



Sustainability beyond buildings: Assessing environmental impacts of Swedish urban life using LCA and emergy indicators

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ABSTRACT

As cities continue to grow, understanding the full scope of environmental impacts associated with urban living becomes increasingly critical to ensure sustainable development and the fulfilment of ecological goals. This study integrates Life Cycle Assessment (LCA) into the Emergy Synthesis (ES) framework, generating a hybrid EmLCA method to assess environmental footprint of urban life, offering a holistic analysis of both material and service-related impacts. Using a Swedish residential complex as case study, results show that lifestyle factors, such as meat consumption, fast fashion, and private car use, are major contributors to climate change, eutrophication, acidification, and resource depletion, while the built environment accounts for only 1–2 % of total impact. These findings challenge the conventional sustainability aspects such as construction materials and energy use, underscoring the need to also address consumption patterns and societal systems that shape urban life. The inclusion of services, despite certain limitations, offers a broader and more realistic perspective on urban sustainability. This study highlights the importance of supporting sustainable lifestyles through policies that promote shared resources, reduce reliance on private vehicles, and encourage shifts toward less resource-intensive diets. By moving beyond the building envelope, the EmLCA approach offers valuable insights for urban planning and policy aimed at reducing emissions and fostering more sustainable cities.

1. Introduction

Urban sustainability faces critical challenges; this is no secret. Modern cities rely on continuous and substantial flows of biophysical resources, and their high-throughput nature generates substantial negative externalities affecting both nature, ecosystems, and human well-being (Pincetl, 2012; Taylor and Howden-Chapman, 2021). As global resource pressures intensify, interest in urban sustainability has grown rapidly (Teixeira Dias et al., 2022; Cai et al., 2023; Herath and Bai, 2024). However, much of this research tends to isolate upstream resource inputs from downstream environmental and social impacts, resulting in fragmented analyses that may misguide policy and intervention priorities. With the global population expected to rise by approximately 60 % by 2050 (Kii, 2021), improving the sustainability performance of urban life is essential. This extends beyond infrastructure and raw material inputs and includes how cities manage resource flows, such as food, consumables, and social services, to support

growing populations efficiently.

Urban areas hold a promising potential for sustainable development; however, there is an urgent need to quantify the current impact and identify hotspots to promote suitable actions for urban sustainability. The environmental footprint of urban living varies substantially depending on region, lifestyle, and consumption habits (Bossek et al., 2021). Yet, across contexts, consumption and transport often yield higher per capita impacts than the built environment (Ritchie and Roser, 2024). This can be attributed to the intensive resource use and short lifespans of consumer goods, such as food and clothing. In response, an increasing number of cities are adopting integrated urban food strategies aimed at enhancing sustainability and resilience (Filippini et al., 2019; Sonnino, 2023). While renewable energy, green materials, and energy-efficient technologies are often emphasized as pillars of sustainable urbanism (Parekh and Smith, 2024), equally important are the social and systemic design features that connect resource use to community well-being. Since the development and maintenance of cities are

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fundamentally dependent on biophysical resources, including both living organisms and non-living elements, systems theorists have stressed the importance of holistically accounting for these aspects (Odum and Odum, 2006). As suggested by Papageorgiou et al. (2024), accounting for the environmental pressures related to material and energy use in urban cities is crucial both to avoid burden shifting and to allow a more holistic assessment of the system. Determining total system sustainability thus calls for the combined assessment of upstream and downstream aspects, such as coupling emergy synthesis with life cycle assessment (Ingwersen, 2011).

Emergy synthesis (ES) is a method first developed by Odum (1996), focusing on systems analysis and environmental accounting that emphasizes resource use associated with, for example, human and ecological systems (Tilley et al., 2000; Brown and Ulgiati, 2004). Applied in studies of urban systems, ES can be used to identify and quantify the environmental cost of inputs needed for e.g., the built environment, transportation, food, and private consumption (Viglia et al., 2018; Lee and Braham, 2020; Alkhuzaim et al., 2021). Using emergy synthesis to assess for the impact of construction and daily life in Uppsala, Sweden, Bergquist et al. (2020) found that long-distance travel, hygiene products, and meat consumption were major contributors, while the built environment and societal services also had substantial effects on total emergy impact. Using a multi-criteria framework for assessing urban socio-ecological systems for the case study of Austria, Galychyn et al. (2022) found a similar trend for services needed to support urban life, such as healthcare, education, and infrastructure, via national monetary expenses and supply data. While the emergy approach primarily focuses on direct and indirect resource use, it can be considered as a relatively weak method for assessing external effects such as emissions and environmental impact (Wang et al., 2020). To address such limitations, several hybrid frameworks have been proposed to better capture the complexity of socio-economic and environmental interactions, such as combining ES with Life Cycle Assessment (LCA). LCA is a systems analysis method developed to assess environmental performance and integration of environmental issues caused by a specific process or product (de Souza Junior et al., 2020; Sporchia et al., 2025). In particular, approaches that combine emergy synthesis with life cycle-based methods have been advanced to integrate upstream resource accounting with downstream environmental impacts (Raugei et al., 2014). For example, Rugani et al. (2014) coupled solar energy demand (SED) and ecological footprint (EF) with LCA inventories, while Marvuglia et al. (2013) developed the SCALE software for calculating emergy based on life cycle inventories. Reza et al. (2014) introduced the first Emergy-LCA model (EmLCA), which over the years gained widespread recognition and has been further developed in later work by Zhang et al. (2023). These studies highlight the methodological progress made in bridging resource use with environmental impacts, but also reveal that further development is needed to address the specific challenges of urban sustainability. Building on these insights, the present study applies a straightforward EmLCA approach by adding the LCA dimension to emergy data.

Following the LCA framework, the environmental impacts are ideally calculated from a cradle-to-grave perspective, beginning with the extraction of raw materials and ending with waste management (ISO 14040, 2006a). Along the way, required inputs, such as energy, materials, transport, and resulting outputs, such as emissions, are accounted for (ISO 14044, 2006b). In theory, all aspects of a given system are considered, but in practice, LCA is used to model and describe a simplified version of a complex system (Klopffer and Grahl, 2014). From a critical perspective, LCA emphasizes environmental impacts downstream through a primarily utilitarian and value-based perspective. As argued by Raugei et al. (2014), LCA is thus weaker in terms of addressing the work of ecosystems in 'freely available' resources such as solar and wind energies, rainfall, and soil organic matter. These primary energy flows present a baseline for the productivity of all Earth systems, economic and human systems included, which grounds system activity

within a planetary boundary. The hybrid EmLCA framework applied in this study expands the LCA boundary upstream by incorporating emergy flows, thereby anchoring urban systems within planetary limits. Previous studies have demonstrated the usefulness of similar integration across diverse urban applications, including waste management (Gala et al., 2015), residential complexes (Cui et al., 2021; Wang et al., 2023), urban waterscapes (Dai et al., 2023), ecological sustainable cities (Zhang et al., 2024), paper production (Santagata et al., 2020), and agricultural products (Yongyang et al., 2022). As voiced by Oliveira et al. (2021), there is an urgent need for multi-stakeholder, multi-dimensional, and multi-criteria approaches to assess circular economy transitions. They further stress that individual methods are insufficient, and that integrated tools are required to capture performance across scales and sustainability dimensions. Hybrid EmLCA frameworks have been applied to assess complex systems such as industrial and urban symbiosis, as demonstrated by Ohnishi et al. (2017), and who integrated material flow analysis and carbon footprint with emergy indicators. However, a critical gap remains as no previous studies have, to our knowledge, yet applied EmLCA to assess the built environment and everyday life activities within a specific urban district. Furthermore, the methodological implications of integrating upstream and downstream perspectives remain underdeveloped. As voiced by Liu et al. (2019) and Wang et al. (2020), combining these tools can mitigate the limitations of each, yet there is still a lack of standardized frameworks and applications to urban sustainability.

