Global Warming Potential of City Districts – a case study in Sweden

Jorik Wolters[1], Simon Kallioinen[2], Maryam Fakhari[1], Johan Holmqvist[3] and L. Ricardo Bernardo[1]

1 Lund University, Lund (Sweden)

2 Fojab Architecture, Stockholm (Sweden)

3 The Swedish Environmental Institute, Malmö (Sweden)

Abstract

The European Union aims to achieve climate neutrality in 2050, 23 cities in Sweden aim to reach that goal already by 2030. A new city district in southern Sweden is being developed with the goal of achieving near net-zero carbon emissions. This study evaluates its first completed construction phase and aims to draw learning outcomes to lower carbon emissions for the remaining upcoming construction phases. An urban energy modelling approach was applied using open access databases to create 3D building energy models and estimate global warming potential over the entire life cycle. Results for seven multi-family buildings show that the average global warming potential for the construction stage (A1 to A5) was estimated to be 360 kg CO_2e/m^2 gross floor area. This value is close to the national average (375 kg CO_2e/m^2) which is still far from net-zero carbon goals. The workflow shows potential for replication on early-stage planning which supports science based urban design towards lower carbon emissions.

Keywords: climate impact, global warming potential, city districts, climate neutral

1. Introduction

Achieving climate neutrality in the built environment requires a fundamental shift in how cities design, construct, operate, and renew their buildings. In Europe, the building sector is responsible for roughly 40 % of total energy use and 36 % of greenhouse-gas (GHG) emissions, making it central to the EU Green Deal and the Energy Performance of Buildings Directive ("Energy Performance of Buildings Directive," 2024). In Sweden, the government has committed to national climate neutrality by 2045, while the "Viable Cities" initiative unites 23 municipalities aiming for net-zero emissions already by 2030 ("Viable Cities," 2021). Among them is Helsingborg, which has embarked on the development of *Oceanhamnen*, a new waterfront district intended to lead the way towards climate-neutral urban construction (Helsingborg, 2023).

1.1. Background and context

Oceanhamnen forms part of Helsingborg's broader vision to transform 600 hectares of former industrial land into mixed-use neighbourhoods with healthy indoor environments, renewable-energy systems, and nearly net-zero carbon ambitions (Fig. 1). Construction of Phase 1 was completed in 2022 and includes six major buildings: five residential blocks and one mixed hotel/office building with a combined area exceeding 50 000 m². Phase 2, started in 2023, adds further dwellings and a distinct architectural typology. This staged development provides a unique opportunity to evaluate actual climate performance iteratively and draw learning outcomes for future phases.

1.2. Policy drivers and regulatory framework

As within the rest of EU, the Swedish building regulatory framework has evolved rapidly. The Swedish building code specifies minimum energy performance standards, while the Act on Climate Declarations (entered into force in 2022) requires developers to quantify life-cycle CO_2 emissions for the construction stage (A1 – A5) for all new buildings ("Boverkets byggregler (2011," n.d.; "Climate Declaration of Buildings in Sweden," 2025). Simultaneously, the newest revision of EPBD mandates Member States to include whole-life-carbon assessment, embodied-carbon thresholds, and deep-renovation roadmaps in their national building-renovation plans. Together these frameworks mark a shift from energy efficiency alone toward comprehensive climate accountability.

1.3. Research motivation and gap

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Despite the proliferation of LCA tools, most existing methods are designed for detailed design stages of individual buildings and require extensive data entry, rendering them impractical for early urban-planning use. While various initiatives have emerged to harmonize building-level carbon accounting, similar work is only beginning at the district scale (Togerö et al., 2023; Uppenberg et al., 2023). Few approaches allow planners to estimate district-scale carbon impacts quickly enough to influence zoning, tendering, or material choices. Recent research has highlighted this gap and called for semi-automatic, open, and adaptable methods that combine spatial modelling with national LCA databases (Budig et al., 2021; Torabi, 2024). This study contributes to this need by testing an urban-modelling workflow based on open data to the real-world case study of *Oceanhamnen*.

1.4. Objectives

This research aims at 1) quantifying embodied (A1 – A5) and operational (B6) carbon emissions for the first construction phase of *Oceanhamnen*; 2) drawing learning outcomes that promote lower carbon emissions for upcoming construction phases; 3) testing a replicable workflow for early-stage district assessment of life cycle carbon emissions.

