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Master Thesis

Making cities and the built environment more sustainable and circular (Circular Cities and Society)

Supervisor
Prof. Patrizia Lombardi
Co-supervisors
Prof. Sara Torabi Moghadam
Dr. Chiara Genta

Candidate
Elina Arzumanian

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Author	Elina Arzumanian
University	Politecnico di Torino
Supervisor	Prof. Dr. Patrizia Lombardi Vice Rector of Politecnico di Torino Full Professor DIST - Interuniversity Department of Urban and Regional Studies and Planning Effective member of School of Planning and Design
Co – Supervisors	Dr. Arch. Sara Torabi Moghadam Assistant Professor DIST - Interuniversity Department of Urban and Regional Studies and Planning Dr. Arch. Chiara Genta DIST - Interuniversity Department of Urban and Regional Studies and Planning
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Abstract - EN

The global population of urban citizens has been steadily increasing since the 1950s. Cities like living organisms require natural resources, raw materials, energy, goods, and food to sustain the inhabitants' daily life and their economic activities. Effective actions taken at different level could potentially tackle environmental issues on a global scale. The thesis aims to analyze and compare different methodologies that exist today to assess urban sustainability. With the aim to give an overview of the present status as regards quantitative tools and provide urban actors and future researchers with guidance and recommendations. This thesis presents the assessment methodological approaches that have been used in prior studies to outline common strategies to evaluate the environmental impact. The purpose is not to rank the different tools and select which is the most appropriate one, but to produce a better picture and indicate pros and cons for the tools as a group; thereby providing important awareness for urban actors as well as future researchers and development of this group of tools. Moreover, the thesis aimed at developing a guidance handbook on how to implement and integrate the existing methodological approaches to decrease the environmental impact of the cities. This guideline will help urban actors and future researchers to develop sustainable cities, guiding them in the choice among a significant number of quantitative methods available for environmental assessment of the cities.

Keywords: Life Cycle Assessment; Ecological Footprint; Carbon Footprint; Urban metabolism; Hybrid methodology; Interdisciplinary Mixed Methodology.

Abstract – IT

La popolazione globale di cittadini urbani è in costante aumento dal 1950. Città come gli organismi viventi richiedono risorse naturali, materie prime, energia, beni e cibo per sostenere la vita quotidiana degli abitanti e le loro attività economiche. Azioni efficaci intraprese a diversi livelli potrebbero potenzialmente affrontare le questioni ambientali su scala globale. La tesi si propone di analizzare e confrontare le diverse metodologie che esistono oggi per valutare la sostenibilità urbana. Con l'obiettivo di fornire una panoramica dello stato attuale per quanto riguarda gli strumenti quantitativi e fornire agli attori urbani e ai futuri ricercatori orientamenti e raccomandazioni. Questa tesi presenta gli approcci metodologici di valutazione che sono stati utilizzati in studi precedenti per delineare strategie comuni per valutare l'impatto ambientale. Lo scopo non è quello di classificare i diversi strumenti e selezionare quello più appropriato, ma di produrre un'immagine migliore e indicare pro e contro per gli strumenti come gruppo; fornendo in tal modo un'importante consapevolezza per gli attori urbani e per i futuri ricercatori e lo sviluppo di questo gruppo di strumenti. Inoltre, la tesi mirava a sviluppare un manuale di orientamento su come implementare e integrare gli approcci metodologici esistenti per ridurre l'impatto ambientale delle città. Questa linea guida aiuterà gli attori urbani e i futuri ricercatori a sviluppare città sostenibili, guidandoli nella scelta tra un numero significativo di metodi quantitativi disponibili per la valutazione ambientale delle città.

Parole chiave: valutazione del ciclo di vita; Impronta ecologica; Impronta ecologica; Metabolismo urbano; Metodologia ibrida; Metodologia mista interdisciplinare.

Contents

List of Acronyms

EF: Ecological Footprint

CF: Carbon Footprint

LCA: Life Cycle Assessment

LCIA: Life Cycle Impact Assessment

UM: Urban Metabolism

ISO: International Organization for Standardization

SGDs: Sustainable Development Goals

GIS: Geographical Information Systems

SWOT: Strengths, Weaknesses, Opportunities, and Threats

GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

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CHAPTER 1- INTRODUCTION

1.1 Problem Statement and background

The global population of urban citizens has been steadily increasing since the 1950s. In 2008, for the first time in human history, more than half of the world's population lived in urban areas. Urban areas are supposed to ingest all the population growth expected in the future. More people reside in cities than in rural areas around the world, with urban areas accounting for 55% of the global population in 2018. In 1950, 30% of the world's population lived in cities, and by 2050, that proportion is expected to increase to 68% 2050. (United Nations, 2012).

Cities like living organisms require natural resources, raw materials, energy, goods, and food to sustain the inhabitants' daily life and their economic activities (Kennedy et al., 2007). The urban system generally relies on its neighborhoods, frequently from afar, for both supply and disposal of materials. Nowadays, increasing urbanization, as well as the concomitant problems of fossil fuel depletion, climate change, and increased pollution, has highlighted the need for more efficient and sustainable resource management. Effective actions taken at different level could potentially tackle environmental issues on a global scale (Bulkeley and Betsill, 2005; Wilbanks and Kates, 1999).

A range of methodologies designed to assess urban sustainability exist nowadays. With the aim to give an overview of the present status as regards quantitative tools and provide urban actors and future researchers with guidance and recommendations, this thesis presents the assessment methodological approaches that have been used in prior studies to outline common strategies to evaluate the environmental impact. The purpose is not to rank the different tools and select which is the most appropriate one, but to produce a better picture and indicate pros and cons for the tools as a group; thereby providing important awareness for urban actors as well as future researchers and development of this group of tools.

1.2 Objective of the thesis

The thesis aims to analyze and compare different methodologies which exist to date. It is also aims at developing a guidance handbook on how to implement and integrate the existing methodological approaches to decrease the environmental impact of the cities. This guideline will help urban actors and future researchers to develop sustainable cities, guiding them in the choice among a significant number of quantitative methods available for environmental assessment of the cities.

1.3 Thesis structure

Thesis consists of five chapters and the contents are organized to achieve the objectives discussed in the previous section.

Chapter 2 describes the literature review regarding circular cities and methodologies used to date. It begins with a definition of circular cities and explains the aspects of what a circular city is.

Chapter 3 illustrates the proposed thesis methodologies, giving a schematic flowchart of four main phases of methodological approach with its steps and objectives. Four phases are explained in detail and give the description that have been taken to achieve the objective of the thesis. **Phase 1)** Research, based on the research, collection and reviewing the existing methodological approaches from different articles and journals. Summary of the current's methodologies which exist nowadays. Four case studies are examined and analyzed using the indicators of sustainable development. **Phase 2)** Analysis, shows results of the methodologies through a SWOT analysis, giving clear understanding which methodologies are the most appropriate for the research topic and how various approaches can be integrated to handle the urban project. Subsequently, a mapping of the proposals with key findings is carried out, trying to compare the results of the different tools. **Phase 3)** Comparison, compare and key findings of analyzed methodologies through mapping. In this step the feasibility of some proposals is seen and the potential of each methodology are highlighted and compared. **Phase 4)** Recommendation and guidance, elaborate recommendations and guidance handbook for urban actors and future researchers. At this stage, interviews are conducted with urban experts to evaluate and find out if the selected methodologies are relevant to date.

Chapter 4 reports the results obtained. According to the proposed four assessment methodologies and tools used in urban studies, it first discusses the methodology selection procedure through different data bases. Second, it explains the SWOT analysis result, third the selected methodologies were compared, and key findings were selected. Finally, it analyses the previous results and based on a post assessment and conducted interview with urban actors, some recommendations and guidance for urban actors and future researchers on selection of methodology for use in environmental impact assessment are elaborated.

Chapter 5 sums up the conclusions and discussions. It provides an overview of the entire thesis procedure and highlights some limitations and recommendations for each Phase of the methodology. Finally, it discusses future developments for further research on the subject.

CHAPTER 2
LITERATURE REVIEW

This chapter briefly explores the literature theory of this thesis going through the definition of main methodologies used in urban sector. By giving the definitions of different methodologies this chapter further reviews the benefits and main tools for impact assessment of cities.

2.1 Main methodologies used in urban sector

Urban environmental assessments are becoming more and more popular and nowadays there are numerous approaches available for evaluating the environmental impacts of the cities. It is known that holistic accounting of urban environmental impacts is still immature (United Nations, 2016). Few quantitative and qualitative metrics exist to evaluate and improve the sustainability of cities from an environmental point of view. The most current quantitative and qualitative approaches to date:

The Ecological Footprint (EF) was the first published footprint indicator and introduced in the early 1990's by Mathis Wackernagel and William works (Rees & Wackernagel, 1996; Wackernagel & Rees, 1997). EF is defined by the Ecological Footprint standards and calculates how much biologically productive area is required to generate the resources needed for human habitation and to absorb humanity's carbon dioxide emissions. It compares the level of consumption with the available amount of bioproductive land and has been conceived to demonstrate a potential exceedance of this «sustainability threshold».(Wiedmann and Barrett, 2010).

The Footprints methods are the most reliable, comparable, and verifiable way to improve environmental performance and help achieve a truly clean and circular sustainability of the cities. To avoid the chaos of the plenitude of indicators, the two most known environmental footprints – i.e., Ecological footprint and Carbon footprint will be overviewed in this thesis (Goldfnger et al., 2014).

The Carbon Footprint term is derived from the ecological footprint (EF) concept, formulated by Wackerangel and Rees (1996). The CF is the most well-known indicator of sustainable development that recently emerged as a general description of the GHG emissions produced by human activities (Wiedmann, 2009). Despite being one of the most significant environmental indicators, it is also the one where the chaos is most apparent, with many different definitions and approaches. Since a footprint is a quantitative measure that describes how much natural resources are used by humans, in the EF context, the CF represents the land area required to neutralize CO2 emissions from fossil fuel combustion (Cuceka et al., 2012). Nowadays, researchers, the media, and the public do not frequently adopt this land-based definition of the CF. From a commercial perspective, it is claimed that the CF gathers the GHG emissions caused by organizations or the production of goods and services. Therefore, the CF is typically interpreted as the total amount of GHG emissions that are caused by activity (Wiedmann, 2009).

The concept of the Urban Metabolism is a concept typically uses a top-down approach and provides insight in the local reality through the inventory of the flows into and out of the city. Material flow analysis (MFA) reports stocks and flows of resources in terms of mass, which included application to cities. MFA alone cannot accurately calculate the environmental impacts of the system, although it can measure the flows in and out of the system.

The Life Cycle Assessment (LCA) method is used to give a cradle-to-grave accounting of the direct, indirect, and supply chain effects of resource transformation and usage. The associated environmental effects of extraction and final disposal can also be considered in LCA. (Chester, 2010; Solli, Reenaas, Stromman, & Hertwich, 2009). In order to analyze the movement of materials through the urban system, LCA analysis incorporates the inventorying part of materials flows analysis to detect the indirect and direct supply chain impacts of cities outside their borders (Barles, 2007a). It’s significant that LCA provides a useful set of approaches and tools for quantifying the materials of an urban metabolism, including the mechanisms producing inputs and outputs. The application of LCA to the urban scale however is limited and the only the urban waste management sector is investigated.

Finally, **Hybrid methodology** assesses the environmental impact in urban areas. It combines principles from the Urban Metabolism/ Material Flow Analysis (UM/ MFA), The Life Cycle Assessment (LCA) and Footprint. Linking the UM/ MFA and LCA methodologies provide a ‘sufficiently accurate’ environmental impacts account when no further data is available.

Material Flow Analysis is a tool to examine the flows and stocks of materials within a complex system. It makes it possible to systematically link regional processes and activities, such as construction, transportation, consumption, and waste disposal, along with inputs and outputs. MFA is helpful in examining the connection between an area or city and its related hinterland (Obernosterer et al., 1998). In large-scale systems, MFA can be used to analyze resource flows and minimize resource losses.

The combination of **LCA with top-down UM methods** have still not been applied to the entire urban system (Pincetl, 2012; Chester, 2012). The proposed UM-LCA converts the city's input-output flows into environmental impacts. The combination of **Life Cycle Assessment and Ecological Footprint is** a new hybrid proposal for a quantitative assessment of environmental impact in the city. That environmental assessment method combines elements from top-down and bottom-up methodologies. The top-down methodologies identify the main fluxes going into and out of the city and support the modelling of urban sub-sectors (Mirabella,2018). They can fill data gap and simplify the data gathering process. A bottom-up LCA approach allows for microscale analyses of various sub-system of the city, and they constituting processes and / or products (e.g. construction products, use of appliances, heating, cooling, ect.). The combination of both approaches results in a more precise and detailed modelling and data inventory and allows for a clearer identification of hotspot and opportunities for efficient and effective improvements of the environmental performance of cities.

Integration of **Urban Metabolism and Ecological Footprint** allows identification of major loads and potential points of intervention for reducing urban impacts (e.g., Kennedy et al., 2010; Lenzen et al., 2003; Hendriks et al., 2000). Combining UM and EF can enhance the benefits of each approach (Curry et al., 2011). An already strong local-level analysis of the flows of energy and materials within the city gains additional insight from an EF based on a UM framework.

CHAPTER 3 – THESIS METHODOLOGY

This chapter discusses in detail the methodological set-up of the thesis research. The aim is to analyze, compare and recommend the main existing methodologies which can support decision-making processes by integrating the different methodologies or choosing the specific methodology for addressing major urban issues at different scale.

3.1 Methodology framework

The methodology framework consists of four main Phases (see Fig.1), in which there are fundamental steps to achieve the objectives previously explained in Section 1.3.

The first Phase (1) is "Research", which includes research, collection, and reviewing the existing methodological approaches from different articles and journals. I make a summary of the methodology and the work that will subsequently be analyzed, compared, and discussed in the chapters below.