This paper addresses this gap by advancing the hybrid EmLCA application to a real-world sustainable urban district in Uppsala, Sweden. While Bergquist et al. (2020) previously analyzed the emergy of the same urban district, called *Rosendal*, this paper contributes a new layer by integrating LCA to evaluate downstream environmental impacts. The combined analysis allows for a more complete assessment of urban sustainability, linking resource inputs with emissions and waste from both resource use, infrastructure, and daily human activities. Via inclusion of multiple impact categories (e.g., global warming, acidification, eutrophication, and abiotic resource use), a broader range of environmental aspects can be accounted for, as called for by Oliveira et al. (2021). In doing so, this study (i) advances methodological development of EmLCA by applying it across multiple domains of urban living, and (ii) provides empirical evidence from a certified sustainable neighborhood to identify key hotspots and inform decision-making. This approach provides a more comprehensive systems assessment that includes both upstream resource dependencies and downstream impacts, a much-needed synthesis of system behavior that is absent when the approaches are used in isolation. By combining the two approaches, the scope of the study includes the total resource use and environmental impacts associated with the built environment, as well as those related to the everyday life of the residents, i.e., food, consumables, transportation, and the societal services required to construct and maintain this specific urban lifestyle.

2. Material and methods

This study applies a hybrid Emergy-LCA (EmLCA) approach to evaluate the environmental sustainability of urban living in Rosendal, a certified sustainable district in Uppsala, Sweden. The EmLCA framework used in this work applies the life cycle assessment framework in combination with emergy synthesis to quantify both upstream resource support and downstream environmental impacts of urban living. Building on the work by Bergquist et al. (2020), this study expands their results by introducing the LCA perspective, enabling a more holistic interpretation of environmental trade-offs and sustainability outcomes. Inspired by the method described in previous work, such as Reza et al. (2014), this hybrid approach allows a more comprehensive system assessment than either method alone.

2.1. Goal and scope definition

The goal of the study is to evaluate the environmental performance of urban living at the district level by integrating both upstream (energy-based) and downstream (impact-based) sustainability perspectives. The analysis aims to identify key resource and impact hotspots across infrastructure and daily life. The functional unit was set to *one person per year*, capturing one person's average lifestyle during one year, which enables comparison of environmental performance based on individual lifestyles over time. The system boundary includes production and processing of inputs required to support urban living (see Fig. 1), including materials, energy, food, consumer goods, mobility, and societal services. Outputs such as waste generation and end-of-life processes are excluded from the direct analysis due to data limitations and scope definition. This study also excludes waste treatment, second-hand consumption, and external transportation associated with urban services. However, ES indirectly includes such contributions via the 'services' input category, which accounts for the resource memory of economic activity (e.g., paid labor supporting system maintenance and flows).

2.2. Case study: Rosendal

Rosendal is among the first urban districts in Sweden to be certified by the 'Sweden Green Building Council' (Uppsala municipality, 2016), reflecting its alignment with regional and national sustainability goals. Uppsala's environmental strategy emphasizes reduced climate impact, eutrophication, and acidification, as well as increased resource efficiency (Kjellberg, 2022). These priorities are consistent with Sweden's national environmental objectives and Agenda 2030 commitments (Swedish Environmental Protection Agency, 2018). This study uses one of the apartment complexes, *Smaragden*, in Rosendal as a representative model of the built environment and lifestyle patterns within the district. *Smaragden* was constructed in 2015 and comprises 115 micro-apartments (23–48 m²). At the time of assessment, the complex housed approximately 135 residents (Rosendal fastigheter, 2024). The choice of *Smaragden* as a reference system reflects its representativeness in terms of design, population density, and sustainability ambitions within this urban area.

2.3. Life cycle inventory

The inventory analysis was structured into five core categories reflecting major components of urban life: (1) food and drinks, (2) consumables, (3) transportation, (4) the built environment, and (5) services and monetary expenses. These categories were selected to

comprehensively represent the material and energy demands associated with daily living in an urban district and align with the system boundaries. Primary input data for categories (1) to (4) were calculated and translated to life cycle inventory using the emergy assessment conducted by Bergquist et al. (2020), which provides quantified resource flows specific to the case study area. This included estimates of dietary intake, consumer goods consumption, mobility patterns, and the embodied resources in construction materials and infrastructure. When more recent or case-specific information was available, such as updates in consumption patterns or transport modes, these were incorporated to refine the original data. The fifth (5) category was assessed using national statistics and average expenditure data, converted into emergy values (UEVs) for economic services. These values account for the indirect resource use embedded in institutional and commercial services, including healthcare, education, and public administration. All data were harmonized to reflect the functional unit of one person per year. Where required, data were adjusted for temporal alignment with the population profile of *Smaragden* during the study period.

2.3.1. Food and drinks

The food and drinks category was defined to reflect average Swedish dietary patterns, following the emergy quantification developed by Maassen et al. (2020) for Rosendal. Input quantities for each aggregated subcategory were based on national consumption statistics (Swedish board of Agriculture, 2022). For instance, the subcategory 'cereals' included pasta, bread, rice, and confectionery items, while potatoes were categorized under 'fruits and vegetables'. The environmental impact of specific items not available or representative in databases were modelled using input from previous LCA studies. The impacts of Swedish eggs, non-alcoholic, and alcoholic beverages were sourced from previous LCA studies. The impact of Swedish eggs data was from Estrada-González et al. (2020) and Bartek et al. (2022). Non-alcoholic beverages were assumed to correspond with the impacts of soft drinks, where an average value was used from previous studies, including glass bottles (Nilsson et al., 2011; Amienyo et al., 2013). Similarly, alcoholic beverages were assumed to be equal parts beer and wine, where an average value from previous studies using aluminum cans for beer and glass bottles for wine was assumed (Amienyo et al., 2014; Amienyo and Azapagic, 2016; Hallström et al., 2018). Fish consumption was assumed to consist of equal parts rainbow trout, sustainably harvested marine fish, and processed products (e.g., fish sticks). All meat products were assumed to be produced within Europe under standard practices, following the consumption of each category reported by national statistics. Table 1 illustrates the input quantities of each subcategory. See table A1-A3 in the Appendix for supporting modelling data.

