evaluate the environmental performance of such districts. However, scaling the LCA approach from district-level demonstrations to entire urban areas introduces substantial challenges, primarily due to limitations in data availability.

Urban environments are inherently complex, characterized by diverse building typologies, infrastructure systems, and socio-economic dynamics. The data and assumptions applied for the LCA of Poppies, while appropriate for a district-scale analysis, are not directly transferable to heterogeneous urban contexts without substantial data collection, such as detailed LCI of buildings. Such granularity is rarely available across an entire city. Energy performance certificates and operational building assessments offer a potential pathway for scaling up and providing valuable data on the building envelope, energy infrastructure and operational energy use [31]. However, data privacy concerns often restrict access to such data.

Moreover, Poppies represents a newly developed district, while the broader Amsterdam building stock is predominantly composed of existing, often old buildings. Transitioning existing districts into PEDs requires fundamentally different strategies and interventions compared to planning for new developments. These retrofits and transformations of existing buildings fall outside the scope of the Poppies case study.

Another significant barrier is the integration of spatial and temporal dynamics at the city scale. Recent studies [17][32] emphasize that capturing the evolving nature of energy systems, mobility patterns, and material stock flows demands advanced, dynamic modelling frameworks that extend beyond traditional static LCA methods. While a preliminary framework as a foundation to address these dynamics was outlined in this report (i.e. the LCI of Poppies in this study is Brightway2-compatible, and Brightway2 has advanced features and extended packages to support regionalized and dynamic LCA (bw_temporalis) given additional data), its full implementation was not feasible due to the aforementioned data limitations.

Institutional and operational challenges further complicate the integration of LCA into urban planning. Embedding LCA practices within municipal governance requires coordination across planning agencies, alignment of tools and methodologies, and substantial capacity building among stakeholders. Without strong policy mandates, the development of accessible, user-friendly frameworks, and the required data, the practical application of LCA in the planning and realization of PEDs at the city-scale is likely to remain limited.

5 Limitations and Outlook

5.1 Limitations

While this study offers a comprehensive LCA of the Poppies district in Amsterdam, several limitations must be acknowledged.

A significant limitation in this study is the absence of dynamic modelling during the operational phase. The assessment relies on static assumptions for energy consumption, maintenance cycles, and system performance across the defined 50-year timeframe. This simplification fails to account for potential variations arising from technological advancements, changes in user behaviour, climate variability, and the ongoing decarbonization of the electricity grid. Moreover, the analysis does not capture short-term temporal fluctuations in grid electricity supply, such as hourly or seasonal variations in the share of renewable energy, which are inherent to intermittent energy sources like solar and wind. For example, certain hours of the day or periods of the year feature a higher proportion of renewable electricity, leading to lower GHG emissions of grid supplies. Such granular, time-resolved data is available from platforms like Electricity Map [30], which could improve the accuracy of operational impact assessments. As noted in Section 1.4.2, the operational phase was modelled using projected values from the project proposal, which may not reflect actual performance dynamics over time. Integrating dynamic LCA approaches—including time-dependent energy mixes, real-time grid carbon intensity, and adaptive building operation strategies—would enhance the robustness and relevance of long-term environmental impact estimates.

Another limitation stems from using a generic background database (EcoInwent v3.9.1) for certain processes, particularly for building material supplies and end-of-life disposal treatments. While the open-source LCA framework developed in this study enhances transparency and reproducibility, it remains dependent on the availability and quality of input data, which may not always reflect the actual local conditions.

Additionally, certain environmental impacts, such as those related to biodiversity loss or social dimensions of sustainability, fall outside the scope of standard LCA methodologies like EF v3.1 and were therefore not assessed.

Despite these limitations, a key strength of this study lies in developing and applying a transparent, open-source LCA framework for assessing urban districts. By openly sharing the methodological structure, datasets, analytical workflows, and result visualization, this framework provides a flexible foundation for continuous improvement and adaptation. It allows future researchers, practitioners, and policymakers to build upon the existing work, integrating more detailed and context-specific data as it becomes available. For example, dynamic operational modelling—such as incorporating real-time grid carbon intensity or adaptive maintenance schedules—can be readily implemented within the current framework without requiring a complete redesign. Similarly, as region-specific datasets or enhanced background inventories emerge, they can replace generic assumptions to reflect local conditions better. Furthermore, the open-source nature of this approach creates opportunities to expand beyond the current system boundary, enabling future integration of additional impact categories, such as biodiversity impacts, ecosystem services, or social sustainability metrics. In this way, while the present study acknowledges certain methodological constraints, it also establishes a scalable and adaptable framework that encourages future refinement, collaborative development, and broader application in pursuing more comprehensive and context-specific sustainability assessments for urban districts.

5.2 Outlook

Addressing these limitations will require a combination of methodological improvement, data integration, and policy support. Advancing dynamic and spatially explicit LCA models tailored for urban systems is critical to reflect real-world complexities and temporal evolutions. Future studies should explore coupling LCA with tools such as GIS, urban metabolism models, and energy system simulations to enhance scalability.

Moreover, expanding open-source frameworks like the one demonstrated in this study, especially by including a more user-friendly interface, can facilitate broader adoption by municipalities and planners. This also includes developing parameterized datasets, which are commonly required by sustainable urban districts, improving interoperability with urban digital platforms, and fostering collaborative data-sharing environments.

On a strategic level, aligning LCA practices with EU initiatives and targets such as the European Green Deal, the 100 Climate-Neutral Cities Mission, and evolving PED programs will be essential. Embedding life cycle thinking into urban policy frameworks, supported by regulatory incentives and capacity-building efforts, can accelerate the transition towards sustainable, climate-neutral cities.

