City Environmental Footprint: insights and application of an innovative LCA-based method to evaluate urban environmental impacts

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Abstract. In 2015, the United Nations chose cities as target of the 11th Sustainable Development Goals, which aims to 'make cities inclusive, safe, resilient, and sustainable'. However, few quantitative methodologies can tackle the sustainability challenge and support cities in this transition. In order to comply with UN SDGs, the City Environmental Footprint (City EF) has been developed. Being systemic and systematic, its aim is the holistic assessment of urban environmental impacts (up to 18), as result of activities performed in key urban sectors (built environment, waste and water management, mobility, production and consumption sectors) by its main stakeholders (e.g. residents, but also important local entities etc.). This facilitates the identification of major hotspots and drivers of impacts in the city, and, based on these, areas of priority interventions and proposals for alternative scenarios. The City EF follows an enhanced LCA-based approach where specific methodological improvements are proposed, both system-related (city as object of investigation), than methodology-related (LCA as effective methodology). Furthermore, a first application of City EF was performed on the city of Leuven (Belgium) to test the method, and its feasibility. The aims of the present contribution are threefold: i) an overview of the City EF, its methodological proposals for urban footprinting, and how it accomplishes to the tasks; ii) provide insights about its first application to the city of Leuven; iii) and critical reflections for future applications, including identified working points and potential research outlooks.

1. Sustainable cities in transition: from performance to impacts assessment
Cities are gaining momentum in the sustainability debate, and they are considered favorable places to take actions to promote the transition for a more sustainable living. The importance of cities in the political agenda has recently emerged for a number of reasons. Cities are growing in terms of size, with 66 per cent of global population residing in urban areas by 2050 [1], and impacts, as they consume 60-80% of total global energy and produce 75% of greenhouse gas emissions [2].

In 2015, the United Nations chose cities as target of the 11th Sustainable Development Goal (SDG), which aims to 'make cities inclusive, safe, resilient, and sustainable'. [2], and includes among others: i) a reduction of the environmental impacts of cities per capita, paying special attention to air quality and waste management; ii) sustainable human settlement planning and management; iii) sustainable mobility and transportation.

Nevertheless, few methodologies and studies address this task in an exhaustive, comprehensive and informative way. The “sustainable city” is a popular upcoming concept of the past decade, not fully in
practice though and still debated [3]. Although the availability of different standards and frameworks, the thorough calculation of the environmental impacts of a city is still in an exploratory-stage [4-5].

To date, Life Cycle Assessment (LCA) is considered one of the most robust scientific methods to evaluate the environmental impacts (up to 18 impact categories) of products and services over their full life cycle. The application of LCA has several advantages: i) a quantitative assessment of impacts; ii) a precise identification of hotspots and drivers of such impacts; iii) an evaluation of various scenarios; iv) performance tracking over time. Notwithstanding, researches show that numerous constraints and bottlenecks exist to make it applicable at city scale. [6-7]

2. Key principles of City Environmental Footprint (City EF)

In order to support sustainable practices in cities, the City Environmental Footprint (City EF) has been developed. Being systemic and systematic, its aim is the holistic assessment of urban environmental impacts which result from activities performed in key urban sectors (built environment, waste and water management, mobility, production and consumption sectors) by various stakeholders (e.g. residents, business activities, local administration, etc), based on an enhanced LCA approach.

As methodological advancements and research efforts were identified and resulted to be necessary for each life cycle stage [4-7], an in depth investigation of the state-of-art was performed [5]. Open challenges for achieving urban sustainability were identified, both as system-related and methodology-related. The system-related challenges involve the city as object investigation, i.e. its multifunctionality comparability issues between cities, etc. The methodology-related issues involve the current LCA bottlenecks [2], and the combination of an appropriate methodological approach (top-down vs bottom-up) to perform a comprehensive, but feasible urban footprinting.

The City EF addresses these issues and proposes potential solutions in five consecutive steps.

2.1. Qualitative assessment and goal and scope definition (step one and two)

A preliminary qualitative step (step one) complements the goal and scope phase (step two).

The qualitative assessment aims at acknowledging the specific social and economic context of cities, defining the context of investigation and providing meaningful terms of comparison between two or more urban settlements. This qualitative assessment follows a three tiers approach: i) city categorization; ii) indicators sets; iii) identification and accounting of all “city-users”, trough the concept of Population Equivalent (PE). First of all, the city is categorized based on its (prevalent) function(s), in order to detect main urban activities and players, as well as identifying areas of attention and priority. A shortlist of ten functional urban categories has been identified so far to apply the City EF. Secondly, a set of core (valid for every city category identified in the previous step) and supporting indicators (to be applied case-by-case) is elaborated. These indicators sets are intended to support both policy actions and LCA studies, facilitating the data collection. Finally, the accounting of PE is performed. This innovative metric is capable to include not only permanent residents but also other potential “city-users” as contributors and drivers of urban dynamics and related impacts (see section 2.1.1).