1.5. Contribution

The paper contributes a complete, transparent case of testing urban modelling and LCA analysis using Swedish open-data sources to an urban district, bridging the gap between national policy targets and project-level practice. The workflow demonstrates how municipalities can screen new developments for carbon performance using publicly available data and limited manual input supporting evidence-based climate requirements in future projects.

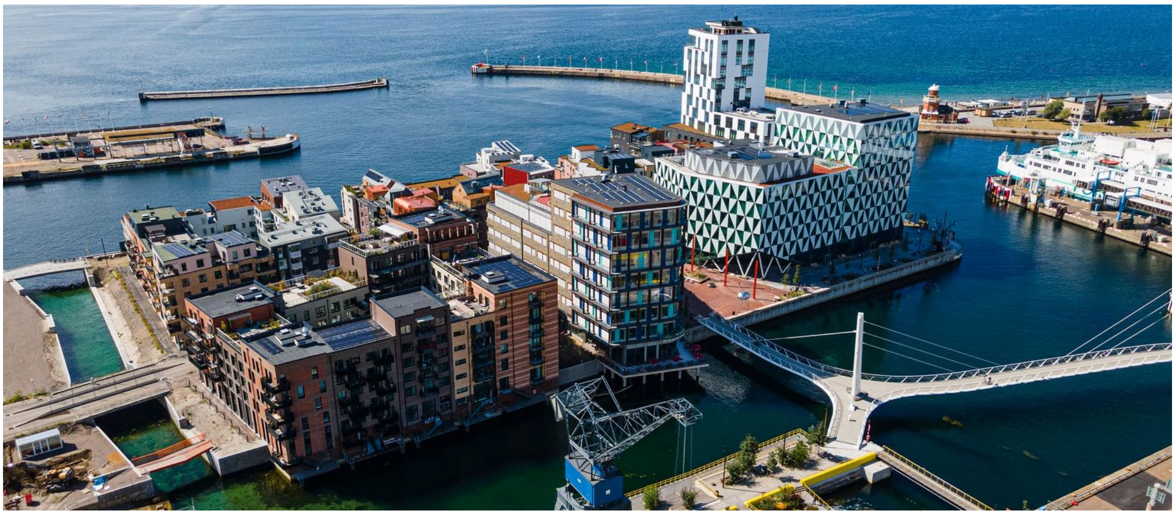

Fig. 1: Photograph of the first construction phase of a new city district in South Sweden, Helsingborg.

2. Method

2.1. Overview

A quantitative, semi-automatic urban energy-modelling approach was implemented and tested to calculate carbon emissions of buildings within a new city district. The method integrates three open-source data types: (1) urban development plans, (2) national building construction databases, and (3) energy performance certificates. It combines Rhinoceros® for 3D modelling, Grasshopper® for parametric processing, and *LCAnt*, a Grasshopper plug-in developed by The Swedish Environmental Institute and partners within previous research projects (“Climate-smart building design in the early stages,” 2024; “Grasshopper - algorithmic modeling for Rhino,” n.d.; “Grasshopper - algorithmic modeling for Rhino,” n.d.).

2.2. 3D geometry and data inputs

Urban plans supplied maximum footprints, heights, and land-use zones for each plot. These were translated into 3D massing models in Rhinoceros®, representing the approximate building volumes allowed by the plans. Each building was then assigned a function (residential, office, hotel, mixed use) and typical window-to-wall ratios (WWR) ranging from 0.25 to 0.43 depending on building typology, orientation and storey height. The resulting parametric model served as the spatial framework for quantifying material volumes and associated emissions (Fig. 2).

2.3. Embodied-carbon calculation

The embodied carbon emissions were computed for modules A1 – A5 (product and construction stage). The *LCAnt* tool maps geometric entities to standard Swedish construction typologies, such as reinforced-concrete frames, hollow-core slabs, timber roofs, and light-frame walls, sourced from a LCA software ("Building Sector LCA Calculator (BM)," 2025) assessing a national climate database. For each element category (basement, load-bearing structure, external walls, roof, room formation) the tool multiplies quantities by cradle-to-site emission factors (kg CO_2e per m² element). Where data gaps existed (e.g., staircases or balconies), additional emissions from the national database were applied manually. Validation of this semi-automatic carbon emission modelling was performed against one building built in Phase 2 where a detailed Climate Declaration exists.