The second Phase (2) is "Analysis", which provides the results of the methodologies through SWOT analysis. That stage provides a clear understanding of which methodologies are the most appropriate for the research topic and how the various approaches can be integrated to assess the urban environmental impacts within the built environment.

The third Phase (3) is "Comparison". In this chapter, the synthesis of the comparison of the key findings of analyzed methodologies will be presented. In this phase, we see the feasibility of some proposals, by highlighting the potential of each methodology. Furthermore, it discusses the significance of the findings and the barriers to the existing approaches.

The fourth Phase (4) is the "Recommendations and Guidance". Recommendations are a crucial tool for addressing the findings of projects studies and they give guidance for other approaches, provide suggestions as to how future urban actors and researchers might address the issues we have identified and which recommendation that can provide with.

3.1.1 First Phase: Research

For the First Phase, the aim is determining the main methodologies used in urban study to date. In Figure 2, the schematic procedure for the First Phase is illustrated.

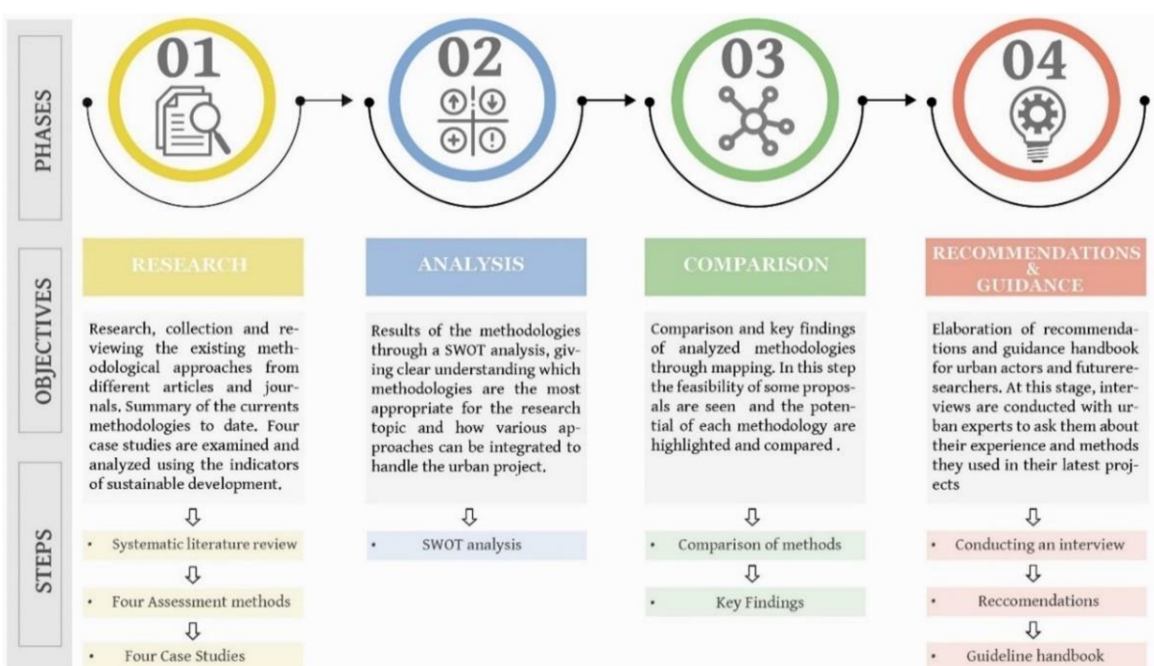


Figure 1: *The schematic flowchart of the methodological framework, with its Phases, objectives, and step.*

Source: Author, 2022.

3.1 Methodology framework

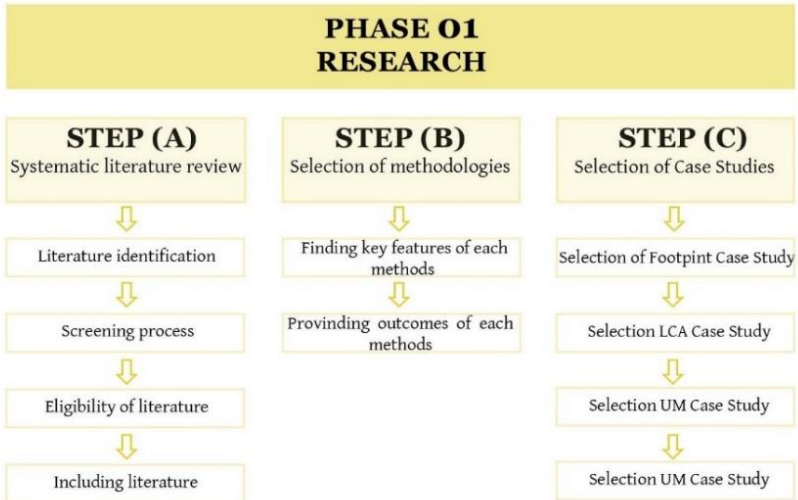


Figure 2: *Systematic literature review methodology.*
Source: Author, 2022.

Firstly, to achieve the goal and highlight the main methodologies, the **STEP (A)** (see Fig. 3) "Systematic literature review" is divided into 4 stages:

The First stage, "Literature identification" the ScienceDirect database and Google scholar were chosen to facilitate the literature search at the beginning of the review process. Google Scholar was chosen because it is a powerful addition to other databases, however, it is not recommended to be used alone for systematic review searches.

The Second stage, "Screening process", based on screening the articles using the relevant keyword combinations. The review study was carried out, taking into consideration the published literature from 2005 to 2022. Possible keyword combinations were chosen, as follows: Built environment/ LCA/ Footprint/ Ecological footprint/ Carbon footprint/ UM/ Urban assessment/ Hybrid methodology.

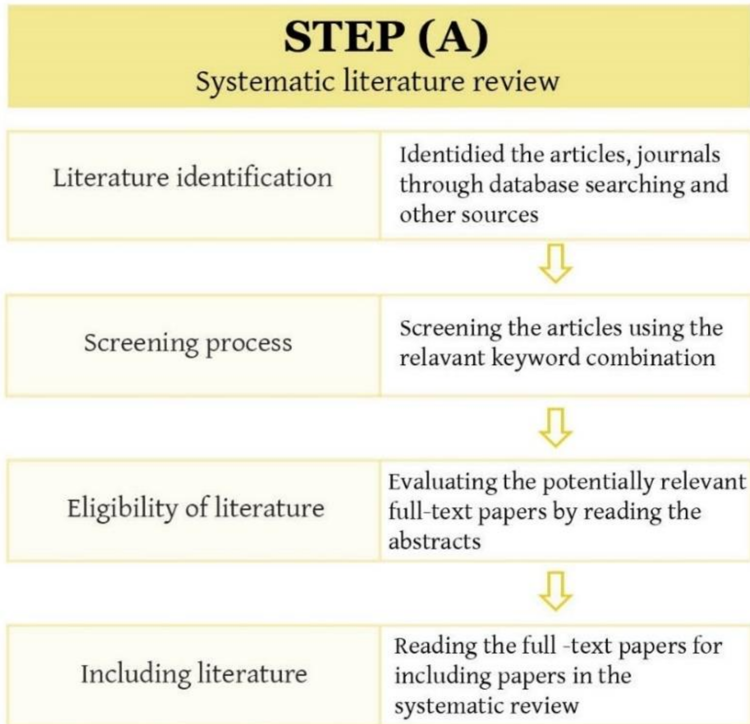


Figure 3: *Method of the Step (A).*
Source: Author, 2022.

As this thesis focuses on methodologies to decrease the environmental impact of the cities, therefore the relevant papers were selected based on the following criteria (see Table 1): 1) papers written in English; 2) papers should be published no earlier than 2005; 3) papers should be related to the environmental assessment of the cities; 4) the assessment tool should be applied for district, city, regional scale; 5) case study presented in the paper should deal with the "integrated" or one of the known assessment method; 6) the study must be relevant to the aforementioned keywords.

INCLUSION CRITERIA
• English language papers; • Papers should be published no earlier than 2005; • Papers should be related to the envoronmental assessment of the cities; • The assessment tool should be applied for district, city, regional scale; • Case study presented in the paper should deal with the "integrated" or one of the known assessment method; • The study must be realvant to the aforementioned keywords;

Table 1: *Inclusion criteria.*
Source: Author, 2022.

The Third stage, "Eligibility of literature", titles and abstracts of all the papers were screened by applying aforementioned criteria. Furthermore, references to the included articles were checked for other articles available for this review.

The Fourth stage, "Including literature", consists of reading selected papers to collect information about existing approaches to provide a guidance for urban actors and future researchers for use in environmental impact assessment of the cities.

Secondly, the **Step (B),** "Selection of methodologies" was divided into 2 stages (see Fig.4):

The First stage, "Key features of each method" consists in a thorough reading and finding the key characteristics of each assessment methodology in the selected papers. This stage includes:

- Concept
- Organization
- Major characteristi

- № Analyzed papers
- Major viewpoints
- Metric
- Implementation categories

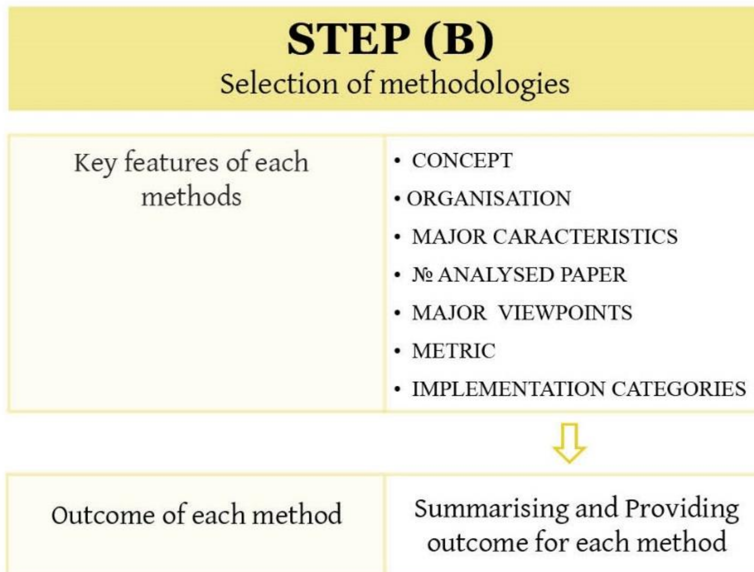


Figure 4: *Method of the Step (B).*
Source: Author, 2022.

The Second stage, "Outcome of each method" summarize and provide the result for each methodology. The aim is to collect information about existing approaches and highlight the most relevant key features to assist future researcher and urban actors in selection the tool for use in strategic environmental assessment.

The third **Step (C)**," Case studies" aimed at selection of relevant case studies to assess the city's environmental impact using various city environmental indicators (see Fig.5). Four case studies are chosen as an example in order to demonstrate how a certain indicator is applied at the city or regional level.

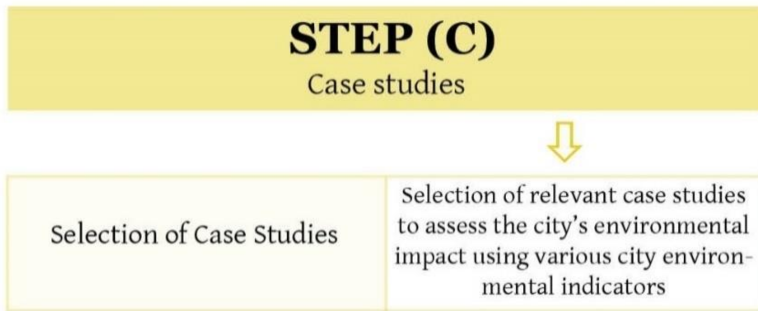


Figure 5: *Method of the Step (C).*
Source: Author, 2022.

3.1.2 Second Phase: Analysis

The SWOT analysis is a strategic management tool that is used to assess four critical areas (strengths, weaknesses, opportunities, and threats). SWOT analysis has been extended beyond companies to countries and is used for planning purposes in almost every published project (Helms and Nixon, 2010). The research has extensively covered the application of SWOT analysis to sustainable development strategies (Berariu et al., 2011). The most recent advances include specific approaches to assessing mitigation and adaptation strategies known as Climate SWOT and Sustainability SWOT (Pesonen and Horn, 2014, 2012).

In this Phase the selected papers are thoroughly scanned, analyzed and the key methodology features (regarding the strengths, weaknesses, opportunities, threats) are identified. Results of the methodologies through a SWOT analysis give clear understanding which methodologies are the most advantageous/ disadvantageous in comparison with other methods.