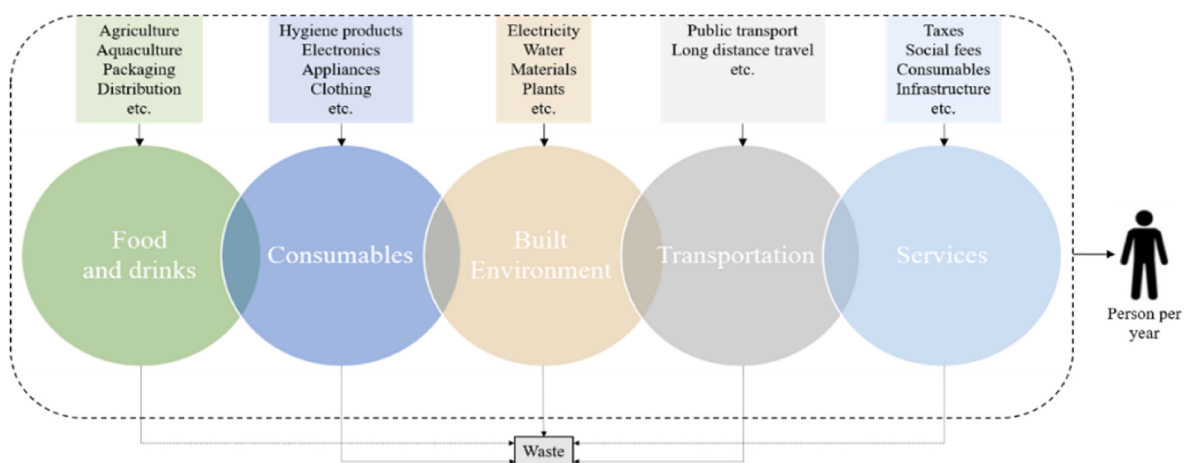


Fig. 1. Illustration of the resources needed to support urban life in *Rosendal*, per person each year. The dashed line represents the system boundary, while the colored areas represent inputs and outputs assessed with the EmlCA approach.

Table 1

Inputs for food and drinks required, expressed per capita each year in *Smaragden*, Rosendal.

Food and drinks	Product	Amount	Unit
Cereals and derived	Wheat	40.2	kg
	Oats	15.1	
	Rice	15.1	
	Sugar	30.1	
Beverages, non-alcoholic	Soft drink	99.0	l
Beverages, stimulants	Coffee	7.5	kg
	Tea	0.5	
Beverages, alcoholic	Beer	23.7	l
	Wine	23.7	
Fruits and vegetables	Tomato, fresh	15.6	kg
	Iceberg lettuce	6.2	
	Potato	71.8	
	Banana	42.1	
	Apple	20.3	
Dairy and eggs	Cow milk	66.3	l
	Cheese	16.8	
	Eggs	15.8	
Fats	Rapeseed oil	8.0	kg
	Butter	5.0	
Fish	Trout	5	kg
	Marine fish	5	
	Fish sticks, frozen	5	
Meat	Beef	8.2	kg
	Pork	12.4	
	Chicken	20.6	

2.3.2. Consumables and transportation

The categories of consumables and transportation include personal and household items, mobility modes, and leisure-related goods. Input quantities were derived from Bergquist et al. (2020) where applicable, complemented by LCA studies for specific products. The contribution from the subcategory ‘hygiene products’ was assumed to mainly correspond with the production of soap, with a smaller contribution from cosmetics products, using impacts calculated by Rocca et al. (2023), foaming agents, and their packaging. An additional 15 kg of toilet paper (Granngårdén, 2021) was included in this category. ‘Electronics and appliances’ were represented through the inclusion of equal amounts, based on mass, of a range of products often found in Swedish households. The lifespan for a smartphone, laptop, and coffee maker was set to five years, respectively, and eight years for a washing machine. Around 14 kg of clothing is used annually per capita in Sweden, and the environmental impact of fashion (including jeans, t-shirts, shoes etc.) was assessed using data from Roos (2017), while an additional 1 kg of complementary textiles was accounted for through the inclusion of woven cotton. Modelling inputs needed for ‘sporting goods and tools’ were split between two types of bicycles, one regular, with an average lifespan of 15 years, and one electric bicycle with a lifespan of 10 years. Transportation distances were used based on Bergquist et al. (2020), using equal amounts for automobile commutes with EURO 5 and electric cars. Public transport was assumed to be represented by regular buses, while both aircraft and trains were included for long-distance travel (Kamb and Larsson, 2019). Inputs required to support the use of consumables and transportation are shown in Table 2.

2.3.3. Built environment

The category ‘built environment’ included materials and energy required for residential living in the Smaragden complex, alongside construction and maintenance flows scaled per capita over the estimated building lifespan and housing density (115 micro-units, 135 residents). The subcategories ‘District heating’, ‘Electricity’, and ‘water’ were sourced from a Swedish consumption mix, using quantifications by

Table 2

Inputs required for consumables and transportation, expressed per capita on a yearly basis.

Consumables	Product	Amount	Unit
Hygiene products	Soap	35	kg
	Foaming agent	5	
	Cosmetics	5	
	Packaging	5	
	Tissue paper	15	
Electronics and appliances	Laptop	9.2	p
	Smartphone		
	Coffee maker		
	Washing machine		
Furniture and utensils	Furniture, wood	2.3	kg
	Mattress	0.1	p
Clothing and textiles	Clothing	14	kg
	Textile, cotton	1	
Sporting goods and tools	Bicycle, regular	0.03	p
	Bicycle, electric	0.05	
Transportation			
Long distance travel	Train, passenger	5538	pkm
	Aircraft, passenger	3692	
Public transport	Regular bus	3390	pkm
Automobile, commute	Passenger car, Euro 5	2070	km
	Passenger car, electric	2070	

Hussein (2016), while a combination of peat, sand, and clay was assumed to represent soil. Mineral wool, including stone and glass, is one of the most common insulation materials for apartment buildings in Europe (Basyigit and Özel, 2003). Both acrylic paint and varnish were used to reflect aesthetic preference and maintenance cycles, while inputs of fruit trees and grass were assumed to represent plants used in the urban setting. The average data for the impact of a lightweight green roof was used based on Bozorg Chenani et al. (2015), which described Nordic conditions. The inputs required to support the built environment were modelled according to quantities specified in Table 3.

2.3.4. Services and monetary expenses

In both ES and LCA, societal services supporting urban life, such as healthcare, education, and infrastructure, were included under the category of services. In emergy synthesis, this was represented by the embodied resources in economic services, following the standard UEV for economic inputs. To obtain a similar representation for the LCA impact, this study deployed a novel calculation approach (equation (1)), to gain an average environmental impact expressed as a function of economic value. Although economic value is preferred on a regional level, this data was not available for the present work, and therefore national values were used and assumed representative for the case study.

Exemplifying using the climate impact, emissions per Swedish krona (SEK) were calculated by dividing Sweden’s total 21 085 ktCO₂e (Swedish Environmental Protection Agency 2024) by the gross national product of 4.96 trillion SEK (Statistics Sweden, 2024), yielding a national average climate impact per SEK spent. The same approach was used for acidification, eutrophication based on nitrogen and phosphorus emissions from 2014 as a proxy for 2024, and abiotic depletion of fossil fuels.

$$\text{Impact per economic value} = \frac{\text{National emission}}{\text{Gross national product}} \quad (1)$$

Acidification was calculated based on the emissions to the air reported by Swedish Environmental Protection Agency (2023) following the Gothenburg protocol, including emissions from agriculture. Emissions from services contributing to eutrophication were calculated based on the reported 3000 tons of phosphorus and 109 000 tons of nitrogen,

Table 3

Inputs required to sustain the built environment in *Smaragden*, Rosendal. Expressed per capita per year.