2.4. Operational-carbon calculation

Operational carbon emissions (module B6 of LCA) were derived from Energy Performance Certificates. The certificates specify delivered energy for heating, cooling, and domestic hot water via district heating and electricity. Swedish average emission factors were used: 0.056 kg CO_2e/kWh for district heating and 0.037 kg CO_2e/kWh for electricity, constant along time. On-site solar PV generation was accounted for based on production and self-consumption ratios (58 % self-use, 42 % export). The operational carbon for each building was then computed for a 50-year reference study period.

2.5. Assumptions and limitations

The workflow prioritizes speed and replicability over detail. It does not model non-building elements such as streets or parks and excludes life-cycle stages B2–B5, C, and D. Despite these limitations, the approach captures the dominant greenhouse gas sources in new construction aiming for comparative assessment between districts. Uncertainty analysis indicates that variations in structural system and extent of basement are the largest drivers of error (±15 %).

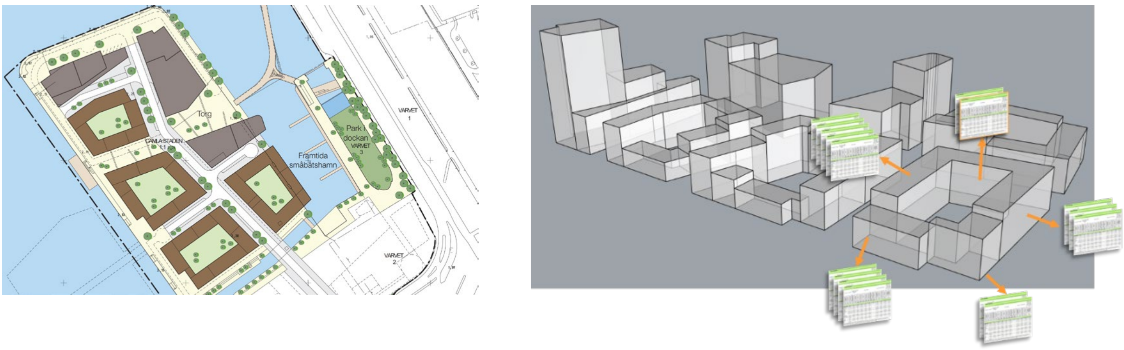

Fig. 2: 2D floor plans to the left and 3D geometries populated with CO_2 and energy use attributes to the right.

3. Results

3.1 Embodied carbon results

The average global warming potential for LCA stages A1 to A5 for all buildings was estimated to be 360 kg CO_2e/m^2 gross floor area, corresponding to a total of 21 540 t CO_2e. Values ranged from 308 to 390 kg CO_2e/m². Figure 3 shows the distribution across different buildings and Figure 4 shows the distribution across building elements. The load-bearing structure accounts for ≈ 48 % of total embodied carbon emissions, basements ≈ 21 %, external walls ≈ 16 %, roofs ≈ 7 %, and room formation ≈ 8 %. Solar panels contribute < 1 % (Fig 3 and Fig 4).

Comparison with national reference values (Malmqvist et al., 2021) shows good alignment: the Swedish average for multi-dwelling buildings is 375 kg CO_2e/m² (A1–A5). The case study's comparable values reflect its concrete-intensive design and basements spanning shared courtyards.