To achieve goals and effective objectives of the thesis the SWOT analysis should focus on (see Fig.6):

- **Strengths.** Strengths may be characteristics of methodology that give it an advantage over others.
- **Weaknesses.** Weaknesses are areas or characteristics where a methodology exhibits weaknesses compared to other methods.
- **Opportunities.** Opportunities are elements the methodology could exploit to its advantage
- **Threats.** Threats are elements in methodology that could cause trouble while implementing

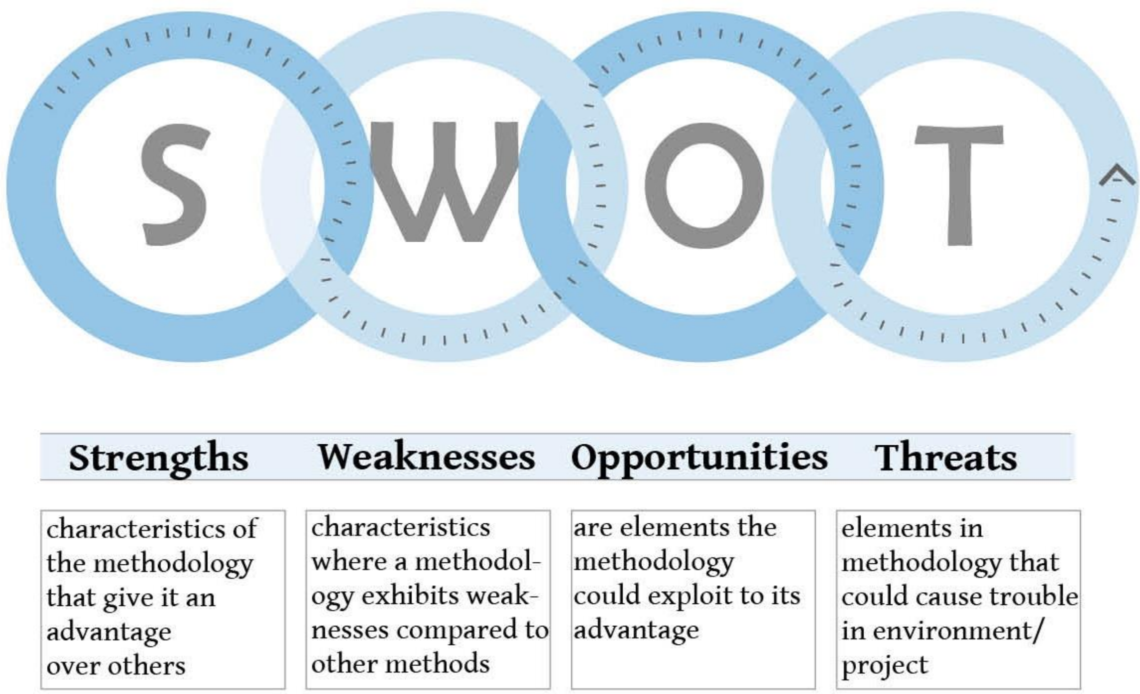


Figure 6*: The concept of SWOT analysis.*

Source: Author, 2022.

3.1.3 Third Phase: Comparison

In this step the feasibility of some proposals is seen and the potential of each methodology are highlighted and compared. The key questions are compiled for each category, namely Strength, Weaknesses, Opportunities, Threats:

I. STRENGTHS - What are the methodologies best at?
II. WEAKNESSES -What could be improved?
III. OPPORTUNITIES – What opportunities are opened?
IV. THREATS – What threat would harm?

3.1.4 Fourth Phase: Recommendations and Guideline

For the last Fourth Phase, "Recommendation & Guidance" the aim was to elaborate recommendations and guidance handbook for urban actors and researchers. The Phase was divided into three steps (see Fig.7):

STEP (A) «Conducting an interview". After identifying the Swot analysis and key features, the Interview is conducted. The aim of this step is to involved different urban experts from Politecnico di Torino to conduct the interview. They are meant to share their experience and talk about methods they used in their latest projects. It is important to ask the experts whether they agree or disagree with the Swot results and key findings of the thesis. Finally, after the interviews, the advantages/ disadvantages of each method are taken into account. In the end, an additional SWOT analysis is developed on the basis of the opinion of the urban experts. To conduct the interview, the following questions are compiled and asked:

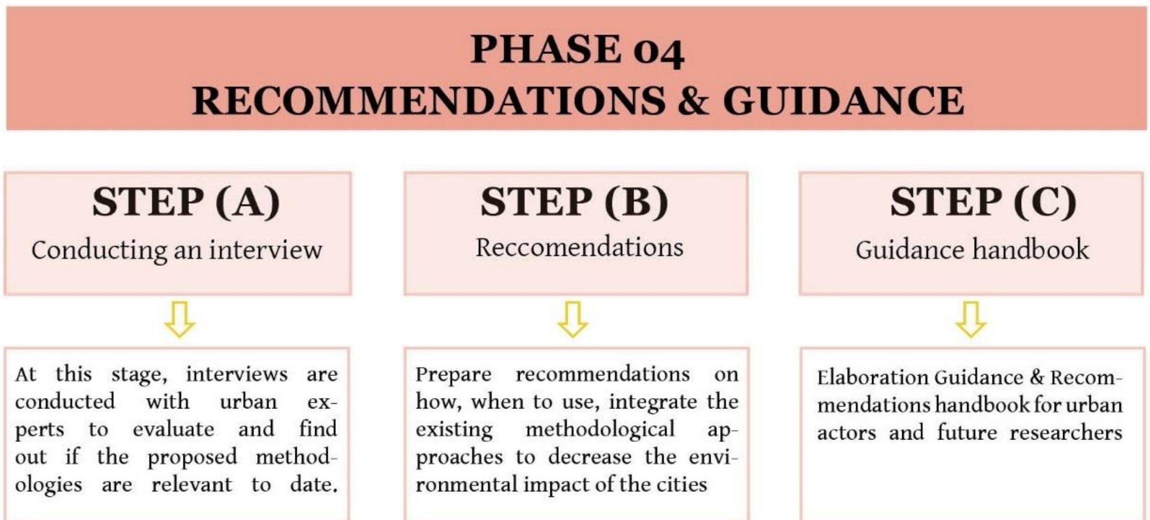


Figure 7: *Recommendations and Guidance Phase.*
Source: Author, 2022.

1. Have you ever implemented those methodologies within your work and expertise? In your opinion did I consider the most important ones? Do you have any suggestion on possible integration in the thesis?

2. What in your opinion are the opportunities and weaknesses of these three methodologies?

3. What are the strong points and limitations of Hybrid methodologies? Why do we need to integrate them? (E.g. LCA & FT, LCA & UM, UM & FT)

4. By what criteria do you choose currently available methods? When I have to use LCA rather than Footprint or Hybrid one? What are the main differences between them?

STEP (B) «Recommendations», aimed at preparation recommendations on selection of existing methodological approaches to decrease the environmental impact of the cities. These recommendations are elaborated to consolidate the main objective of the thesis and assist local urban experts and future researchers in selecting the right tool to tackle the different environmental issues.

The recommendations for urban actors and future researchers are developed using the frameworks from the CESBA Med Commission (2019) and Restrepo Arias et al. (2020). They are focusing at promoting four assessment methodologies known in urban study and providing the advice on the use of a particular tool. They are structured in six points as listed below:

- Name of the Recommendation.
- Scale of Applicability – Neighborhood, Urban, Regional scale
- Linkage with the 17 Sustainable Development Goals (SDGs) outlined by the United Nations General Assembly

Figure 8 : *Example of Sustainable Development Goals (SDGs).*
Source: Wikipedia.

- Background information and justification
- Description of the Recommendation
- Examples and/or references related to the recommendations to reflect the concept behind it

STEP (C) «Guidance Handbook» presents an assessment methodology to assess the environmental impact of products using a Footprint, Life Cycle Assessment, Urban metabolism, and Hybrid. The aim of this handbook is to underline the need to systemize and analysis all available approaches and tools to assist the urban actors/ future researchers use of a particular metrology in different urban context. Therefore, that guidance presents the outcome of the analyzed papers and articles, trends, and concepts of different environmental assessment methodologies. Moreover, advantages and disadvantages that can be outlined in different tools are highlighted. Considering the guidance context, the Handbook includes recommendations and suggestion which lays a foundation to support future work.

CHAPTER 4 - RESULTS

The results are presented in this chapter following the four main Phases of the methodology illustrated in Chapter 3, namely Research, Analysis, Comparison and Recommendations and Guidance.

4.1 FIRST PHASE - Research Results

The Result of First Phase is determining the main methodologies used in urban study. To achieve the result and highlight the main methodologies, the Research results was divided into three steps: “Systematic review methodologies”, “Selected methodologies”, "Selection and analysis of Case Studies".

4.1.1 Systematic review methodologies

A total of 138 papers, ranging from 2005 to 2021, have been selected in this stage (see Fig.9). These papers are composed of 4 groups as follows: 36 papers regarding the Footprint methodology to calculate at different scale, 47 papers that assess Life Cycle Assessment, 40 articles regarding quantification of Urban Metabolism and last 15 paper studies are Integrated Hybrid approaches for the environmental evaluation.

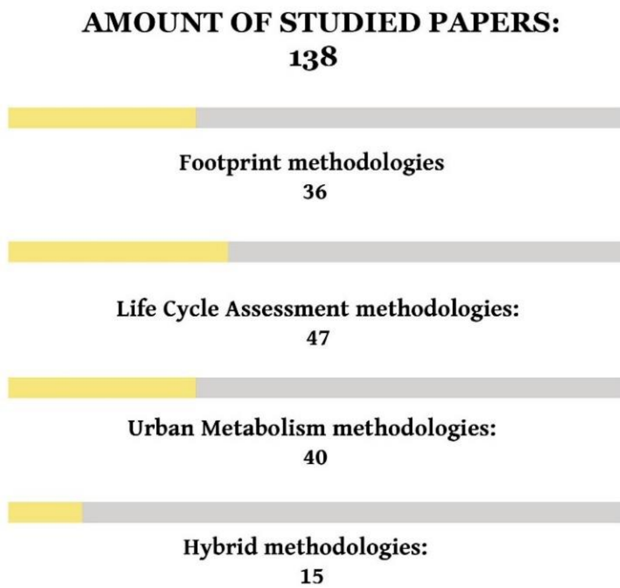


Figure 9: *Amount of studied papers.*
Source: Author, 2022.

Finally, analysis for several urban implementation categories was carried out. The main categories were identified: built environment, water, food, energy system, material cycling, open spaces and green (including aspects related to land, mobility (including the transportation network), waste flow (see Fig.10).

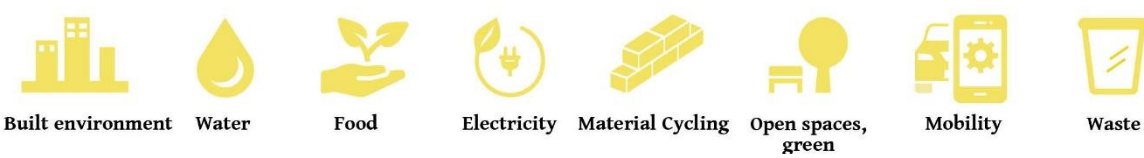


Figure 10: *The representation of the urban implementation categories.*
Source: Author, 2022.

4.1.2 Selected methodologies

It is acknowledged that comprehensive accounting of urban environmental impacts is still immature (United Nations, 2016). Nowadays there are few quantitative metrics available to assess and improve the environmental sustainability of cities. Based on the analyzed literature, the main four methodologies were identified to date: the Ecological and Carbon Footprint, the Urban Metabolism (UM) approach, the Life Cycle Assessment and Hybrid methodologies. (see Fig.11). Figure 11 presents the chronological review of the existing methodologies as of today.

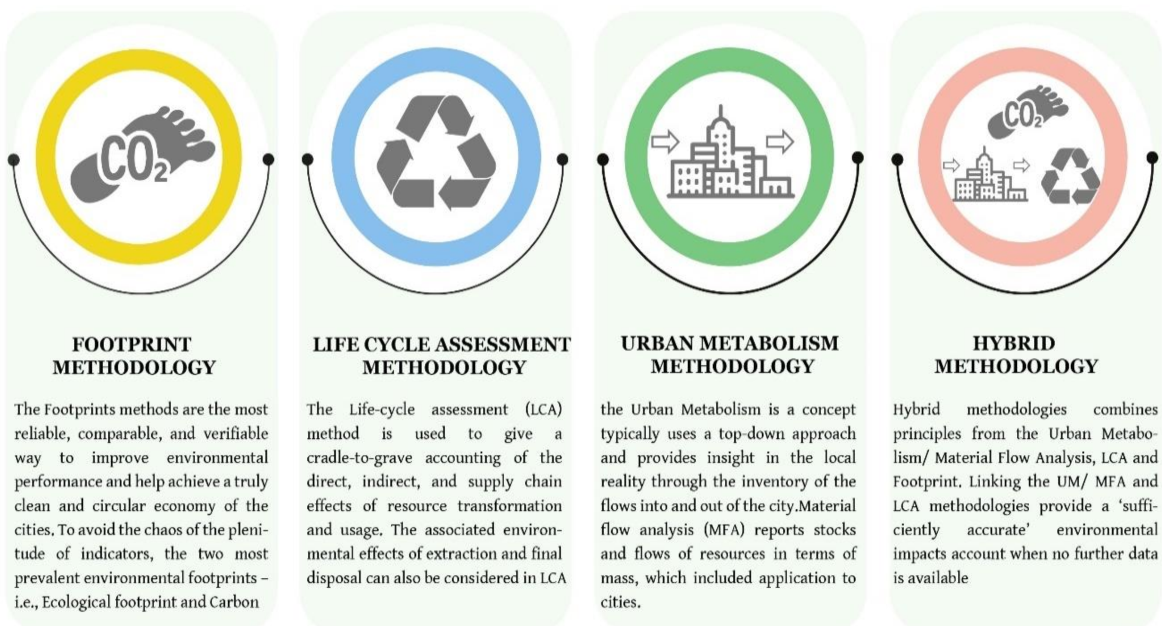


Figure 11*: The main four methodologies existing in urban study.*
Source: Author, 2022.

4.1 First Phase – Research Results

4.1 First Phase – Research Results

Table 2: *Chronological review of the existing methodologies as of today.*

Source: Author, 2022.

4.1.2.1 Footprint methodology

A review of the existing literature in the field of Footprint were collected in relation to the entire urban context. In total 36 papers were analyzed using Footprint methodology. Outline of the major features of the Footprint methodology are presented in Table 3. The overview of the main Footprint case studies is presented in Table 4.

The Footprint is a quantitative tool; therefore, the Footprint data collection method is divided into:

- Bottom-Up approach is used in 42% of reviewed Footprint studies
- Top-Down approach is used in 58% of reviewed Footprint studies

The top-down approach (compound) uses national aggregate input data on production, trade flows (import and export data), and consumption to calculate a nation's Footprint or actual materials and energy flows. This method might make it possible to compare the EF of many different cities across different nations. (Moore et al., 2013; Wilson and Grant, 2009).