In conclusion, while this study demonstrates the value of LCA in assessing and guiding sustainable district development, realizing its full potential at scale will depend on overcoming methodological, operational, and institutional barriers through coordinated research, innovation, and governance.

6 Conclusions and Recommendations

6.1 Summary of Key Results

This study has provided a comprehensive LCA of the Poppies district in Amsterdam, a demonstration PED designed around circular construction principles, renewable energy integration, and social inclusivity. The LCA covered 50 years and evaluated life cycle GHG emissions, non-renewable primary energy demand, and a broad spectrum of environmental impacts through the Environmental Footprint method. The analysis revealed that the total life cycle GHG emissions exceeded 3 million kg CO_2-equivalents. Embodied GHG emissions from construction materials, particularly concrete and timber, emerged as the dominant contributors to environmental impacts. Although Poppies benefits from energy-efficient operations and renewable electricity supply, the production of construction materials remained the largest source of non-renewable primary energy demand and GHG emissions. Geographically, the majority of GHG emissions originate from generic global supply chains, as well as from European countries and China, underscoring the need to address GHG emissions beyond the territory boundary of the district. Manufacturing solar PV systems, despite their operational benefits, also contributed substantially to non-renewable primary energy demand due to their fossil-fuel-intensive upstream supply chains. The EF results further highlighted land use and fossil resource depletion as major impact categories, with significant burdens associated with major construction materials (i.e., wood-based materials, concrete, steel, etc.) used in the buildings.

Beyond the environmental results, a key contribution of this study was the development of a transparent, open-source LCA framework based on Brightway2 and Excel-input inventories that can be applied to the LCA of any other urban districts. This approach ensures full reproducibility and allows for easy adaptation of the methodology to other urban contexts. Interactive visualizations enhance the usability of the results and provide a basis for evidence-based decision-making in sustainable urban development.

6.2 Recommendations for Stakeholders

The insights from this assessment point to several important recommendations for stakeholders engaged in sustainable urban development.

For urban planners and municipalities, the results reinforce the need to prioritize low-carbon materials and circular design strategies early in the planning process. Since embodied GHG emissions dominate the life cycle impacts in energy-efficient districts like Poppies, planners should focus on reducing material demand, substituting high-impact materials, and enabling reuse both in the construction phase as well as in the planning of end-of-life decommissioning of buildings (e.g., modular design for easy re-use or -adaptations). Embedding life cycle thinking into procurement procedures and design standards can support these goals and ensure more sustainable outcomes.

Policymakers and EU program administrators should support harmonizing and integrating LCA practices in urban development policies, especially within high-level policy frameworks like the European Green Deal and the 100 Climate-Neutral Cities Mission.

For architects and developers, closer engagement with material suppliers to obtain specific EPDs and their underlying models consisting of unit process data is crucial for more accurate environmental assessments. Adopting supplier-level circularity initiatives, such as suppliers' take-back guarantee for cross-laminated timber, could offer additional environmental benefits and align with emerging regulations on circular construction. Strategies that reduce dependence on generic datasets while improving traceability of impacts through supply chains can substantially improve the transparency of accuracy of environmental performance for future developments.

Finally, LCA practitioners and researchers are encouraged to build on the open-source framework demonstrated in this study. The framework allows for the further integration of methods and data, such as dynamic energy modelling and region-specific LCI to better reflect the spatial and temporal complexity of urban systems. Continued development of flexible, transparent tools is critical to scaling the use of LCA from single buildings to city-wide applications. By addressing current methodological and institutional limitations, and promoting cross-stakeholder collaboration, city planners and designers can better leverage LCA to guide the transition toward more sustainable urban district developments.

7 Acknowledgement

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Annex 1. Normalization factors of EF 3.0

LCIA Methods	Unit	NF
Acidification	mol H+ eq./person	55.569541
Climate change	kg CO2 eq./person	7553.083163
Ecotoxicity, freshwater	CTUe/person	56716.586337
EF-particulate matter	disease incidences/person	0.000595
Eutrophication, freshwater	kg P eq./person	1.606852
Eutrophication, marine	kg N eq./person	19.545182
Eutrophication, terrestrial	mol N eq./person	176.755000
Human toxicity, cancer	CTUh/person	0.000017
Human toxicity, non-cancer	CTUh/person	0.000129
Ionising radiation	kBq U-235 eq./person	4220.163390
Land use	pt/person	819498.182923
Ozone depletion	kg CFC-11 eq./person	0.052348
Photochemical ozone formation	kg NMVOC eq./person	40.859198
Resource depletion, fossils	MJ/person	65004.259664
Resource depletion, minerals and metals	kg Sb eq./person	0.063623
Water use	m3 water eq of deprived water/person	11468.708641

https://eplca.jrc.ec.europa.eu/permalink/EF3_1/Normalisation_Weighting_Factors_EF_3.1.xlsx

Annex 2. Weighting Factors (WF) of EF 3.0

	WF [%]
LCIA Methods	
Acidification	0.0620
Climate change	0.2106
Ecotoxicity, freshwater	0.0192
EF-particulate matter	0.0896
Eutrophication, freshwater	0.0280
Eutrophication, marine	0.0296
Eutrophication, terrestrial	0.0371
Human toxicity, cancer	0.0213
Human toxicity, non-cancer	0.0184
Ionising radiation	0.0501
Land use	0.0794
Ozone depletion	0.0631
Photochemical ozone formation	0.0478
Resource depletion, fossils	0.0832
Resource depletion, minerals and metals	0.0755
Water use	0.0851

https://eplca.jrc.ec.europa.eu/permalink/EF3_1/Normalisation_Weighting_Factors_EF_3.1.xlsx