Built environment	Product	Amount	Unit
District heating	Renewable (wood)	186	kWh
	Non-renewable (waste)	2139	
Electricity	Low voltage	639	kWh
Water	Tap water	58 400	l
Soil	Peat moss	3.5	kg
	Sand	3.5	
	Clay	3.5	
Wood	Plywood, outdoor	0.02	m ³
Concrete and mortar	Concrete	0.45	m ³
	Mortar	56.5	kg
Steel	Steel, low alloyed	2.1	kg
	Steel construction	0.027	m ²
Aluminum	Aluminum alloy	0.4	kg
Copper	Copper	0.4	kg
Iron (electrical)	Solder, bar	0.3	kg
Plastics	Polyethylene, pipe	2.5	m
	Polystyrene, high impact	2.7	kg
Glass	Flat glass, coated	2.5	kg
Paper	Kraft paper	0.3	kg
	Paper sack	0.3	
Insulation	Stone wool	0.15	kg
	Glass wool	0.15	
Paint	Acrylic paint	0.8	kg
	Acrylic varnish	0.2	
Plants	Fruit tree	1	p
	Grass	0.9	kg
Roof	Green roof	0.04	m ²

Table 4

Input data in monetary expenses for services required to sustain urban life, expressed per capita per year.

Services	Amount	Unit
Food	40 000	SEK
Consumables	81 000	SEK
Built environment	54 000	SEK
Transport	27 000	SEK
Taxes and social fees	130 000	SEK

roughly, emitted to water and air during 2014 (Svendsen et al., 2015). Abiotic depletion of fossil fuels was calculated based on the total fossil energy use at national level, which was roughly 345 000 TWh (Swedish Energy Agency, 2018).

2.4. Life cycle assessment

The system modelling was performed using SimaPro 9, employing the Ecoinvent (v3.6) and Agri-footprint (v5.0) life cycle inventory databases. The Ecoinvent Cut-off system model was selected to ensure attributional modelling, excluding the burdens of recycled or reused materials beyond the first user. For Agri-footprint datasets, economic allocation was applied, in line with the default database setting. To reflect site-specific conditions, the study prioritized Swedish or European market datasets when available to approximate regional technology and environmental performance. The impact assessment was conducted using the standardized CML-IA baseline method, which quantifies midpoint indicators including global warming potential (GWP, 100-year time horizon), acidification, eutrophication, and abiotic resource depletion (Dreyer et al., 2003). These impact categories were

selected to collectively cover multiple dimensions essential for informed urban sustainability planning. Emergy analysis provides a systemic perspective on resource use and renewability, while these CML-IA categories allow for quantification of specific environmental burdens, ensuring complementarity and robustness in the overall evaluation framework. All assessed impact categories were expressed in their respective reference units, and the impacts for products described using previous LCA studies were included in Excel when analysing the results.

3. Results

The main results of the LCA indicate that urban living in Rosendal, Uppsala, Sweden, generates approximately 8400 kgCO₂eq per person per year with respect to climate impact, excluding societal services. Regarding the other impact categories, the annual per capita impact were 54 kgSO₂eq for acidification, 20 kgPO₄eq for eutrophication, and 71 000 MJ for abiotic depletion of fossil resources (Table 5). Since the emergy results have been published previously, they are included in all figures and tables for reference, but are not the main focus of this results section.

A closer analysis of the category impact contributions reveals that, within the food and drinks category, the consumption of 'meat' alongside 'dairy and egg', presented the highest and second-highest contributions, respectively, considering all assessed midpoint indicators. Within the consumption category, clothing and textiles were found to have the most prominent impact, followed by hygiene products. Within transportation and the built environment, the use of automobiles per person each year, alongside inputs of concrete and mortar in the built environment, were the highest contributing factors.

The EmLCA signature, in Fig. 2, highlights the substantial role of services in the environmental footprint of urban life across all assessed impact categories. Services contributed 14 % to total global warming potential, the lowest among the categories, but accounted for as much as 91 % of the total emergy and 54 % of abiotic depletion. In the cases of acidification and eutrophication, services contributed 35 % and 16 %, respectively. If services were to be excluded from the analysis, the main contributors to global warming, acidification, and eutrophication would be the categories 'food and drinks', followed by 'consumables'. For abiotic depletion, the highest impacts were associated with transportation and consumables. Notably, the built environment made only a minor contribution, accounting for just 2 % of the total environmental impact of urban life.

4. Discussion

One of the main findings was that three main contributing factors could be identified for all four impact categories, namely meat consumption, fast fashion, and personal travel with car. While these aspects are well-established drivers of environmental impact in broader sustainability research, our study highlights their critical and often underappreciated relevance within the context of urban life specifically. Another important finding was the substantial influence of services on the overall environmental footprint of urban life (Fig. 2). When services were included (top graph), they dominated several impact categories, thus underscoring how upstream societal infrastructure, such as healthcare and education, plays a considerable role in shaping urban environmental impacts, particularly through indirect energy and material flows. On the contrary, when services were excluded (bottom graph), the environmental profile shifted notably. Food and drinks become the dominant contributors to global warming, acidification, and eutrophication, while consumables and transport emerge as the primary drivers of abiotic depletion. The transport and consumables category heavily influenced the impact on fossil abiotic depletion and global warming. Since abiotic depletion of fossil resources is dependent on the extraction of the same petroleum products that release carbon dioxide through combustion, this finding is unsurprising. Moreover, the

Table 5

Emergy and environmental impact for each input category, expressed per capita per year.