The bottom-up approach (component) directly uses city-level data either local monetary input-output data or physical flows of materials and energy collected by the industry to calculate the city Footprint value. (Moore et al., 2013; Wilson and Grant, 2009).

However, this bottom-up approach uses a lot of resources and data, frequently takes longer to execute since the data is unavailable and does not simply allow comparing cities across various countries due to varied data sources and assumptions within the calculation.

Whereas a direct application of the Footprint method to the entire urban scale does not exist yet, Ecological Footprint analyses can allocate total Footprint among implementation categories:

4.1 First Phase – Research Results

FOOTPRINT METHODOLOGY		
CONCEPT	FOOTPRINT AND BIOCAPASITIES	CARBON FOOTPRINT
ORGANISATION	Global Footprint Network 2009	
MAJOR CARACTERISTICS	Assessment of the amount of biologically productive land and human activity that compete for biologically productive space	Assessment of the amount of carbon dioxide emissions
№ ANALYSED PAPER	36 papers from 2005 -2021	
MAJOR VIEWPOINTS	• Quantative method • Consumption-based or input-output analysis (IOA) • Top down method. (24 papers) • Bottom-up method (16 papers) • Combination of "low tech"data(statistics,literature) "high tech data "(detailed GIS data)	
METRIC	Global hectares(gha)	(tCO2)
IMPLEMENTATION CATEGORIES	• mobility • water consumption • energy consumption • waste • food consumption • open space and green	

Table 3: Outline of the major features of the Footprint methodology.

Source: Author, 2022.

Built environment. An essential component of the urban sustainability agenda is the built environment. One of the largest in the spectrum of human endeavors is the contribution of impacts produced by the building industry. Construction-related materials account for over 40% of all materials utilized in the world economy (Lavagna 2008), and up to 30% of all trash produced globally is created in the European Union. Energy consumption in buildings is highly substantial since buildings use direct and indirect energy throughout their life, i.e., from their construction to their demolition (Cabeza et al. 2014).

Water. Water footprint is the amount of water human consume on daily basis, including the water used to grow the food to eat, to produce the energy people use and for all of the products in today's consumer society. Although water is a natural resource used to sustain human daily life, it is not a material generated by a "biologically productive" area, nor a waste absorbed by it. Therefore, the EF method does not calculate the footprint that is directly related to water consumption. On the other hand, the footprint associated with the water delivery system is quantified and then converted into gha. (Genta et al.,2021).

Food. According to study (Crippa, 2021) 71% of food emission in 2015 came from agriculture and related to land use and land-use change activities. Food production is associated with three different types of land: forested area (needed to absorb CO_2 emissions related to the energy consumed to process food); grazing and cropland land.

Energy. According to estimates from UN Habitat (2016), more than 70 percent of the world's energy consumption and GHG emissions occur in metropolitan areas. The four factors that make up ultimate energy consumption in urban systems are heating, cooling, electrical use, and mobility. Most studies that are published in the literature focus on one of the four components or on their energy sources, frequently for carbon emission accounting reasons.

Transportation. Road transportation is a significant contributor to the rise of CO_2 in urban atmosphere, particularly in metropolitan or touristic places where substantial quantities of people move. footprint might help us understand how fossil fuel consumption is currently occurring in a city. To do this, it is important to consider factors such as the quantity of various fuels used over time, the area covered by transportation infrastructure, the energy used during network development.

Waste flow. As cities are often intensive producers in terms of waste, the EF associated with waste produced by households and businesses represents the forested area necessary to absorb the CO_2 emissions produced by combustion, degradation and disposal of waste generated by the various activities of cities.

Overview of the main urban level Footprint application conducted as of today.			
Country	**City**	**Methodology**	**Reference**
Australia	Sydney	Top-down	(Lenzen, 2008)
Brazil	Curitiba	Top-down	(Global Footprint Network, 2010)
Canada	Calgary	Top-down	(Wilson and Anielski, 2005)
	Calgary	Bottom-up	(Global Footprint Network, 2007)
	Edmonton	Top-down	(Wilson and Anielski, 2005)
	Edmonton	Top-down	(Anielski, 2010)
	Québec City	Top-down	(Wilson and Anielski, 2005)
	Toronto	Top-down	(Wilson and Anielski, 2005)
	Vancouver	Bottom-up	(Moore et al., 2013)
	Vancouver	Top-down	(Wilson and Anielski, 2005)
China	Chongqing	Top-down	(WWF, 2012)
	Hong Kong	Top-down	(Global Footprint Network and WWF, 2013)
	Shanghai	Top-down	(WWF, 2012)
	Shenyang	Bottom-up	(Geng et al., 2014)
	Taiwan	Top-down	(Wang and Chou, 2012)
	Tianjin	Top-down	(WWF, 2012)
Ecuador	Quito	Top-down	(Moore and Stechbart, 2010)
Iran	Isfahan	Bottom-up	(Shayesteh et al., 2015)
	Tehran	Bottom-up	(Tavallai and Sasanpour, 2009)
Israel	Beer-Sheva	Bottom-up	(Zeev et al., 2014)
	Ra'anana	Bottom-up	(Kissinger and Haim, 2008)
Italy	Piacenza	Bottom-up	(Scotti et al., 2009)
	Siena (and its Province)	Bottom-up	(Bagliani et al., 2008)
	Turin	Bottom-up	(Genta et al., 2021)
	Turin	Bottom-up	(Genta et al., 2019)
Japan	Kawasaki	Bottom-up	(Geng et al., 2014)
Philippines	Manila	Top-down	(Global Footprint Network and Laguna Lake Development Authority, 2013)
Spain	Madrid	Top-down	(Zubelzu et al., 2015)
United Kingdom	Birmingham	Top-down	(Calcott and Bull, 2007)
	Cardiff	Top-down	(Collins et al., 2006)
	Edinburgh	Top-down	(Calcott and Bull, 2007)
	Glasgow	Top-down	(Birch et al., 2005)
	Greater Nottingham	Bottom-up	(Calcott and Bull, 2007)
USA	San Francisco	Bottom-up	(Moore, 2011)
OAE	Qatar	Bottom-up	(Alhorr et al., 2014)
South Africa	Cape Town	Top-down	(Swilling, 2006)

Table 4 *:Overview of the main Footprint case studies conducted as of today.*
Source: Author, 2022.

4.1.2.2 Life Cycle Assessment methodology

In total 47 papers were analyzed using LCA methodology. Outline of the major features of the Life Cycle Assessment methodology are presented in Table 5. The overview of the main Footprint case studies is presented in Table 6. Although there has not yet been a direct application of the concept to the entire urban scale. The literature for the various urban sub-sectors was examined.

LCA is a quantitative tool and consist of two data collection methods:

- **Process-based LCA**

Process-based LCA is a bottom-up process analysis where a system is represented using its specific information.

- **Input-Output LCA**

It takes sector-wide economy or industry inventory data and breaks it down in a top-down process (Lotteau et al.2015).

The following implementation categories and activities have been identified and are being reviewed: (I) built environment; (ii) energy systems; (iii) water; (vi) waste; (v) consumption patterns; (vi) transportation networks; and (vii) green areas (including land use) urban open spaces:

Built environment. Buildings are responsible for a significant amount of final energy use and greenhouse gas emissions in urban areas. Most existing urban environmental assessments for buildings use top-down or bottom-up methods. Many studies have already used LCT at the building level, concentrating on the design, construction, materials, etc. of individual buildings, but few have used LCA of the built environment at the neighborhood level. There is not comprehensive LCA studies have met the selection criteria.

LIFE CYCLE ASSESSMENT METHODOLOGY	
CONCEPT	LIFE CYCLE ASSESSMENT
ORGANISATION	ISO 14001
MAJOR CARACTERISTICS	Analysing the impact of material goods on their environment
№ ANALYSED PAPER	47 papers from 2005-2017
MAJOR VIEWPOINTS	• Qualitative and Quantative method • Bottom up' approach • Stock Agregation method • Cradle to grave approach
METRIC	kg CO2-equiv
IMPLEMENTATION CATEGORIES	• energy • water • food • material cycling • waste flow • open space and green • built environment • mobility

Table 5 :Outline of the major features of the Life Cycle Assessment methodology.
Source: Author, 2022.

Mastrucci et al. (2017b) evaluated a number of bottom-up LCA studies examining the environmental impact of building stocks at various scale: from urban scale to international one. The archetypal and building-by-building methodologies are used to model individual buildings and extrapolate results at the stock level, according to the authors' findings.

Energy system. Energy consumption has rapidly expanded globally since the industrial revolution as a result of economic growth and population expansion. Moreover 70% of the world's total energy use and GHG emissions, according to estimates, come from metropolitan regions (UN Habitat 2016). The four factors that make up ultimate energy consumption in urban systems are heating, cooling, electrical use, and mobility. Most studies that are published in the literature focus on one of the four components or on their energy sources, frequently for carbon emission accounting reasons. There aren't much research that apply a holistic LCT approach to urban energy systems. Six studies were chosen for this analysis, one at the national scale level and five at the urban scale level.

Three-quarters of Turkey's electricity demand is met by fossil fuel power plants, which were the subject of an analysis by **Atilgan and Azapagic (2015).**

A methodology to evaluate the viability of integrating deep geothermal energy and woody biomass in an urban energy system was presented by **Moret et al. (2016).** The city of Lausanne (Switzerland) is modeled as a multi-period optimization problem with the purpose of determining the overall annual cost while also evaluating the environmental impact using LCA.

The environmental impact of various energy resources used in urban area (such as coal, oil, natural gas, and electricity) was calculated by **Chen et al. (2014)** which were also applied to the case study of Beijing (China). At the size of the urban sector, a second study in a row proposes an optimization model with several objectives (Su et al. 2016). By incorporating the goals of minimal energy use, energy cost, and environmental impact, the model considers the perspectives of energy, economics, and the environment.

The environmental performance of an improved mechanical and biological treatment demo plant erected at Mertesdorf was examined by **Ripa et al. in 2017** in Germany. The plant under the study is created to concentrate the biodegradable portion of municipal solid waste (MSW) and produce a marketable biomass fuel meeting the criteria for biomass power plants to produce urban decentralized heat and power (CHP). Materials, emissions, energy consumption, costs and recovery level were all pointed toward the disposal of 100,000 pounds of waste.

Bonamente et al. (2015) studied renewable energy plant aiming to reduce the primary energy consumption from fossil fuels. The aim of his study is to reduce GHG emissions, to maximize the amount of renewable energy production available in one location, and to use the least amount of land possible. The Italian city of Rome was the subject of a case study. Sewage sludge and biomass digester for urban organic waste is used in conjunction with a photovoltaic and geothermal plant, and other technologies to create a single system.

Water. Water and sanitation issues are expected to get worse in the future due to demographic changes and climate effects that may affect resource availability and demand (UN Habitat 2016).

According to this assessment, one of the most mature areas of use for the LCA technique is the sustainability of urban water management systems. Water and wastewater treatment, management, and supply are all covered in the selected studies. While the remaining research only focus on wastewater services, the majority of the studies under review deal with both water and wastewater systems. The main methodological approach used in all of the research is comparative LCA.

Slagstad and Bratteb (2014) looked at the operation of the city's water and wastewater system's possible environmental impact during the system's entire life cycle.

The environmental impact profiles for two city-scale urban water systems in Australia were created by **Lane et al. (2015).** One system is typical of many urban centers, relying on freshwater extraction and discharging the majority of treated wastewater into the sea. The other system uses a wider variety of water supply and wastewater recycling technologies.

Opher and Friedler (2016) compared the environmental effect of four options for wastewater service system: one conventional linear scenario, three different scales of distribution for the wastewater treatment phase and domestic non-potable water reuse, urban irrigation. Through comparative and consequential LCA, the study provides policy support.

Due to its suitability as a representative of Romania's water services, Iasi (Romania) serves as the reference city for two studies. In the case study **(Barjoveanu et al. 2014)** Iasi's entire water system was analyzed.

A second on Iasi **(Teodosiu et al. 2016),** the environmental impact of municipal wastewater treatment plant discharges was assessed using a variety of methods, including LCA and Environmental Impact Quantification methods.

Mahgoub et al. (2010) assessed the environmental impact of Alexandria's urban water system (Egypt). They looked for solutions to strengthen the system's sustainability.

In Tarragona, **Pintilie et al. (2016)** conducted a comparative LCA to evaluate the environmental costs of several wastewater post-treatment scenarios (Spain). Two options are examined after the ordinary treatment: (a) direct discharge into a natural water stream and (b) tertiary treatment to enable water reuse in the neighboring industrial area. For wastewater line and sludge processing, the wastewater plant uses mechanical and biological treatment.

Liu et al. (2016) examined water supply alternatives in the South-to-North Water Diversion Project's water receiving zones. A water-diversion project that transports water from water-sufficient southern China to water deficient northern China. Because they are the project's key water-receiving zones, Beijing, Tianjin, Jinan, and Qingdao were investigated as representative cities. Because they are the key water-receiving areas of the project, Beijing, Tianjin, Jinan, and Qingdao were investigated as representative cities.

Another set of research examines a process-based method to assessing current infrastructure and identifying major hot spots.

Jeong et al. (2015) conducted an LCA assessment for Atlanta's centralized water system to identify the causes of the most significant environmental impact. The complete metropolitan water system, including water supply, storm water collection, and wastewater collection and treatment, was considered.

Uchea et al. (2013) evaluated the urban water cycle impacts in two Spanish areas: Zaragoza and Gran Canaria. The study's main goal was to determine the relative pollutant weights of the various water cycle phases in two different conditions.