As the City EF is a LCA-based approach, the definition of goal and scope phase is part of step two. Here the most important methodological concepts are defined. The function of the system (i.e. city) is the provision of goods and services, allowing to sustain urban activities for city-users (assessed as PE) in one year, and the yearly total flows of a city required fulfilling its (main) activities shall be considered in order to comply with the function. Administrative boundaries are considered the most appropriate system boundaries for a city, including in situ activities, along with upstream and downstream activities. Attributes and allocations of responsibilities are assigned according to a service-based rationale [8], i.e. the city is responsible for the impacts induced by its activities within and outside its boundaries.

2.1.1. Impacts driven by multiple users: inside the PE concept. Users in a city are numerous and, often, not limited to its residents. In order to provide a fair comparison between cities, urban environmental impacts may be scaled not only to the entire city or to the number of residents, but also and more meaningfully to the permanent residents and other city users. The PE reflects the people
using the services provided by the city during the year of reference, and acknowledges for their specific “responsibilities” in the total environmental burdens. In order to account for the PE, once urban functions and relevant city-users are identified, the relevant energy and material flows in the city per sector are calculated and allocated to each city-user identified. Finally, the flows are normalized and related to the residents’ performance to acknowledge for the additional share of people (using city services) to be considered.

2.2. Data collection, impacts assessment and interpretation (steps three, four, five)
Step three involves the appropriate data collection of urban flows. Here an extensive collection of local foreground data shall be performed per urban sector and identified stakeholder, in terms of material and energy flows, as well as emissions and waste. Additional background data shall be retrieved with the use of appropriate databases. In order to ensure geographical and time representativeness, local data shall be collected as much as possible for the year of reference. If these are not available, the most updated top-down data shall be downscaled with appropriate proxies.

The data collection shall be performed to the highest extent possible for each identified stakeholder and can be gathered and processed using a combination of low-tech (traditional data banks) and high-tech sources (GIS, BIM, remote sensing data), properly combined.

In step four the impact assessment need to be performed with the selection of a suitable life cycle impact assessment (LCIA) method. This allows for translating materials and energy flows in environmental impacts with the application of specific characterization factors. Nowadays, several methods are available, and authors’ recommendation is to use the most updated methods available, including geographical differentiation.

In the last step (interpretation and visualization), further investigations and identifications of major hotspots and drivers are persecuted, as well as sensitivity and scenario analysis. The visualization of results, e.g. for georeferenced data with GIS, is particularly encouraged for communication purposes.

3. Application of City EF to the city of Leuven
The combination of appealing features and data availability made Leuven a good case study for a first test of the method. Leuven (99,288 inhabitants in 2016) is categorized as University city because of the important role played by KU Leuven (one of the most ancient and biggest Universities of Low Countries). The accounted PE in 2016 is 134,289, 35% higher than its official population, mainly due to the high number of students (over 50,000) living in the city during the academic year.

An extensive data collection of available local data involved numerous entities and data sources, in order to model input and output flows of the identified stakeholders (residents, business, KU Leuven, UZ Leuven, Stad Leuven) for each urban sector (built environment, waste and water management, mobility, production and consumption activities). Background data were retrieved from the Ecoinvent Database 3.3 available in Simapro 9 (ones of the most popular to perform LCA studies) and they were properly adapted to reflect local conditions as much as possible.

Data quality and availability greatly varied across sectors and stakeholders. Local data about waste and water management (high quality) were mainly collected from stakeholders, waste and water management facilities. The building stock (medium quality) was modelled combining local GIS data (for typology, footprints and year of construction) with 16 flemish representative archetypes (domestic buildings) or the material intensity (no-domestic building), while local energy consumption data were assigned top-down to each economic sector. Mobility patterns were estimated combining statistics and surveys (medium quality) of average kilometre travelled per person, purpose and mean of transportation. The information were properly combined and upscaled to the different users to get the total kilometre travelled in one year. Freight transportation was estimated downsampling available data at European, national and district level. Local production and other consumption activities (e.g. purchases of food and goods) are the least represented because data were often missing or incomplete. For this reason, only the impacts related to the domestic consumption of food and goods were estimated using the Basket of Product approach [9]. The Environmental Footprint 3.0 (2019) was selected as LCIA method.
4. Conclusions

At the moment of writing, full final results about the first application of the City EF are not available yet. Nevertheless, the following important considerations and take-home messages are possible:

- The present research and its test on the city of Leuven is the first application of LCA at urban scale, simultaneously assessing multiple environmental impacts and considering various sectors and stakeholders.

- The City EF provides a thorough and replicable assessment (in time and space) of urban lifestyles, able to detect hotspots and related drivers, in order to support the achievement of the 11ths SDG, as well as the application of targeted sustainability policies.

- Synergies with other disciplines and practices are possible, i.e. evaluation of circular economy strategies/practices, or strategical urban planning at design and policy level, based on environmental impacts and performances.

- Future (interdisciplinary) research efforts shall focus on: i) further refinement of urban categories and PE for comparability and benchmarking purposes; ii) management of local data: accessibility and automatization for their collection and processing; iii) estimations of potential truncation errors and biases; iv) integration of social and economic dimension for a full sustainability assessment.

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