	Solar Emergy[Sej]	Global warming[kgCO ₂ eq]	Acidification[kgSO ₂ eq]	Eutrophication[kgPO ₄ eq]	Abiotic depletion, fossil [MJ]
<i>Local renewable inputs</i>					
01 Sun	1.9×10^{10}	–	–	–	–
02 Rain	2.8×10^{11}	–	–	–	–
<i>Food and drinks</i>					
03 Cereals and derived	5.8×10^{13}	1.0×10^2	1.0×10^0	1.0×10^0	7.1×10^2
04 Non-alcoholic beverages	1.9×10^{13}	2.4×10^1	6.9×10^{-2}	5.3×10^{-2}	4.4×10^2
05 Beverage, stimulants	3.5×10^9	5.8×10^1	7.4×10^{-1}	6.6×10^{-1}	3.3×10^2
06 Fruit and Vegetables	7.3×10^{13}	5.0×10^1	5.0×10^{-1}	3.7×10^{-1}	4.9×10^2
07 Dairy and Eggs	9.6×10^{13}	3.5×10^2	4.1×10^0	2.1×10^0	1.4×10^3
08 Beverages, alcoholic	1.7×10^{14}	5.3×10^1	5.3×10^{-1}	1.4×10^{-1}	9.3×10^2
09 Fats	2.4×10^{14}	5.9×10^1	4.1×10^{-1}	3.3×10^{-1}	3.1×10^2
10 Fish	3.6×10^{14}	4.2×10^1	5.1×10^{-1}	2.7×10^{-1}	4.2×10^2
11 Meat	1.2×10^{15}	1.6×10^3	8.0×10^0	6.8×10^0	2.6×10^3
<i>Consumables</i>					
12 Hygiene products	1.7×10^{15}	3.0×10^2	1.2×10^0	3.1×10^0	2.3×10^3
13 Electronics	4.8×10^{13}	9.6×10^1	5.7×10^{-1}	3.0×10^{-1}	1.2×10^3
14 Furniture, etc.	2.0×10^{14}	1.9×10^1	9.7×10^{-2}	7.9×10^{-2}	2.5×10^2
15 Clothing and textile	1.3×10^{14}	3.2×10^3	2.5×10^1	6.5×10^{-1}	2.9×10^4
16 Sporting goods	6.6×10^{14}	1.3×10^1	8.9×10^{-2}	2.9×10^{-2}	1.4×10^2
<i>Built environment</i>					
17 District heating	2.5×10^{14}	1.5×10^0	4.0×10^{-2}	1.4×10^{-2}	1.6×10^1
18 Electricity	1.4×10^{14}	2.8×10^1	1.1×10^{-1}	6.5×10^{-2}	2.0×10^2
19 Water use	1.7×10^{13}	2.0×10^1	1.2×10^{-1}	6.2×10^{-2}	2.3×10^2
20 Soil	2.3×10^{14}	2.8×10^{-1}	1.0×10^{-3}	4.3×10^{-4}	2.3×10^0
21 Wood	7.7×10^{12}	1.0×10^1	6.5×10^{-2}	2.3×10^{-2}	1.6×10^2
22 Concrete & mortar	2.1×10^{15}	7.9×10^1	1.9×10^{-1}	6.7×10^{-2}	3.5×10^2
23 Steel	1.4×10^{13}	3.5×10^0	1.6×10^{-2}	1.2×10^{-2}	3.7×10^1
24 Plastics	4.0×10^{13}	1.7×10^1	6.8×10^{-2}	2.1×10^{-2}	3.7×10^2
25 Glass	2.4×10^{13}	3.0×10^0	2.5×10^{-2}	3.8×10^{-3}	3.3×10^1
26 Aluminum	5.9×10^{12}	4.1×10^0	2.9×10^{-2}	1.7×10^{-2}	4.0×10^1
27 Paint	1.9×10^{13}	2.1×10^0	2.4×10^{-2}	4.6×10^{-3}	3.3×10^1
28 Copper	3.7×10^{13}	1.6×10^0	1.5×10^{-1}	1.1×10^{-1}	1.6×10^1
29 Plants	1.6×10^{12}	1.2×10^{-1}	5.4×10^{-4}	2.1×10^{-4}	1.2×10^0
30 Paper	1.1×10^{12}	6.8×10^{-1}	4.0×10^{-3}	1.8×10^{-3}	8.0×10^0
31 Iron, electric	1.5×10^{12}	5.3×10^{-1}	2.3×10^{-3}	9.0×10^{-4}	5.9×10^0
32 Insulation	4.2×10^{12}	8.1×10^{-1}	4.5×10^{-3}	1.8×10^{-3}	1.1×10^1
33 Green roof	8.6×10^{11}	1.1×10^0	4.3×10^{-3}	1.5×10^{-3}	7.2×10^{-3}
<i>Transport</i>					
34 Long distance	2.2×10^{15}	7.6×10^2	3.3×10^0	1.0×10^0	9.5×10^3
35 Public transport	1.6×10^{14}	3.7×10^2	2.3×10^0	5.6×10^{-1}	5.3×10^3
36 Automobile	1.3×10^{15}	1.1×10^3	4.9×10^0	1.7×10^0	1.4×10^4
<i>Services, monetary expenditures</i>					
37 Food	1.4×10^{16}	1.7×10^2	3.5×10^0	4.5×10^{-1}	1.0×10^4
38 Consumables	2.8×10^{16}	3.4×10^2	7.1×10^0	9.2×10^{-1}	2.0×10^4
39 Built environment	1.9×10^{16}	2.3×10^2	4.8×10^0	6.1×10^{-1}	1.4×10^4
40 Transport	9.1×10^{15}	1.1×10^2	2.3×10^0	3.0×10^{-1}	6.7×10^3
41 Taxes and social fees	4.5×10^{16}	5.6×10^2	1.2×10^1	1.5×10^0	3.3×10^4
<i>Outputs</i>					
42 Urban life excl. services	1.1×10^{16}	8.4×10^3	5.4×10^1	2.0×10^1	7.1×10^4
43 Urban life incl. services	1.3×10^{17}	9.8×10^3	8.3×10^1	2.3×10^1	1.5×10^5

eutrophication emissions were mainly generated by the production of food and drinks, which is closely linked to agricultural activities involving fertilizer use, livestock manure, and food processing, all well-known hotspots for eutrophication. Interestingly, the built environment consistently contributes the least across all impact categories, with its share never exceeding approximately 10 % of impact, and dropping as low as 2 % when services are included. This comparative view demonstrates the added value of a hybrid EmlCA approach, as it reveals not only the direct impacts of lifestyle choices but also the often-overlooked background services that sustain urban living. Important to note, however, is that the present work indirectly estimated service impacts through the concept of "resource memory", which introduces uncertainty as indirect methods risk under- or overestimating hidden resource use. Future studies could address this by integrating direct data support to improve accuracy and account for, e.g., hidden labor consumption. Moreover, since regional economic value was not available for the service calculation, this study employs national values. Future studies

could improve on these calculations by, for instance, applying a regional input-output framework, which better link micro-scale LCA with macro-scale emergy (Arbault et al., 2014).

While the built environment previously has been attributed to approximately 25 % of the total emergy, excluding services (Bergquist et al., 2020), the expanded perspective using LCA in the present study indicate that its contribution to global warming, acidification, eutrophication, and abiotic depletion, was comparatively minor, ranging between only 1–2 % (Fig. 2). This finding is particularly noteworthy given the prevalent focus on the built environment in urban sustainability strategies, where improving building materials and energy efficiency are often prioritized over for instance consumption or food supply chains. The results thereby underscore the importance of expanding the sustainability discourse beyond buildings themselves to include the urban lifestyles they are designed to support. Instead, the category 'services' emerged as a substantial contributor to total impact across all assessed categories, reinforcing the significance of broader

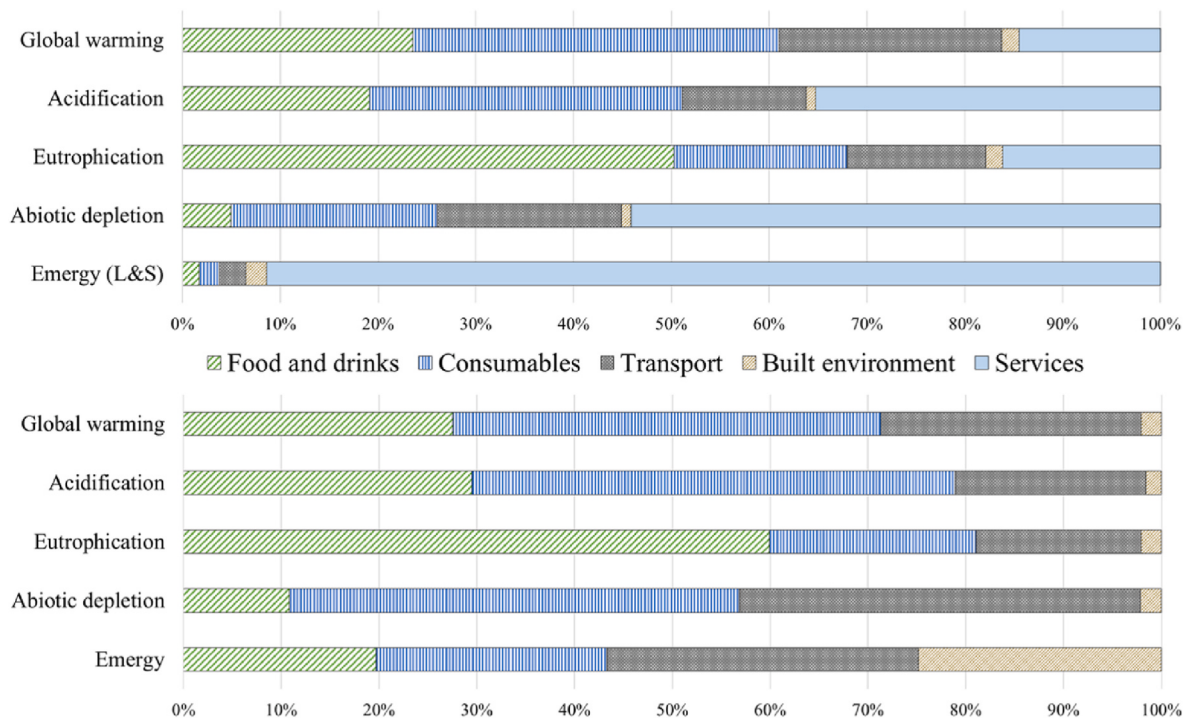


Fig. 2. EmLCA signature for the apartment in Rosendal, illustrating the percentage of total impact for each input. Above is the result including contributions from labor and services (L&S), and below are the results when excluding services.