Risch et al. (2015) conducted a comprehensive inventory that included detailed construction and operation of sewer systems and wastewater treatment plants in Grabels, France (Risch et al.2015) Using a combination of primary and secondary data, the attempt is made to estimate the relative contributions of sewer systems to total environmental impacts, considering construction, operation, and finally dismantling and end-of-life alternatives for wastewater treatment and sewer components.

Loubet et al. (2016) developed framework and an associated modeling tool to perform LCA for urban water system. The model WaLA applied to a real-world case study, the urban water system of the Paris suburbs (France). The urban water system must serve many types of users, and 1 m3 of drinking water given to consumers is the related FU. That model represents different components that reflect various technologies, users, and resources, such as drinking water production and distribution, consumers, storm water and wastewater collection and treatment within system boundaries. (Loubet et al., 2016).

The innovative and comprehensive strategy is supported by primary and secondary data (measurement flow meter, calculation from an external model or mass balance result), and it includes stakeholders.

In order to identify impacts caused by withdrawal or release at different sites within the Seine River basin, the ILCD category Bwater resource depletion was replaced with the impact category Bwater deprivation.

Cai et al. (2016) used a fuzzy inexact two-stage programming model to develop an integrated approach for supporting comprehensive decision-making in urban water allocation systems (i.e., to effectively utilize water resources for satisfying multiple targets without causing too much environmental stress). The model was created and integrated with uncertainty and LCA. The study is being applied to the situation in Dalian (China).

Waste. As cities are generally producers of waste, the linked industry is one of the most closely monitored and present in literature, as demonstrated by this review.According to studies conducted in developing countries, there is an urgent need to replace or reduce waste.Review research gives an overview of strategic choices in critical conditions, such as those encountered by developing countries, where increasing rates of urbanization and product consumption, as well as a lack of proper waste management systems, exacerbate the situation (Othman et al. 2013). The review is based on a selection of MSW management strategies in several Asian nations, with an emphasis on LCA as an integrated approach to choose the most desirable and environmentally friendly choice.

Coventry et al. (2016) offers results from a comparative LCA of four solid waste treatment systems for Austin, Texas, which is defined as a typical US metropolis. Austin was chosen as a case study due to its waste management and waste treatment technology alternatives, which might accurately represent the most typical circumstances in North America. The four cases collectively represent the fate of nearly 100% of all non-recycled MSW in the United States. Moreover, the general spectrum of MSW treatment technologies accessible for US cities ranging from industry standard to pilot-scale.

Ghinea et al. (2012) used a similar technique while comparing four distinct scenarios developed as alternatives to the existing waste management system in Iasi (Romania), emphasizing on the impact of system limits. All management scenarios consider the collection of the annual amount of MSW generated in Iasi City from residential areas, their transportation, and various treatment options (recycling, composting, landfilling).

Chi et al. (2015) provides an additional comparison to compare the business-as-usual system in Hangzhou (China) with alternate waste management scenarios.

Finally, Erses Yay (2015) conducted a study for the city of Sakarya to assess the environmental aspects of less impactful MSW management (Turkey).

A second series of studies investigates and compares urban waste to energy possibilities. **Gunamantha and Sarto (2012**) provide a comparison of Asian waste-to-energy management procedures in the intercity areas of Yogyakarta, Sleman, and Bantul (Indonesia).

Grosso et al. (2012) conducted a comparative LCA of two distinct food waste management solutions based on an investigation of a real metropolitan setting (Milan, Italy).

Bezama et al. (2013) propose a third waste-to-energy case study, in which they technically investigated suitable and improving opportunities to compare with landfill project in Coyhaique (Argentina).

The final set of articles evaluated tried to provide a more comprehensive assessment of sustainability by combining social and economic concerns or assessments.

Koroneos and Nanaki (2012) evaluated the environmental performance of various MSW treatment systems for Thessaloniki.

Reichert and Mendes (2014) assessed eight possible scenarios for MSW management in Porto Alegre. All of which were prepared with the collaboration of social and technical municipal stakeholders. The results were then combined with social and economic qualitative indicators (e.g., job quality and quantity, investment and costs, etc.). The aim of the case study is improving the results and provide further assistance to integrate social and economic sustainability.

A third study examines the economic and environmental aspects of sludge management in Hong Kong (Lam et al. 2016). The suggested eco-efficiency analysis methodology includes environmental and economic criteria based on LCA and LCC. The framework's goal is to give credible information for sustainable town planning based on decision-makers' priorities.

Finally, **Teixeira et al. (2014)** describe a methodological tool for assessing the operational, economic, and environmental aspects of MSW collection. The suggested tool evaluates independent operational and economic efficiency and performance of collection procedures using key performance metrics.

The last study focusses on the application of LCA methodology to help waste prevention measures and urban planning. **Cleary's (2013)** study compares lightweight and refillable packaging alternatives to traditional single-use glass bottles in Toronto.

A new greenfield settlement with carbon neutral objectives was proposed in Trondheim, and the business-as-usual plus four possible scenarios for the new settlement's waste management system were compared **(Slagstad and Bratteb 2012)**. Over a one-year period, the waste management system must ensure the collection, transportation, and treatment of waste streams containing mixed trash, paper, plastic from 1500 new dwellings (3315 people).

Transportation. The transportation sector is often critical topic in urban policies, particularly in metropolitan or touristic towns with high population flows. Because transportation involves dynamic fluxes in time and space, collecting high-quality data is frequently necessary.

In terms of impact assessment and energy are key priority, particularly in the context of North America. Indeed, only several studies use LCA to assess a wide variety of effect categories, while the others focus solely on energy and/or GHG emissions using an LCT method.

François et al. (2017) provide a comprehensive mobility assessment by evaluating the transportation system using an LCT method. The model is built on a city commuting scale and may evaluate the economic, environmental, and social impact of various public policies in transportation planning. The authors define urban mobility in this study as the activity that allows persons living or working in an urban area to travel during the working day; thus, the FUs evaluated are person per kilometer and per trip daily.

Another use of LCA for policy assistance was studied by **Vedrenne et al. (2014),** who assessed the potential advantages of policy actions to renovate Madrid's municipal taxi fleet. Data from Madrid's nine traffic control zones, as well as a specialized traffic model combined with GIS, were collected to model the vehicle's use phase. The impact assessment phase was carried out utilizing the ILCD approach, which compared several scenarios.

Simon et al. (2010) aimed to investigate the annual environmental impact of the public bus transportation system utilized in Hungarian cities, using Budapest as a case study. Liu et al. (2016), Nichols and Kockelman (2015), Fraser and Chester (2016), and Shahraeeni et al. (2015) conducted urban transportation LCAs that focused solely on energy consumption and/or carbon footprint. The case study considers the innovative and comprehensive manner to model urban transportation patterns.

Liu et al. (2016) evaluated different means (including aviation, intercity bus, and vehicles) in terms of energy consumption, CO2 emissions. The evaluations focus on 165 intercity travels (varying from 200 to 1600 km) between 79 locations in the United States and Canada.

Nichols and Kockelman (2015) combined everyday operations and their embodied energy demands to model urban transportation behaviors and estimate life-cycle energy in various urban contexts. The investigation considered different neighborhood area in Austin (Texas, USA). It considers five different city types in North American cities in terms of accessibility and and employments. Various surveys and literature were used to collect data, which was then converted into energy use.

Fraser and Chester (2016) created a methodology and an operational LCA tool (City Road Network) to examine the extent to which roadway commitments have long-term and escalating environmental and economic implications. The suggested paradigm aims to improve knowledge of sustainability and it is transferable to other permanent urban infrastructure systems.

Finally, **Shahraeeni et al. (2015)** used statistical data and models to assess the environmental performances of light duty commercial vehicles driven by compressed natural gas and diesel under typical North American conditions.

Consumption patterns. With the rise of the industrialization and capitalist eras, a massive amount of commodities are created and consumed globally. The European Union-28, China, and the United States have been the three most important worldwide actors in international commerce, with the European Union-28 accounting for 3.517 billion € in 2015. (Eurostat 2016). Consumption is also promoted as one of the best remedies for economic crisis, a remedy that frequently culminates in consumerism.

In any case, it is obvious that people require household products in order to sustain their lives and activities. According to **Ivanova et al. (2016**), household environmental pressure accounts for more than 60% of worldwide GHG emissions and between 50 and 80% of overall resource utilization. Consumption sociology has made progress in finding and dissecting several mechanisms that maintain and expand demand for services and goods but supporting tools for an adequate environmental evaluation and comparison of goods and scenarios remain insufficient (Padovan et al. 2015).

The consumption sector becomes strategic and recognizing and acting on present consumption tool could be a way to move cities and their residents toward a more sustainable way of living. Nonetheless, comprehensive LCA studies focused on urban consumption patterns that are few in the literature, with just three articles identified to be relevant for this issue.

Heinonen et al. (2013a, b) investigated the urban form-lifestyle relationships in Finland, as well as the resulting GHG emissions embedded in various goods and services, using both monetary expenditure and time use data to depict lifestyles in four basic urban forms: metropolitan, urban and rural. For each of the four types of living locations, statistical household and time data on a comprehensive basket of consumption products (comprising 12 categories and divided into 52 sectors) for one citizen were collected over a one-year period.

The second section of the study **(Heinonen et al. 2013b)** focuses on the middle-income category and examines lifestyle differences when budget limitations are equal. The authors include the factors dwelling type and motorization in this assessment.

Kalbar et al. (2016) investigated consumer lifestyles using several methods. A systematic commodity consumption, commodity disposal, and lifestyle study of 1281 people living in urbanized Danish areas (specifically, Personal Metabolism (PM) patterns, consumption method) was done The authors identified direct and indirect flows connected to consuming patterns such as food, lodging, energy use, road transportation, and air travel using a combination of primary and secondary data corresponding to the consumption of one resident each year.

Urban green. Cities both effect and rely on the hinterlands for resources such as food, energy, and services. Urban planners are recognizing that cities play a vital role as environment managers (Elmqvist et al. 2013). However, there is a gap between using resources for metropolitan regions and protecting or conserving ecosystem services that exist outside of urban areas. The ability of the LCA technique to capture both direct and indirect impacts can assist to avoid that gap, but the topic is unfortunately neglected, and only two contributions were chosen for the scope of this review.

Using LCA and a stochastic urban watershed model, **Spatari et al. (2011)** investigated the energy and greenhouse gas emissions of various Low Impact Development (LID) techniques applied to a neighborhood in New York.

Rothwell et al. (2015) analyze the provision of another ecological service. The authors developed a technique for integrating housing and agricultural production land uses in peri-urban areas based on relative environmental consequences, using a fictional city in the Australian context as a case study.

4.1 First Phase – Research Results

LCA case studies		
Impact category	**Country**	**Reference**
Built environment	Different countries	(Mastrucci et al., 2017b)
Energy system	Turkey	(Atilgan B, Azapagic A., 2015)
Energy system	Switzerland	(Moret et al., 2016)
Energy system	China	(Chen et al., 2014)
Energy system	China	(Su et al., 2016)
Energy system	Germany	(Ripa et al., 2017)
Energy system	Italy	(Bonamente et al., 2015)
Water	Norway	(Slagstad and Bratteb, 2014)
Water	Australia	(Lane et al., 2015).
Water	Israel	(Opher and Friedler, 2016)
Water	Romania	(Barjoveanu et al., 2014)
Water	Romania	(Teodosiu et al., 2016)
Water	Egypt	(Mahgoub et al., 2010)
Water	Spain	(Pintilie et al., 2016)
Water	China	(Liu et al., 2016)
Water	U.S	(Jeong et al., 2015)
Water	Spain	(Uchea et al.2013)
Water	USA	(Risch et al.,2015)
Water	France	(Loubet et al.,2016)
Water	China	(Cai et al.,2016)
Waste	Asian countries	(Othman et al. 2013)
Waste	USA	(Coventry et al.,2016)
Waste	Romania	(Ghinea et al.,2012)
Waste	China	Chi et al. (2015)
Waste	Turkey	Erses Yay (2015)
Waste	Indonesia	Gunamantha and Sarto (2012)
Waste	Italy	Grosso et al. (2012)
Waste	Chile	Bezama et al. (2013)
Waste	Greece	Koroneos and Nanaki (2012)
Waste	Brazil	Reichert and Mendes (2014)
Waste	China	(Lam et al. 2016
Waste	Portugal	Teixeira et al. (2014)
Waste	Canada	Cleary's (2013)
Waste	Norway	(Slagstad and Bratteb 2012)
Transportation	France	François et al. (2017)
Transportation	Spain	Vedrenne et al. (2014)
Transportation	Hungary	Simon et al. (2010)
Transportation	USA	Liu et al. (2016)
Transportation	USA	Nichols and Kockelman (2015)
Transportation	USA	Fraser and Chester (2016)
Transportation	USA	Shahraeeni et al. (2015)
Consumption patterns	Different countries	Ivanova et al. (2016)
Consumption patterns	Finland	Heinonen et al. (2013a, b)
Consumption patterns	Denmark	Kalbar et al. (2016)
Urban green	Netherlands	Elmqvist et al. 2013)
Urban green	USA	Spatari et al. (2011)
Urban green	Australia	Rothwell et al. (2015)

Table 6:Overview of the main LCA case studies conducted as of today.

Source: Author, 2022.

4.1.2.3 Urban metabolism methodology

A summary of the reviewed UM studies reveals that more than 30 different cities have been assessed. They are widespread over the world but are primarily found in Europe (more than 14 cities) and Asia (more than 8 cities). The period coverage varies greatly from 2005 to 2016. In 2007, Kennedy et al. (2007) made the following claim in his review: “With data from metabolism studies in eight cities, spread over five continents and several decades, observation of strong trends would not be expected”. This statement emphasizes the necessity for UM evaluation methodologies to address a wide range of sustainability issues because cities all over the world face unique challenges that require different scopes. In total 40 case studies were analyzed and the outline of the major features of the UM methodology are presented in Table 7. The overview of the main UM case studies is presented in Table 8 and 9.