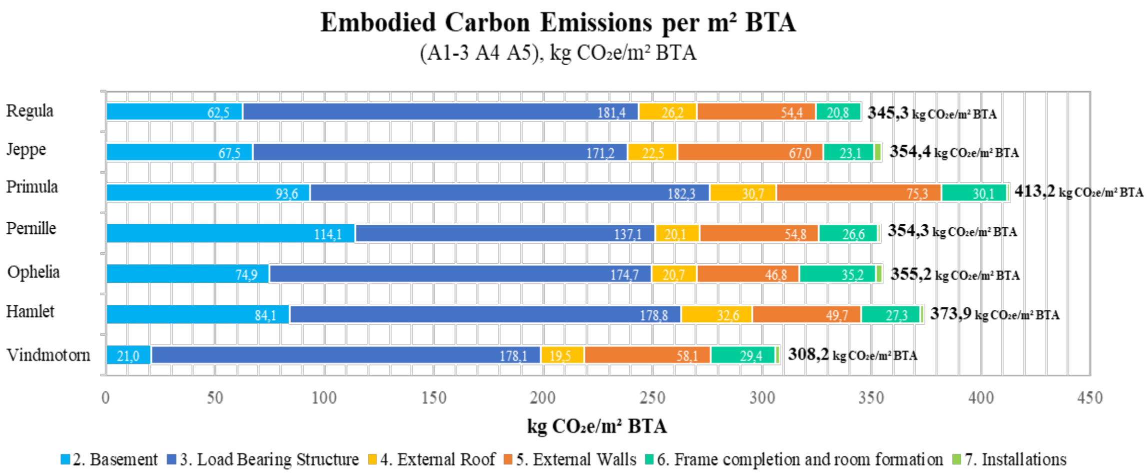

Fig. 3: Results of carbon emissions for LCA stages A1 to A5 per gross floor area and building.

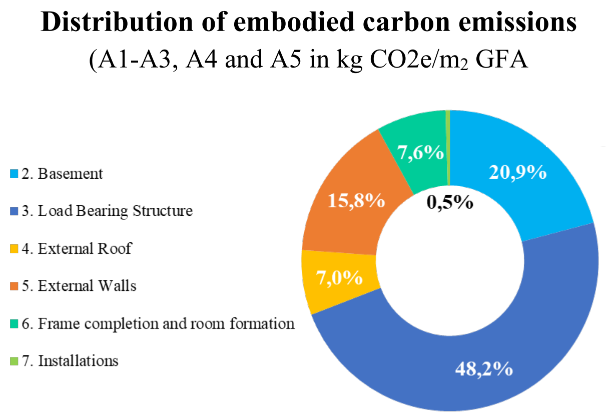

Fig. 4: Results of carbon emissions for LCA stages A1 to A5 for different parts of the building.

3.2 Validation of workflow

For the building called *Vindmotorn*, the modelled A1–A5 result of 308 kg CO_2e/m^2 differs by 14.9 % from its detailed Climate Declaration (362 kg CO_2e/m^2). Discrepancies mainly stem from roof-type simplifications and window assumptions. After refinement using the national database of carbon emissions for building elements, the difference narrows to < 10 %, illustrating that the urban modelling tool *LCAnt* can be valuable in estimating LCAs in early design stages.

3.3 Operational carbon results

The average operational carbon emissions over 50 years was 158 kg CO_2e/m^2 GFA, equating to 10 112 t CO_2e. Overall, electricity accounts for 13% of total operational carbon emissions, while district heating contributes 88%. Individual buildings showed specific energy uses (final energy) between 53 and 68 kWh/m² per year. PV generation reduced electricity impact by 5 – 10 %. Compared to international benchmarks, these values are low due to Sweden's clean energy mix, yet they remain significant relative to the district's net-zero aspiration.

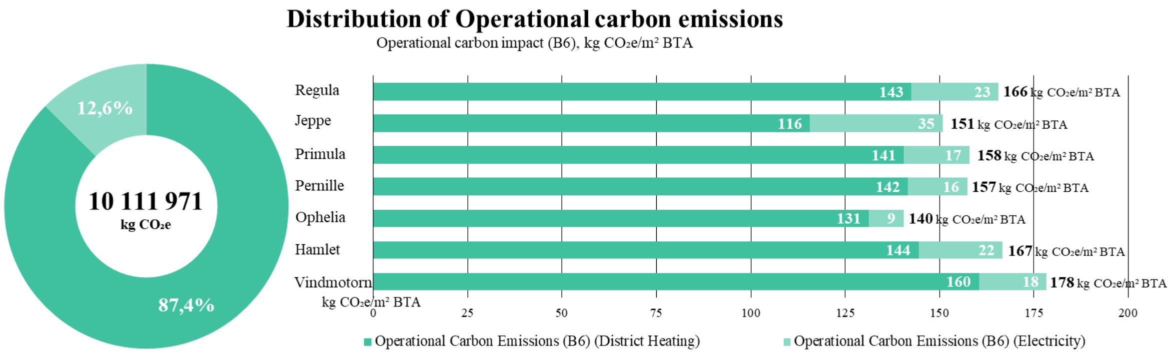

Fig. 5: Distribution of operational carbon emissions per gross floor area and building.