societal systems such as healthcare, education, and public infrastructure in shaping environmental performance. These results align with previous findings by [Galychyn et al. \(2022\)](#) and [Bossek et al. \(2021\)](#), both of whom emphasize the importance of individual-level behavioural changes in reducing environmental burdens. The earlier energy-based assessment by [Bergquist et al. \(2020\)](#), which evaluated both construction and daily life in Uppsala, concluded that neither lifestyle patterns nor building practices could be considered sustainable in their current form. Major individual contributors to impact included long-distance travel, hygiene products, and meat consumption, while the built environment and societal services also had a notable influence on total energy use. The findings of the present study partially support these conclusions but, through the added lens of LCA, demonstrate that the environmental impacts of the built environment are relatively lower than those associated with for instance food and consumables. By integrating energy synthesis and life cycle assessment, the hybrid EmLCA approach enhances the robustness of the sustainability evaluation, offering both cross-verification of findings and a more holistic understanding of the complex interplay between infrastructure, lifestyle, and systemic resource use.

Urban life is an inherently complex system, which requires certain simplifications in this study. For example, the impacts of domestic pets were excluded, even though around 20 % of Swedish households own a cat and 15 % own a dog. Previous studies suggest that pet dogs alone can account for up to 7 % of the annual climate impact of an average EU citizen ([Yavor et al., 2020](#)), and excluding this factor in the present work likely inferred an underestimation in the results. While such omissions highlight the challenge of fully capturing the complexity of urban living, the overall results of this study remain broadly consistent with national estimates of consumption-based emissions. According to Swedish Environmental Protection Agency (2023) just over 84 000 kgCO₂eq per person originates from consumption-based greenhouse gas emissions every year in Sweden. This is very similar to the results presented in this study when excluding the contribution from services ([Table 5](#)). However, by including contributions from services, we gain a more holistic assessment of impact for urban life. The results presented by [Bossek et al.](#)

(2021) for the impact of a human life, suggest an annual impact per person to global warming, acidification, and eutrophication is roughly 23 000 kgCO₂eq, 91 kgSO₂eq, and 34 kgPO₄eq, respectively. This is in the same order of magnitude as the result in this study, when accounting for the contribution from services (see [Fig. 2](#)).

One important limitation is the scope of Sweden, a high-welfare country with a predominantly renewable energy mix and tax-funded healthcare and education, which highly influences the universality of the results. Other countries or regions may face higher environmental impacts related to their different socio-economic structures and display distinct consumption patterns. Moreover, this study is also limited by its static scope, as relying on a single-year dataset does not capture long-term dynamics such as technological progress, policy shifts, or the accelerating transition to renewable energy in Sweden. To better reflect future trajectories, subsequent research could integrate time-series data, scenario simulations, and real-time updates to account for factors such as evolving energy systems, policies, and consumer behaviors. On this note, another aspect to consider is that the inputs and consumption patterns analyzed in this study are specific to the case study, and do not necessarily reflect broader national averages in Sweden. For example, beef consumption in Rosendal was estimated at 8.2 kg per person annually (see [Table 1](#)), whereas the national average in 2022 was 11.5 kg per person ([Swedish board of Agriculture, 2022](#)). A similar discrepancy was observed for several other food categories. For instance, average annual sugar consumption reported by the [Swedish board of Agriculture \(2020\)](#) ranged between 38 and 49 kg per person, while the corresponding estimate in this study was approximately 30 kg. Conversely, certain categories, such as eggs, showed slightly higher consumption levels in Rosendal compared to the national average, indicating variation in dietary patterns at the local level. These differences may be attributed to the specific socio-demographic and cultural context of Rosendal, an urban area marketed as a sustainable district, or to methodological uncertainties in the consumption data. Food-related environmental impacts can vary considerably between cities ([Riveros et al., 2024](#)), not only due to dietary composition but also due to differences in total consumption volumes. In this study, food intake data

were derived from [Maassen et al. \(2020\)](#), who employed a 24-h dietary recall survey conducted with 34 residents of the *Smaragden* apartment complex. While this approach captures location-specific behaviour, the method itself introduces potential limitations such as underreporting, especially for food items perceived as unhealthy or environmentally damaging. Moreover, it is plausible that residents of a sustainability-oriented district like Rosendal may consciously reduce their intake of red meat and other high-impact foods due to greater environmental awareness. Taken together, these factors help explain the differences between the consumption data used in this study and national averages. Had national averages been applied instead of local data, the environmental impact attributed to food and drink consumption would likely have been higher than reported in [Table 5](#). Another limitation of the present work is the exclusion of food waste and excessive caloric intake, even though a considerable amount of food is wasted in, e.g., households ([Sjölund et al., 2025](#)) and schools ([Malefors et al., 2024](#)), losses at retail ([Ghosh and Eriksson, 2019](#)) and primary production ([Pasanen et al., 2025](#)), or consumed beyond nutritional needs ([Sundin et al., 2021](#)). These are all factors known to considerably influence environmental outcomes of food systems ([United Nations Environment Programme, 2024](#)), and should thus be covered in future research.

Likewise, in any model of a system there are uncertainties tied to the necessary assumptions made, in this work this is especially relevant for the kind of inputs used to model each category. While these assumptions enabled a comprehensive assessment, they also introduce uncertainty, and therefore the precise numerical results should be interpreted with caution. Moreover, as highlighted by [Wilfart et al. \(2021\)](#), methodological choices, such as allocation method, highly influence the environmental impact attributed to a product or service. In this study, economic allocation was applied rather than system expansion, due to the combined use of both Ecoinvent and Agri-footprint databases. This choice is important to acknowledge, as it likely affected the quantitative outcomes, especially given the complexity of agri-food systems where numerous by-products are generated during cultivation and processing stages. Future research could strengthen the robustness of environmental assessments by explicitly addressing such allocation challenges and by incorporating more detailed data for individual products and processes. Additionally, this study did not consider waste management pathways and the treatment of different waste streams, which were beyond its scope. Including waste management is likely to increase the estimated environmental impacts across all input categories, as waste occurs throughout urban life, from food cultivation and concrete production to the handling of public meals in the service sector. Investigating these aspects further would provide a more holistic and accurate understanding of urban environmental impacts and is therefore strongly recommended for future studies. A similar discussion was held by [Cano Londoño et al. \(2019\)](#) on evaluating gold mining practices, highlighting the need for implemented methods that facilitate increased resource efficiency and reduced dependency on imported resources. Future studies could also benefit from expanding on included energy indicators, such as Environmental Sustainability Index (ESI) and Environmental Loading Ratio (ELR), for a more holistic analysis of complex systems. A similar recommendation was also voiced by [Santagata et al. \(2020\)](#) in their work on integration of LCA and Emergy Accounting approaches. It would also be insightful to evaluate the present results through the lens of another Em-LCA framework, for instance by [Zhang et al. \(2023\)](#), to identify potential deviations.