The flows of the urban metabolism can be estimated in a variety of methods and there is no right technique to identify flows. However, there is two main methods:

- **bottom-up method** is typically providing more information about a city (such as how much water is utilized) and tend to be time consuming and data intensive. Since it might be challenging to disaggregate data from the national size to the urban scale, the bottom-up approach is also more accurate tool. By requesting information from the appropriate authorities, it is possible to identify the bottom-up flows. The local companies, for instance, can provide data on flows related to the consumption of water, electricity, gas, and other resources. However, gathering these data might be difficult because local companies might not even have access to data (Derrible et.al.,2021) Bottom-up data is typically used in the process-based LCA method.

- **top-down** method is based on economic input-output data and may be easier to apply and relies on global datasets, which makes easier to create time-series assessments to monitor development over time. From the top-down method, economic input-output (IO) data can be gathered at the country level and then disaggregated to the city level.

URBAN METABOLISM METHODOLOGY	
CONCEPT	**URBAN METABOLISM**
ORGANISATION	European Commission 2010
MAJOR CARACTERISTICS	UM is largerly an accounting tool measuring inputs and waste flows
№ ANALYSED PAPER	40 papers from 2005-2016
MAJOR VIEWPOINTS	• Quantative method (quantifying energy flows) • Top-down method • Bottom-up method • Material flow analysis(e.g. mass flow) Input/Output Approach
METRIC	kg,t/cap
IMPLEMENTATION CATEGORIES	• energy • water • food • materials • waste flow

Table 7:*Outline of the major features of the Urban Metabolism methodology.*
Source: Author, 2022.

With all environmental assessment techniques, top-down data have been used in more over 65% of the UM studies that have been selected. Every UM study that used MFA included top-down data from a specific year, and the models frequently did not provide insights on how the urban region and its activities were changing. Only a few MFA studies describe the drivers (such as population increase and densification) that they used to predict the evolution of UMs. 20% of the reviewed UM studies which use the bottom-up tool were not included in the selected literature since as was mentioned before the Bottom-up tool is typically used in the process-based LCA method.

Other approaches including using emergy, ecological, or environmental network analysis and other methodological advancements have found lesser momentum but can be powerful tools for UM study (Derrible et.al.,2021).

Finally, the remaining studies that were assessed (less than 9%) did not provide enough details to determine the type of data that was used. This last score indicates a lack of transparency in the case study descriptions.

Overview of Input/Output studies		
Notes/contribution	**City/ Country**	**Reference**
Assessment of urban energy use	Melbourne, Australia	(Baynes et al., 2011)
Assessment of energy for houshold	Sydney, Australia	(Lenzen et al., 2004)
Urban solid waste recycling	Suzhou, China	(Liang and Zhang, 2012 2011b)
The energy and mass balance	Los Angeles,USA	(Ngo and Pataki, 2008)
Analysis for GHG emission of the case study	Beijing, China	(Xia et al., 2015; Yi et al., 2007)
Urban Metabolism concept applied for the case study	Budapest, Hungary	(Pomazi and Szabo, 2009)
The LCA framework applied for case study	Beijing,China Cape Town,South Africa Hong Kong,China London,UK Toronto, Canada	(Goldstein et al., 2013)
The LCA framework applied for case study	Quartier Vauban, Freiburg	(Herfray et al., 2011)
The LCA framework applied for case study	Paris,France	(Loiseau et al., 2014)
The Life Cycle Assessment applied to urban design	Freiburg,Germany	(Peuportier et al., 2012)

Table 8 *:Overview of Input/Output studies.*
Source: Author, 2022.

Chronological review of urban metabolism studies. Flow analysis method used in UM studies		
Notes/contribution	**Country/ City**	**Reference**
Material Flow Analysis (MFA)	Berlin, Germany	(Baccini and Brunner, 2012)
Material Flow Analysis (MFA)	Dalian, China	(Bao, 2010)
Material Flow Analysis (MFA)	Paris, France	(Barles, 2009, 2007a)
Measures product and waste flows	Paris, France	(Billen et al., 2009)
Material Flow Analysis (MFA)	Irish city-region, Ireland	(Browne et al., 2011, 2009, 2005)
Assessment of total urban metabolism	Toronto, Canada	(Codoban and Kennedy, 2008)
Assesment of metal flow	Stockholm, Sweden	(Cui et al., 2009)
Relationship between metabolism and city surface		(Deilmann, 2009)
Energy metabolism	Prague, Czech	(Fikar, 2009)
Nitrogen balance for the urban food metabolism	Toronto, Canada	(Forkes, 2007)
Assessment of total urban metabolism	Prague, Czech	(Garcia et al., 2009)
Socio-metabolic transition	Czech,Slovakia	(Kuskova et al., 2008)
Assessment materials and energy flow, case study	Curitiba,Brazil	(Conke and Ferreira, 2015)
MFA applied for the case study	Jinchang, China	(Li et al., 2016)
MFA of inputs and outputs	Chinese Cities	(Liang and Zhang, 2011)
Assessesment water flows	Lisbon, Portugal	(Marteleira et al., 2014)
MFA applied for the case study	Viena, Austria	(Niza et al., 2016, 2009)
MFA applied for the case study	Lisbon, Portugal	(Rosado et al., 2016, 2014)
MFA applied for the case study	Singapore, Singapore	(Schulz, 2007)
MFA applied for the case study	Greater Moncton, Canada	(Thériault and Laroche, 2009)
Energy flow applied for the case study	Beijing, China	(Zhang et al., 2014, 2013)
	Xiamen, China	(Zhao, 2012)

Table 9*: Chronological review of urban metabolism studies. Flow analysis method used in UM studies*

Source: Author, 2022.

4.1.2.4 Hybrid methodology

A summary of the reviewed UM studies reveals that 15 different cities have been assessed. They are widespread over the world. The period coverage varies greatly from 2005 to 2021. Different hybrid techniques are covered by this review to draw attention to the ongoing studies. For example, hybrid techniques, which combine LCA with other top-down methodologies (UM, Input-Output Analysis, etc.) or other technical tools used in urban planning and administration, such as geographic information systems (GIS) and remote sensing were found in the literature. The most important key feature was highlighted, and a summary is provided in Table 10. The overview of the main Hybrid case studies is presented in Table 11. The results provide hybrid techniques available at the urban scale level, as well as the usage of supporting spatial tools:

Goldstein et al. (2013) concentrated on the application of the LCA framework to the idea of urban metabolism (UM). Using the product system modeling software GaBi 4.4 along with the ecoinvent 2.0 database and national statistics, a hybrid UM-LCA model was applied to five case cities (Cape Town, London, Hong Kong, Beijing, and Toronto), taking into account the metabolic flows of food, construction materials, buildings, energy, and industry. The FU takes a cradle-to-grave approach and evaluates the material, social, and institutional demands of a single city citizen over a year.

Clark and Chester (2017) integrated UM with LCA, using vehicle mobility in the Phoenix metropolitan region. UM framework is used to examine the direct energy flows of fuel and vehicles in Phoenix, and it is then combined with a process based LCA to evaluate indirect flows during the fuel feedstock phases. The author takes advantages of estimations and model to estimate inbound and outbound journeys as well as related data. The impact assessment is limited to energy and GHG emissions and energy. Moreover, using the GREET model, a process based LCA model for both vehicle and fuel created by the US Department of Energy.

HYBRID METHODOLOGY

CONCEPT	FT & LCA	LCA & UM	UM & FT
ORGANISATION	Global Footprint Network ISO 14001	ISO 14001	European Commission, 2010 Global Footprint Network
MAJOR CARACTERISTICS	Comprehensive urban environmental assessment of energy and material use in cities	Comprehensive urban environmental assessment of energy and material use in cities	Quantify and assess urban environmental loads
№ ANALYSED PAPER	paper from 2007 - 2021	papers from 2007-2021	papers from 2007-2021
MAJOR VIEWPOINTS	• Qualitative and Quantative method • Input-output approaches • Combines Top-down and Bottom up methods • Combination of "low tech"data(statistics,literature) "high tech data "(detailed GIS data)	• Qualitative and Quantative method • Material flow analysis (MFA) tool & Bottom-up approach (process-based LCA method)	• Qualitative and Quantative method • Direct component analysis • Bottom up methods • Both use material flow analysis
METRIC	kg CO2-equiv gha per capita	kg CO2-equiv kg,t / cap	kg,t / cap gha per capita
IMPLEMENTATION CATEGORIES	• build enviroment • energy • waste • water • mobility • urban spaces and green • food • material cycling		

Table 10: *Outline of the major features of the Hybrid methodology.*
Source: Author, 2022.

Gerber et al. (2013) suggested a systematic framework for designing sustainable process systems that integrates industrial ecology, LCA, process design and process integration. An application to the environmental and economic design of an urban energy system in La Chaux-de-Fonds exemplifies the paradigm (Switzerland).

Padeyanda et al. (2016) conducted MFA and LCA analyses to investigate various food waste recycling facilities to identify ecologically viable option for the Daejeon Metropolitan City (South Korea).

Ulgiati et al. (2011) used a multi-method multi-scale assessment procedure (SUMMA) based on LCA to generate consistent performance indicators based on the same set of input data and to emphasize the importance of a multiple points of view for the proper environmental assessment.

Kissinger et al. (2013) examine the material consumption component of ecological footprint along with LCA approach for solid waste. The approach uses data that many communities collect about municipal solid waste composition.

Mastrucci et al. (2017a) propose developing a framework for characterization of building material stocks and assessment of potential environmental impacts connected with the end-of-life of buildings at the metropolitan scale. The case study aims to assist waste management strategy decisions. The methodology combines a bottom-up material stock model based on GIS and a spatial-temporal database with life-cycle assessment (LCA) to evaluate end-of-life situations. The framework is used to assess the housing stock in Esch-sur-Alzette (Luxembourg).

Cousins and Newell (2015) offer a political-industrial ecology approach to investigating Los Angeles' urban water metabolism, combining theory and method from urban ecology. The city's historical and political context are said to call into doubt the possibility of more environmentally friendly choices.

The conversion of data from site-generic or site-dependent LCA into smaller spatial units is referred to by **Liu et al. (2014).** This is accomplished using GIS, because the authors believe that GIS has the potential to easily assign potential impacts to smaller spatial units.

Davila and Reinhart (2013) provide an analytical framework as well as a new Rhino3d CAD tool for estimating the total embodied energy content of an urban design concept.

Mirabella and Allacker (2018) present a concept of a new methodological approach, the City Environmental Footprint (City EF). The proposal is to develop an LCA-based approach, such as City Environmental Footprint that combines elements from top-down and bottom-up methodologies. Such a combination of both approaches results in a more precise and detailed data inventory and modeling.

Li et al.(2021) propose GIS-LCA methodology framework, namely the geographic information system (GIS) is integrating into LCA as a frontier methodology to spatialize the environmental footprint. In particular a geographically referenced system is established in the aim and scope description by systematically specifying the geographic scope of the study region, spatial characteristics of key unit processes, and spatial resolution required for analysis. During the LCI analysis phase, an implementation method for the spatialization of life-cycle data is established.

Moore et al. (2013) introduce a detailed, bottom-up urban metabolism and ecological footprint analysis for a North American metropolitan region. It aims to demonstrate the application of a bottom-up ecological footprint analysis using an urban metabolism framework at a regional scale. The authors show why and how the methodological approach for subnational ecological footprint research is based on economy-wide input-output estimates, which is standard in Europe. They show how to apply an alternate way, the direct component approach, which we believe can be more effective in addressing local government concerns and interests in the North American setting.

Garc´ıa-Guaita et al. (2018) carried out a simplified MFA-LCA analysis of the city of Santiago de Compostela (Spain) based on 7 primary flow: climate change, ozone layer depletion, terrestrial acidification, freshwater eutrophication and human toxicity. The combined MFA-LCA methodology takes into account all of the background and foreground flows involved with a city's metabolism, groups them into specific impact categories, and finally identifies the sectors causing those impacts.

Goldstein et al. (2013) present a UM-LCA model that improves on previous UM methods for quantifying mass and energy flows through cities. The hybrid model approach also allows for the identification of the dominant sources of a city's various environmental footprints, making UM-LCA a novel and potentially powerful tool for policymakers in developing and monitoring urban development policies.

Chester et al. (2012) propose that urban sustainability assessments should incorporate urban metabolism and life-cycle impact assessments in order to provide an integrated multi-scale framework for assessing resource depletion and environmental impact within the city.

Goldstein et.al. (2013) Integrate UM with life cycle assessment (UM-LCA) to measure the environmental impacts of cities by simulating pressures embedded in the flows entering and leaving the actual urban systems examined. The developed UM-LCA approach provides better quantification of mass and energy flows through cities than previous UM techniques.

Ipsen et al. (2018) investigated the impact of seven different Smart City Solutions (SCSs) on an urban system from a UM-LCA perspective. The assessment is carried out using a UM-LCA technique, which combines urban metabolism (UM) and life cycle assessment (LCA). Using this approach, all life cycle stages of metabolic fluxes can be accounted for, and load shifting from one stage to another is quantified and hence transparent. The ReCiPe method is used for the impact evaluation.