3.4 Combined life-cycle impact

When combining embodied and operational carbon emissions, the total climate impact of the buildings reaches almost 31 652 t CO_2e, with a clear concentration of values within the range 490-570 kg CO_2e/m^2 gross floor area. Embodied carbon constitutes ≈ 69 % of this total, with the remaining ≈ 31 % being operational carbon emissions. This confirms that embodied emissions dominate the carbon profile of new buildings, especially in regions with low-carbon energy supply despite Sweden's cold climate.

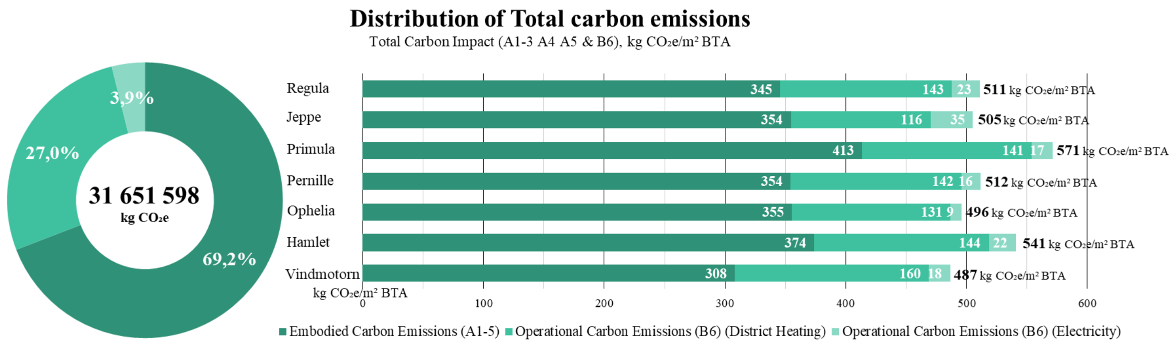

Fig. 6: Distribution of total carbon emissions per gross floor area and building.

4. Discussion

4.1. Interpretation and hotspots

The dominance of the load-bearing structure in the total embodied carbon emissions (48 %) highlights the critical importance of material choice. Preliminary investigations indicate that replacing reinforced concrete with hybrid or timber structures could reduce embodied carbon emissions by ≈ 30 % but living area would be reduced due to thicker walls. Basements represent the second largest source and offer opportunities for optimization: partial basements or shared utility spaces could halve the impact without affecting functionality significantly. Envelope materials and window to wall rations (WWR) also deserve attention, as large glazing increases both embodied and operational loads.

4.2. Comparative perspective

When benchmarked against similar Scandinavian developments, *Oceanhamnen*'s average A1–A5 emissions (360 kg CO_2e/m^2) align with Sweden's national average (375 kg CO_2e/m^2) but remain higher than timber-framed districts (≈ 250 kg CO_2e/m^2). The results show therefore comparable values to those of contemporary Swedish baseline.

4.3. Methodological reflection

Early-stage LCA inevitably balances speed and accuracy. This study shows that standardized datasets combined with open geometry can deliver reliable screening results within ±15 % of detailed LCA calculations (Climate Declaration), adequate to guide decisions on structure, material, and energy concepts before design lock-in.

5. Conclusions

This study illustrates the potential of using urban energy modelling with open databases to effectively quantify life cycle carbon emissions at the district scale. Results from the first construction phase show that the average value for global warming potential of life cycle assessment stages A1 to A5 of seven multi-family buildings was estimated to be 360 kg CO_2e/m^2 gross floor area. Roughly two-thirds of total emissions originate from materials and construction. Low-carbon structural systems and basement reduction offer the largest potential savings. Embodied carbon calculated within this city district is below but close to the national average, highlighting the gap to net-zero carbon emissions. The applied workflow offers a replicable method that can support early-stage design decisions toward lower carbon emissions. The approach contributes to science-based, scalable strategies for climate-neutral urban development.

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