It is important to note that, in line with the goal of most system-level studies, this assessment aims to expand the sustainability dimension by providing a broad overview and comparative insights rather than a precise quantification of individual values. Accordingly, the exact figures are less critical than the relative differences between impact categories and the identification of environmental hotspots. In this study, we explored a novel approach by estimating emissions from services using principles derived from emergy synthesis (see equation (1)), an

approach that, to our knowledge, is new in the context of life cycle assessment. While this method offers a new perspective, it also introduces uncertainties. This is especially relevant in terms of data representability and availability, where the underlying national statistics are available and well-established but less precise in capturing local conditions. Furthermore, the service inventory was based on national-level economic and emission data from a single year (see [Table 4](#)), meaning that key factors such as inflation and the process of downscaling from national to local conditions were not comprehensively addressed. As also noted by [Galychyn et al. \(2022\)](#), downscaling procedures may result in overestimated consumption levels, influencing the results. Thus, while the exact values found for service-related impact should be interpreted with caution, we argue that, despite the potential inaccuracies, including services provides a highly relevant aspect to environmental assessments, especially since it is an inherent and unavoidable component of urban life.

Based on the findings of this study, several recommendations can be made to policymakers aiming to promote more sustainable urban living. In addition to reducing material requirements per capita across urban systems, strategies should focus on enabling urban lifestyles that are less dependent on high levels of consumption. This includes urban planning that prioritizes walkability, cycling, and access to public transportation to reduce reliance on private vehicles. Product categories with particularly high environmental impacts, such as electronic devices, meat, and dairy products, also present opportunities for targeted interventions. While such areas are more closely tied to individual lifestyle choices than to the built environment itself, public policies can play an important role by encouraging extended product lifespans (e.g., for electronics) and reducing subsidies for resource-intensive foods like meat and dairy. Future studies should also evaluate the environmental potential of shifting focus from energy optimization in buildings to more holistic strategies for sustainable consumption, such as promoting local food production, supporting circular retail models, or enabling neighborhood-level sharing of resources such as tools, vehicles, and communal spaces. Beyond consumption patterns, urban design parameters, such as mobility management, hold a promising potential to reduce environmental pressures in future cities ([Kamení Nematchoua et al., 2020](#); [Bertolini, 2023](#)). Initiatives like urban farming can also offer promising synergies, not only in enabling neighborhood-level sharing. As [Benis et al. \(2018\)](#) suggest that urban greenhouse agriculture may yield greater sustainability benefits than traditional green roofs or solar PV. Likewise, [de Oliveira Alves et al. \(2024\)](#) highlight the role of urban farming in boosting local food supply, while [Drottberger et al. \(2023\)](#) explore its contribution to the fulfilment of SDGs. Taken together, these findings underscore the need for integrated, consumption-aware strategies in future efforts to design more sustainable urban environments. While the proposed policy directions provide valuable orientation, their current form often lack in operational detail, as also voiced by [Eriksson et al. \(2025\)](#), limiting practical applicability. Future research should therefore develop context-specific implementation pathways, such as subsidy schemes, technical standards, and pilot projects, preferably through multi-stakeholder collaboration. This would aid in enabling evidence-based and replicable policy frameworks that align with local socio-economic conditions.

The built environment remains a key area for targeted sustainability efforts, especially given the long lifespan of buildings and infrastructure. Decisions made today regarding building standards and urban design will shape environmental outcomes for decades to come. This was also voiced by [Parekh and Smith \(2024\)](#), who further emphasized that sustainable urban design could reduce environmental burdens alongside generating important social benefits, both critical aspects concerning the accelerating global urbanization. However, findings from the present study suggest that emissions directly associated with the built environment represent only a small portion of the total environmental footprint of urban life. This indicates that while building materials and energy efficiency remain highly important, their relative contribution

may be diminishing. This is especially relevant in contexts where building standards are already comparatively high and with a (hopefully) long lifespan. In such cases, the potential for further emission reductions through improved insulation or material choices may be limited. Instead, a greater opportunity lies in designing urban environments that actively enable and reinforce low-impact lifestyles. This includes, for instance, prioritizing compact and high-density developments, such as multi-family apartment complexes, which tend to be more resource-efficient per square meter of living space than detached single-family homes. It also calls for a broader perspective that moves beyond the efficiency of individual buildings to consider how urban form and infrastructure can support sustainable consumption patterns in daily life. Ultimately, while continued improvements in building practices are essential to reduce environmental pressures and increase resource efficiency, they must be complemented by systemic strategies that promote sustainable behaviour across all aspects of urban living. These actions arguably should go hand in hand with broader efforts to support sustainable lifestyles; only then can we achieve the kind of deep, lasting change that truly sustainable cities require. This study reinforces the need to frame urban sustainability as a system-wide challenge, moving beyond the traditional focus on buildings to encompass the broader material and energetic flows that support everyday urban life. By integrating life cycle assessment with emergy indicators, we illustrate that services, mobility, and consumption patterns may carry a far greater cumulative impact than the physical structures themselves, underscoring the urgency of systemic, cross-sectoral solutions.

5. Conclusions

This study demonstrates that urban sustainability is shaped not only by the physical built environment but also, and perhaps more critically, by lifestyle choices and societal systems. Although buildings remain a key part of the urban landscape, their direct contribution to the total environmental impact was found to be relatively minor, accounting for just 1–2 % of overall emissions. Instead, lifestyle factors such as meat consumption, fast fashion, and car travel were more impactful contributors to climate change, eutrophication, acidification, and abiotic depletion. These findings challenge the traditional emphasis on

construction materials and energy efficiency, highlighting the need for a broader systems perspective that addresses the full spectrum of urban life. The integration of Emergy Synthesis and Life Cycle Assessment to a hybrid EmLCA framework offers a more holistic view, revealing that services also play a key role in the overall environmental impact of urban living. By extending the analytical focus beyond buildings, this study underscores how combining LCA and emergy indicators can uncover overlooked drivers of urban environmental impacts and inform more comprehensive strategies for sustainable urban development. Moving towards sustainable futures, urban planning and policy should prioritize both efficient infrastructure and low-impact lifestyles. Our recommendations include reducing reliance on private vehicles, extending the lifespan of consumer goods, and encouraging dietary shifts toward plant-based alternatives to lower the consumption of animal-based foods, such as meat and dairy. Achieving meaningful reductions in environmental impact requires not only improvements in building standards but also systemic changes that support sustainable consumption patterns. This study highlights that addressing lifestyle and structural factors together, considering both upstream and downstream factors, will likely become increasingly important for realizing truly sustainable cities.

CRediT authorship contribution statement

Louise Bartek: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel Bergquist:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Daniela Garcia-Caro:** Writing – review & editing, Validation, Investigation. **Christopher Malefors:** Writing – review & editing, Validation, Resources, Formal analysis. **Mattias Eriksson:** Writing – review & editing, Supervision, Project administration, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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

Appendix A

The environmental modeling in this study was conducted using SimaPro 9. Datasets were selected to represent Swedish or European systems where available, with economic allocation applied in line with database conventions. When specific local data were unavailable, global or average datasets were used as proxies. A full list of the SimaPro datasets used for each input category is provided in [Table A1–A3](#).