Integrated (combination of the previous methods)		
Impact category	**Country**	**Reference**
EF and LCA	Denver,US	(Hillman and Ramaswami, 2010)
Industrial and Energy Structure Optimization, Energy Saving, Circular Economy	Shangai, China	(Lu et al., 2016)
Energy Flow Accounting, LCA and Energy Footprint	Barcelona,Spain	(Oliver-Sol a et al., 2007)
Economic Cost Analysis and Emergy Index	Uppsala, Sweden Stockholm,Sweden	(Russo et al., 2014) (Shahrokni et al., 2015)
(LMDI) methods and Emergy Index	Shenyang,China	(Sun et al., 2016)
Input-Output (MRIO) and Ecological Network Analysis	Beijing,China	(Zheng et al., 2016)
DEA method and Window Analysis	Taipei City, Lienchiang County Taiwan	(Yang et al., 2016)
GIS and LCA	Different countries	(Junjie et al.,2021)
UM and LCA	Beijing,China	(Goldstein et al.,2013)
UM and EF	Cape Town, South Africa. Hong Kong,China London,UK Toronto, Canada Vancouver, Canada	(Moore,2013)

Table 11: *Overview of the main UM case studies conducted as of today, Source Author. Source: Author, 2022.*

4.1.3 Selection and analysis of Case Studies

Taking into account all methodological approaches and tools from the literature review, the fourth case studies were selected and analyzed, Beer Shea, Vienna, Curitiba, Porto, and Denver. The proposed case studies were selected from articles, reviews, and reports about implementation of methodologies towards sustainable cities. Moreover, they are also useful as example of the application of the indicator on the real projects.

4.1.3.1 The Case of Beer Sheva, Israel

An illustration of the domestic and global hinterlands of the city of Beer-Sheva (Zeev et al., 2014).

This case study examines the urban hinterland of Beer-Sheva and use an extended ecological footprint analysis method. The detailed local consumption data was used to calculate the global average data and domestic share of the footprint. The domestic biocapacity area also were analysed from the area needed abroad.Two main types of data are necessary to calculate the city's ecological footprint: :(a) material/energy consumed used in a range of activities, sectors and services in the examined city; (b) a set of conversion coefficients that enable converting urban activities into the corresponding land areas needed to support the activities over the time.

Figure 12:*Beer Sheva city, Israelю Source: Wikipedia.*

The following categories of activity/consumption are the subject of study: food, materials, electricity, transportation, and water (see Fig. 13). The area of biologically productive land required to produce the various material and energy inputs is included in Beer-ecological Sheva's footprint. The data was integrated from domestic, national and international sourse. The footprint conversion coefficients were obtained from the Global Footprint Network and from Kissinger et al., 2013 (GFN, 2009).

4.1 First Phase – Research Results

	Urban scale	National Scale	International and Global Scale
Electricity Use 	• Promoting local energy efficiency programs • Promoting energy saving educational programs	• Promoting and financing energy efficiency and saving programs. • Reducing emissions from electricity production by changing fuel composition (e.g., less coal more natural gas) • Advancing the use of renewable energy sources • Implementing international GHG emissions targets.	• Advancing global agreements on climate change mitigation. • Developing new energy efficiency technologies • Developing renewable energy technologies
Transportation 	• Urban transportation planning – increasing urban walkability, the use of public transportation, mixing land use etc.	• National transportation plan • Supporting cities by funding domestic infrastructure. • Investing in public transportation • Regulating the use of different types of vehicles (e.g., taxing high emitter vehicles) • Implementing international GHG emissions targets	• Advancing global agreements on climate change mitigation. • Supporting the advancement of new transportation technologies.
Food 	• Advancing urban agriculture • Promoting education programs about food losses	• National food supply policy • Advancing sustainable trade agreements • Advancing domestic food production • Promoting sustainable diets (e.g., less meat or any other items with significant footprint)	• Advancing more efficient food technologies (e.g., increasing yields, minimizing energy and chemical inputs).
Materials 	• Promoting education programs on sustainable consumption • Advancing 'zero waste' programs	• Regulate the use of various materials.(e.g., reducing the use of non-recyclable materials) • Advancing sustainable trade agreements • Promoting economically based mechanisms (tax, subsidies etc.) to minimize waste generation • Advancing national waste management policies	• Supporting the advancement of new technologies.

Figure 13 *:Categories of activity/consumption.*
Source: (Zeev,2014).

The following equation were used to calculate the size of the domestic and overseas land hinterland that sypply food and materials:

$$EF_{(cpf)} = \sum \left(\frac{C_{(Dcpf)}}{DY_{(Dcpf)}} + \frac{C_{(Icpf)}}{WY_{(Icpf)}} \right) \times EQF_{(Cpf)}$$

Figure 14: *Equations to calculate the size of the domestic and overseas land hinterland.*
Source: (Zeev,2014).

The following equation is used to calculate the footprint of the energy land needed to capture the carbon dioxide associated with energy use in the city (both direct and embodied):

$$EF_{(e)} = \sum PS \times C_{(e)} \times EQF_{(e)}$$

Figure 15 *: Equations to calculate the size of the domestic and overseas land hinterland. Source: (Zeev,2014).*

After calculating the ecological footprint of each component, the ecological footprint was divided into domestic and global hinterland. According to this case study, there are two main types of hinterland that support cities: hinterland of crop, pasture, and forest land that provides the city with food and materials, and hinterland of energy land that captures CO_2 emissions from city activities.

The overall footprint of Beer-Sheva is 3.98 gha per capita. Footprint per capita is shown in Fig. 1 broken down into three types of hinterland: built land; forest land (which includes forest products and forest that serves as energy land); and agriculture (crop and pasture fields). It also separates the area supporting the city into domestic and global. It is clear from Fig. 1 that the largest category is connected to direct and embodied use of energy. The chart also shows the domestic carrying capacity for each land category and the global carrying capacity for each. The study found that 94% of Beer-Sheva's hinterland is situated outside Israel. Furthermore, only 1% of the footprint of the city falls within the city boundaries, while the remaining 5% of the city's hinterland is located in other parts of the country. According to the study, 94% of Beer-hinterland Sheva's is located outside of Israel. Furthermore, only 1% of the city's footprint is contained within its boundaries, with the remaining 5% located in other parts of the country.

4.1 First Phase – Research Results

The size of the hinterland required for the various urban components covered by this study is shown in Fig. 16. Food consumption (1.82 gha per capita) is the primary category, followed by electricity use (0.85 gha per capita), materials (0.74 gha per capita), transportation (0.31 gha per capita), and built area (0.16 gha per capita).These components are examined in Table 18. The land needed to produce food and the energy land needed to store CO2 emissions from food production operations are both included in the food footprint. It draws attention to the considerable impact that animal-based products have on the urban footprint. As can be seen, most of that hinterland—pasture, feed, and forest land—is outside of Israel. Two food categories, fruits, and vegetables are farmed domestically, despite the fact that more than 95% of the world's food footprint is international. Even still, the energy needed for this local production (for the use of the machinery, fertilizers, transportation, etc.) is substantial. This usage of fossil fuel energy necessitates storage of emissions in foreign hinterlands. As a result, it

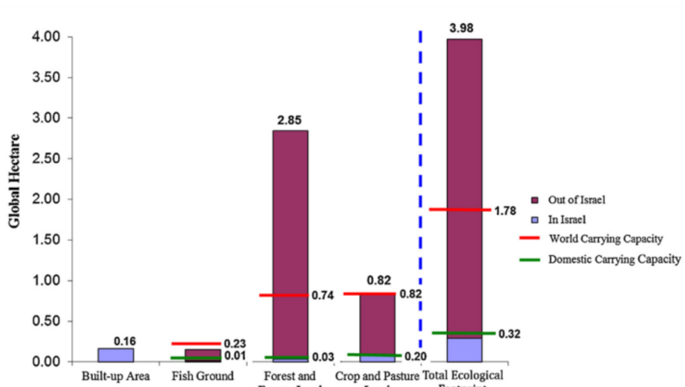


Figure 17: *Ecological footprint components of Beer-Sheva 2007*

Source: (Zeev,2014).

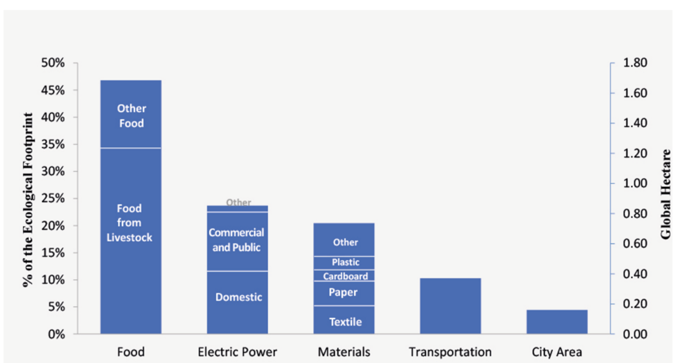


Figure 16 :*Hinterland types per capita urban ecological footprint, Beer-Sheva 2007.*

Source: (Zeev,2014).

appears that in the instance of Beer-Sheva, even goods like locally grown crops entail far-off hinterlands. A sizable global hinterland is also needed for the other aspects of urban activities, namely, to trap emissions related to energy use.

	EF in Israel (global hectares)	EF out of Israel (global hectares)	EF in Israel (global hectares)	EF out of Israel (global hectares)	
Total EF	47,408	163,592	6195	523,337	740,530
Food	17,563	163,592	1887	159,435	342,475
Food from livestock	5101	77,532	1179	99,549	183,360
Cereals	3573	29,292	134	11,354	44,353
Fruit	2365	1548	258	21,813	25,984
Vegetables	2354	254	167	14,097	16,872
Oilseeds and nuts	1804	9125	0	0	10,929
Pulses	0	13,238	0	0	13,238
Stimulants	0	5541	43	3603	9187
Sugar and sweets	0	504	95	8015	8614
Potatoes and Starch	505	504	1	61	1071
Fish	1861	26,054	10	943	28,868
Electric power	25,162		1856	156,778	158,634
Domestic consumption			865	73,044	73,909
Commercial and public			856	72,276	73,132
Street lighting			28	2391	2419
Water supply and sewage treatment			106	8964	9070
Other			1	103	104
Materials			1603	135,398	137,001
Paper[a]			59	4986	43,269
Cardboard[a]			18	1500	22,050
Plastic			102	8638	8740
Plastic bottle			9	757	766
Metal			97	8189	8286
Glass			10	812	822
Diapers[a]			52	4399	6506
Textiles	561	20,964	252	21,284	46,563
Transportation			800	67,579	68,379
Private cars			649	54,789	55,437
Taxis			41	3476	3518
Bus with in the city			21	1763	1784
Commercial vehicle with in the city			25	2142	2168
Truck with in the city			63	5335	5398
Others			1	74	75
City area	29,845				29,845
Use of liquefied petroleum gas			48	4073	4121

[a] Total forest ecological footprint for paper, cardboard and diapers is 61,000 gha.

Figure 18 : *Beer-Sheva's ecological footprint components 2007.*
Source: (Zeev,2014).

4.1.3.2 The Case of Vienna, Austria

An illustration of the domestic and global hinterlands of the city of Beer-Sheva (Zeev et al., 2014).

This work successfully applied city-LCA for the first time with real city data and the example of Vienna. The LCA methodology was created to assist local governments in monitoring their environmental performance and identifying the most important mitigation strategies. It includes multi-stakeholder activities that go beyond providing public services and emissions that go beyond greenhouse gases. Currently, it is being carried out using actual data from Vienna. 2016 was chosen as the reference year since it had the finest data consistency across all four assessment levels are distinguished by the city LCA framework (Figure 20). Level 1 considers activities related to the provision of public services by city-owned businesses. Private enterprises that provide public services are likewise included in Level 2. Level 3 is broken up into two parts. Level 3a is made up of activities that rely on the city's infrastructure and are indirectly impacted by the local government. Individual transportation, residential and non-residential structures are all included in this. Activities outside of governmental obligations are

Figure 20: *The location of the case study, Vienna, Austria .*
Source: Wikipedia.

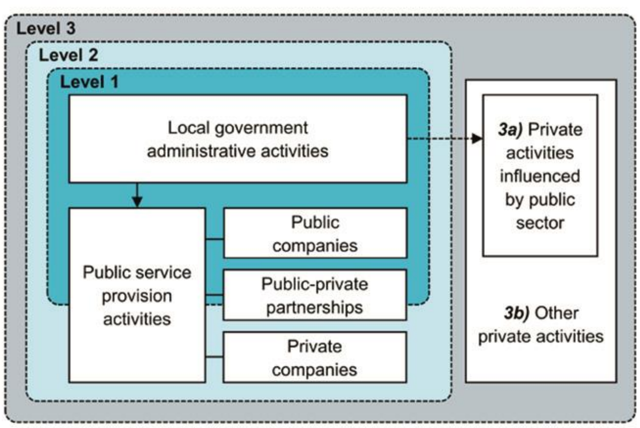


Figure 19: *City-OLCA framework.*
Source:(Cremer,2021).

included in Level 3b. This covers freight transportation, industry, agriculture, and consumption of goods and food.

The system boundary is described by 3 Levels. The production and use phase of activities are included in each evaluation level. As shown in Table 20, the actions at each assessment level make up the reporting flow in city-LCA.

Level	Reporting Flow	2016 Value
Level 1	Administration	30,219 Employees
	Electricity production	5747 GWh/a
	Heat production	6205 GWh/a
	Public transport	8,285,773,793 pkm/a
	Waste management	763,325 t/a
	Community housing	18,344,800 m^2
Level 2	N/A	N/A
Level 3a	Individual transport	10,983,467,586 pkm/a
	Residential buildings	55,034,400 m^2
	Non-residential buildings	35,328,000 m^2
Level 3b	Freight transport	4,242,399 tkm/a
	Industry	Heat & Power [1]
	Agriculture	Heat & Power & Fuel [1]
	Goods consumption	3887 kt CO_2 eq.
	Food consumption	2333 kt CO_2 eq.

Table 12: *City-OLCA framework. Source:(Cremer,2021).*

The ReCiPe 2016 midpoint (E) V1.04 methodology was used for the life cycle impact assessment. Global warming, stratospheric ozone depletion, ionizing radiation, ozone formation (human health), fine particular matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, human carcinogenic toxicity, mineral resource scarcity, and fossil resource scarcity were all considered. SimaPro (version 8.5) and the Ecoinvent database (version 3.4) were used to create the Vienna city-OLCA model. Figures S1–S4 show the parameterized city-model, which consists of 194 nodes (processes and materials).