Table A1

Datasets used to model inputs for the category ‘Food and Drinks’ ([Table 1](#)). Datasets describing live weight were recalculated to capture the amount needed to provide the consumption input.

Product	Dataset	Amount
Wheat	Wheat flour mix {GLO} market for wheat flour mix Cut-off, S	40.2 kg
Oats	Oat grain {GLO} market for Cut-off, S	15.1 kg
Rice	Rice, basmati {GLO} market for rice, basmati Cut-off, S (50 %)	7.5 kg
Sugar	Rice, non-basmati {GLO} market for rice, non-basmati Cut-off, S (50 %)	7.5 kg
	Sugar, from sugar beet {GLO} market for Cut-off, S	30.1 kg
Soft drink		
Coffee	Coffee, green bean {GLO} market for coffee, green bean Cut-off, S	7.5 kg
Tea	Tea, dried {GLO} market for tea, dried Cut-off, S	0.5 kg
Beer Wine		
Tomato	Tomato, fresh grade {GLO} market for tomato, fresh grade Cut-off, S	15.6 kg
Iceberg	Iceberg lettuce {GLO} market for Cut-off, S	6.2 kg
Potato	Potato {GLO} market for Cut-off, S	71.8 kg
Banana	Banana {GLO} market for Cut-off, S	42.1 kg

(continued on next page)

Table A1 (continued)

Product	Dataset	Amount
Apple	Apple {GLO} market for Cut-off, S	20.3 kg
Cow milk	Yogurt, from cow milk {GLO} market for Cut-off, S	66.3 kg
Cheese	Cheese (Gouda 48+), at processing/NL Economic	16.8 kg
Eggs		
Oil	Refined rapeseed oil (pressing), at processing/DE Economic	8.0 kg
Butter	Butter, from cow milk {GLO} market for Cut-off, S	5.0 kg
Trout	Trout {GLO} market for trout Cut-off, S	5.0 kg
Marine fish	Marine fish {GLO} market for marine fish Cut-off, S	5.0 kg
Fish sticks	Frozen fish sticks, hake {GLO} market for frozen fish sticks, hake Cut-off, S	5.0 kg
Beef	Red meat, live weight {GLO} market for Cut-off, S	82 kg
Pork	Swine for slaughtering, live weight {GLO} market for Cut-off, S	17.7 kg
Chicken	Chicken for slaughtering, live weight {GLO} market for Cut-off, S	30.9 kg

Table A2

Datasets used to model inputs for the category ‘Consumables’ and ‘Transport’ (Table 2). Lifespan was re-calculated, alongside unit conversions to account for the functional unit in this study.

Product	Dataset	Amount
Soap	Soap {GLO} market for Cut-off, S	34.7 kg
Foaming agent	Foaming agent {GLO} market for Cut-off, S	4.96 kg
Cosmetics		
Packaging	Polystyrene, general purpose {GLO} market for Cut-off, S	4.96 kg
Tissue paper	Tissue paper {GLO} market for Cut-off, S	15.5 kg
Laptop	Computer, laptop {GLO} market for Cut-off, S	0.2 p
Smartphone	Consumer electronics, mobile device, smartphone {GLO} Cut-off, S	0.2 p
Coffee maker	Coffee maker {GLO} market for coffee maker Cut-off, S	0.2 p
Washing	Washing machine {GLO} market for washing machine Cut-off, S	0.125 p
Furniture	Furniture, wooden {GLO} market for furniture, wooden Cut-off, S	2.3 kg
Mattress	Mattress {GLO} market for mattress Cut-off, S	0.1 p
Clothing		
Textile	Textile, woven cotton {GLO} market for Cut-off, S	1.0 kg
Bicycle	Bicycle {GLO} market for Cut-off, S	0.033 p
Bicycle, el	Electric bicycle {GLO} market for Cut-off, S	0.05 p
Train	Transport, passenger train {GLO} market for Cut-off, S	5538 pkm
Aircraft	Transport, passenger aircraft, long haul {GLO} Cut-off, S	3692 pkm
Regular bus	Transport, regular bus {GLO} market for Cut-off, S	3390 pkm
Passenger car,	Transport, passenger car, EURO 5 {RER} market for Cut-off, S	2070 km
Passenger car, el	Transport, passenger car, electric {GLO} market for Cut-off, S	2070 km

Table A3

Datasets used to model inputs for the category ‘Built environment’ (Table 3).

Product	Dataset	Amount
Renewable and non-renewable	Heat, district or industrial, other than natural gas {Europe w/o Switzerland} Cut-off, S	2325 kWh
Low voltage	Electricity, low voltage {SE} market for Cut-off, S	639 kWh
Tap water	Tap water {RER} market group for Cut-off, S	58 400 kg
Peat moss	Peat moss {RoW} peat moss production, horticultural use Cut-off, S	0.003 m ³
Sand	Sand {CH} market for sand Cut-off, S	3.5 kg
Clay	Clay {CH} market for clay Cut-off, S	3.5 kg
Packaging	Packing, clay product {GLO} market for Cut-off, S	7.0 kg
Plywood, outdoor	Door, inner, wood {GLO} market for Cut-off, S	0.133 m ²
	Plywood {RER} market for plywood Cut-off, S	0.02 m ³
Concrete	Concrete, high exacting requirements {CH} market for Cut-off, S	0.45 m ³
Mortar	Cement mortar {RoW} market for cement mortar Cut-off, S	56.5 kg
Low alloy	Steel, low-alloyed {GLO} market for Cut-off, S	2.1 kg
Construction	Building, hall, steel construction {GLO} market for Cut-off, S	0.0268 m ²
Aluminum alloy	Aluminium alloy, metal matrix composite {GLO} market for Cut-off, S	0.4 kg
Copper	Copper-rich materials {GLO} market for copper-rich materials Cut-off, S	0.4 kg

(continued on next page)

Table A3 (continued)

Product	Dataset	Amount
Solder, bar	Solder, bar, Sn63Pb37, for electronics industry {GLO} market for Cut-off, S	0.3 kg
Polyethylene	Polyethylene pipe, corrugated, DN 75 {GLO} Cut-off, S	2.54 m
Polystyrene	Polystyrene, high impact {GLO} market for Cut-off, S	2.7 kg
Flat glass, coated	Flat glass, coated {RER} market for flat glass, coated Cut-off, S	2.5 kg
Kraft paper	Kraft paper {RER} market for kraft paper Cut-off, S	0.3 kg
Paper sack	Paper sack {RER} market for paper sack Cut-off, S	0.3 kg
Stone wool	Stone wool {GLO} market for stone wool Cut-off, S	0.15 kg
Glass wool	Glass wool mat {GLO} market for Cut-off, S	0.15 kg
Acrylic paint	Alkyd paint, white, without solvent, in 60 % solution state {RER} Cut-off, S	0.8 kg
Acrylic varnish	Acrylic varnish, without water, in 87.5 % solution state {RER} Cut-off, S	0.2 kg
Fruit tree	Fruit tree seedling, for planting {GLO} Cut-off, S	1.0 p
Grass	Grass seed, Swiss integrated production, at farm {GLO} Cut-off, S	0.9 kg
Green roof		

Data availability

Data will be made available on request.

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