All activities were grouped in one group whenever possible:

- Electricity
- District Heating
- Transport
- Buildings
- Waste Management
- Industry and Agriculture
- Goods and Food Consumption

In total 14,686 kt CO2 eq. were found for Vienna's baseline year (Figure 22). This equates to about 8 tons of CO2 equivalent per person. The local government is directly or indirectly responsible for more than half (53%) of the city's GHG emissions (up to level 3a). The remaining half (47%) is outside of the purview of the government (level 3b). Food and goods consumption make up the majority of level 3b (91%) consumption. The remainder (9% of level 3b) is made up of freight transportation, industry, and agriculture.

About 25% of the city's emissions are brought on by its own operations (level 1 and 2). This covers the actual administration as well as the supply of energy, public transportation, waste management, and affordable housing. Level 3a's final 28% of costs are related to construction and transportation. Nearly 80% of Vienna's total electricity consumption is supplied by the city, which is also the country's largest electricity producer. It has a slightly higher grid mix emission factor than the national average (420 g CO2 eq./kWh). This is primarily because Vienna has a large percentage of gas-fired power plants.

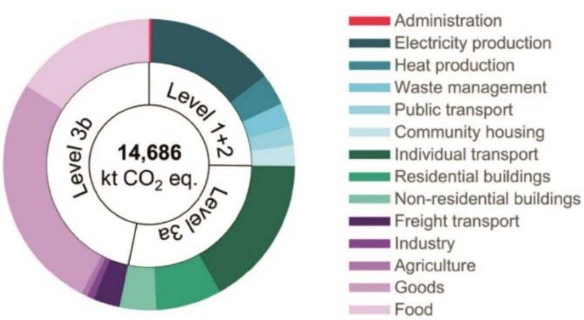


Figure 21: *City-OLCA results for global warming in kt CO2 eq.*

Source:(Cremer,2021).

Moreover,11 additional impact categories were added and shown in Table 13. Figure 22 shows the contribution of activities at each assessment level to the overall outcome. These values don't include food or product consumption because the data for those activities wasn't available.

Most impact categories are personal transportation and electricity production. The provision of public services by the city determines (>50%) ozone depletion, marine eutrophication, and freshwater ecotoxicity (level 1). These categories show notable contributions from waste management (42%), electricity production (29%), and heat production (58%), respectively. The highest impact category among all shows a 29% freight transportation contribution to terrestrial ecotoxicity. The remaining level 3b impacts are all less than 17% overall. When all building types are considered, the total emissions from building production come to about 159 kt CO2 eq. The production of passenger cars for individual use results in emissions

that are roughly equal to 553 kt CO2 eq. (or 21%, respectively) (see Figure 6a).

Table 2. City-OLCA's impact assessment results for Vienna's 2016 baseline in absolute values.

Impact Category	Unit	Value
Global warming	kg CO_2 eq.	1.47×10^{10}
Stratospheric ozone depletion	kg CFC-11 eq.	6.80×10^{3}
Ionizing radiation	kBq Co-60 eq.	7.01×10^{8}
Ozone formation, human health	kg NO_X eq.	1.58×10^{7}
Fine particulate matter formation	kg $PM_{2.5}$ eq.	7.40×10^{6}
Ozone formation, Terrestrial ecosystems	kg NO_X eq.	1.64×10^{7}
Terrestrial acidification	kg SO_2 eq.	1.80×10^{7}
Marine eutrophication	kg N-eq.	3.10×10^{5}
Freshwater ecotoxicity	kg 1,4-DCB	4.82×10^{8}
Human carcinogenic toxicity	kg 1,4-DCB	1.90×10^{10}
Mineral resource scarcity	kg Cu eq.	2.37×10^{7}
Fossil resource scarcity	kg oil eq.	2.96×10^{9}

Table 13 *City-OLCA's impact assessment results for Vienna's 2016 baseline in absolute values10*

Source:(Cremer,2021).

According to the case study's findings, 47% of greenhouse gas emissions are not directly under the control of the government. This ought to motivate local governments to come up with solutions for a sizable portion that is frequently ignored by traditional methods.

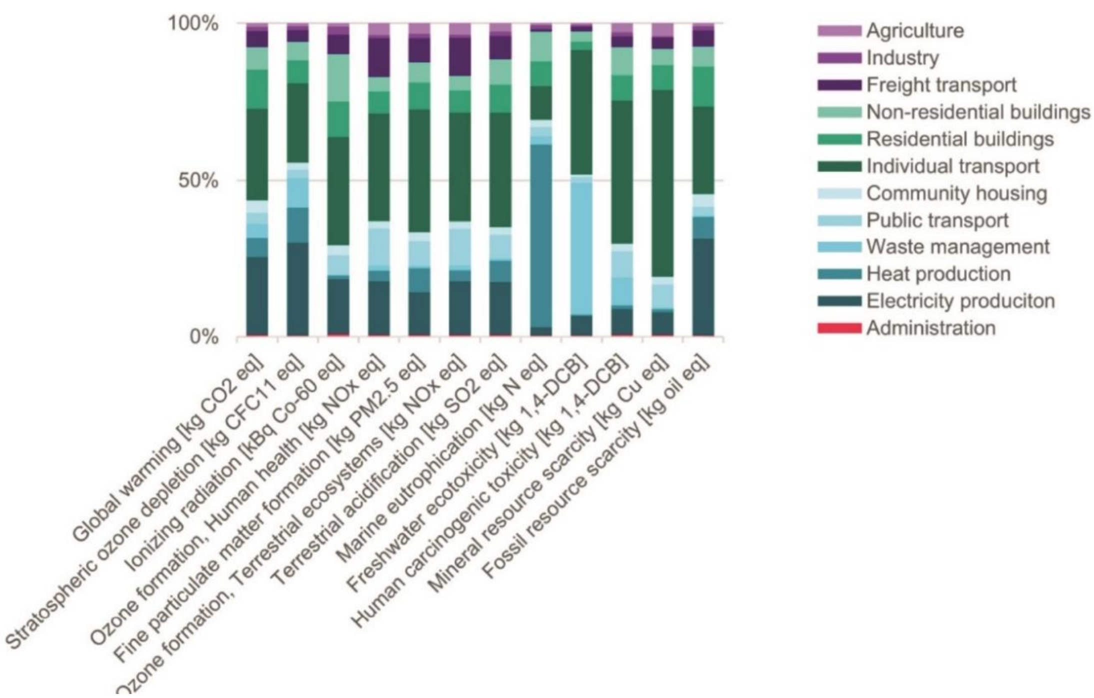


Figure 22 *Environmental profile of Vienna according to city-OLCA*

Source:(Cremer,2021).

4.1.3.3 The Case of Curitiba, Brazil

Urban metabolism: Measuring the city's contribution to sustainable development

Curitiba is located in southern Brazil and is the administrative capital of the state of Parana (see Fig. 1) as well as one of the state's major industrial production areas. Curitiba has a land area of approximately 435 km2 and is located 945m above sea level. The main goal of this paper is to measure the changes in material and energy use that occurred in Curitiba (Brazil) during the decade of 2000–2010.The collection of data on this city's material and energy flows over the next ten years is the first step toward a more complex analysis that will hopefully support planning and decision-making about its sustainability.Kennedy and Hoornweg proposed the specific framework used to evaluate Curitiba's urban metabolism (2012). The case study also includes in the analysis some of the methods from the works of Newman (1999),since is well-known for expanding the metabolism model in one of the first attempts to incorporate social issues into urban studies, Curitiba case study includes inflows (water, building supplies, fossil fuels, electricity, etc.), production (food, wood, etc.), stocks (minerals, nutrients, etc.), and outflows (wastewater, air emissions, and solid waste).The urban metabolism of Curitiba was chosen for two reasons:

Figure 23*: Location of Curitiba (city) and Paran a (state) in Brazil. Source: IPPUC, IPARDES, IBGE.*

- First, the city is well-known for its efforts toward sustainability.
- The second reason is that there is a scarcity of studies on urban metabolism in Latin American cities. Kennedy et al. (2011) discovered 36 studies in a

chronological review, none of which were from a South or Latin American city.

The Urban Metabolism of Curitiba in 2000 and 2010 is summarized in Tables 14. The gross and per capita volumes of materials and energy used and produced in the city, as well as their changes over ten years, are shown in Tables 14 .

In terms of material inputs, Curitiba shows a slight increase in total food intake (13%), but not in per capita food intake (2%).It is important to note that the state of Paraná leads Brazil in terms of soybean and corn production. Curitiba is entirely urban area and lacks any rural households, its production of food, wood, and minerals is very low and has been declining over time, which highlights the city's dependence on other outside resources.

Curitiba, which is well served by rivers, was able to maintain its average daily water consumption of 160 liters per person. Only 0.10 percent of households lacked access to drinkable water in 2010 thanks to infrastructure investments, which also helped many households outside the center area. However, Shenzhen, China (734 l/cap/day) and other developing cities like Shenzhen, China, as well as other developed cities like Vancouver, Canada (554 l/cap/day) and London, England (324 l/cap/day), have higher per capita water consumption than any of these cities (Zhang and Zhifeng, 2007).

Some trends in electricity and energy use can also be seen in the data. The largest increase in electricity use (46% increase) was seen in the commercial sector. Evidently, the energy needs of industry have expanded to include sources like coal (5878%) and natural gas (243%) Although fossil fuels are still the most common form of energy, they experienced the least growth (12%), which will aid in slowing GHG emissions.

In addition to energy, the city used more building supplies (by about 57%). For instance, the amount of construction materials used annually per capita was comparable to London's (3757) (IWM, 2002). This is most likely a result of the real estate market's dizzying expansion, which peaked in 2010 with the approval of more than 33,500 construction permits. Farmland that had previously been used for (family) agriculture had been converted into building space to meet the city's housing needs.

The results of the economic expansion can be observed in the material outflow data, especially on the larger generation of wastewater (54%). The city extended the infrastructure, leaving only 0.62% of the households without sewage treatment. The amount of solid waste per capita produced decreased 6% along with a raise of 33% in the recyclable waste. Household waste thrown away in 2010 was almost half that of a city with the same population as Budapest (1.7 million), at 335 kg per year compared to 630 kg per year in the Hungarian city (Pomazi and Szab o, 2009).

Despite an increase in industrial activity, air emissions have decreased 32% in the last ten years. Except for a greater quantity of inhalable particles, most components showed a decline during the studied period. GHG emissions are still below the cities in other developing nations such as Russia (12.2 tons/year), South Africa (9.2 tons/year), and China (6.2 tons/year), but still close to the Brazilian average (2.2 tons/year) (UNDP, 2010).

Material Category	Unit	2000	2010	%	Source
Inputs					
Food intake[a]	ton	503,535	567,457	13	IBGE
Electricity consumption (total)	GW/h	3423	4239	24	
Residential	GW/h	1251	1498	20	COPEL, IPPUC
Industrial	GW/h	931	1057	14	COPEL, IPPUC
Commercial	GW/h	897	1314	46	COPEL, IPPUC
Public Services	GW/h	332	358	8	COPEL, IPPUC
Other	GW/h	12	12	−7	COPEL, IPPUC
Energy consumption (total)	TJ	58,010	76,255	32	
Natural gas	TJ	1969	6748	243	COPEL
Fossil fuels[b]	TJ	47,184	52,949	12	ANP
Coal (mineral + vegetable)	TJ	6	330	5878	COPEL
Biomass/biofuels	TJ	8851	16,228	83	COPEL
Construction materials (use)	ton	4,221,841	7,308,036	73	
Cement	ton	371,432	628,935	69	SNIC, CBIC
Steel	ton	146,985	239,836	63	IABr
Aggregates (sand, gravel)	ton	3,703,424	6,439,265	74	ANEPAC, DNPM
Water consumption	ML	90,906	103,529	14	SANEPAR
Production					
Food	ton	2394	1303	−46	IBGE, PMC
Wood	m^3	4,110[c]	2738	−33	IBGE
Construction materials	ton	940,993	1,256,202	33	
Cement	ton	680,506	953,570	40	SNIC, CBIC
Steel	ton	260,487	302,632	16	WSA
Minerals (clay, gold, crushed stones)	ton	30,368	15,173	−50	DNPM
Water production (surface water)	ML	162,771	169,086	4	SANEPAR, SNIS
Stocks					
Minerals (clay, gold, crushed stones)	ton	1,427,256	560,409	−61	DNPM
Landfill waste (accumulated)	ton	3,607,122	8,711,683	142	PMC, IPPUC
Outputs					
Municipal solid waste	ton	702,974	728,453	4	
Domestic and public waste	ton	532,135	462,587	−13	PMC, IPPUC
Recyclable waste	ton	132,173	193,470	46	PMC, IPPUC
Healthcare waste	ton	3807	2704	−29	PMC, IPPUC
Toxic waste	ton	7286	8495	17	PMC, IPPUC
Tree and junk waste	ton	27,573	61,197	122	PMC, IPPUC
Wastewater	ML	58,594	90,486	54	SANEPAR, SNIS
GHG emissions[d]	t-CO_{2eq}	3,174,630	3,515,890	11	ECOWOOD
Air emissions	$\mu g/m^3$	158	107	−32	
Total suspended particulate (TSP)	$\mu g/m^3$	86	36	−58	IAP
Smoke	$\mu g/m^3$	22	16	−29	IAP
Inhalable particles	$\mu g/m^3$	15	27	79	IAP
Sulfur dioxide (SO_2)	$\mu g/m^3$	11	3	−71	IAP
Nitrogen dioxide (NO_2)	$\mu g/m^3$	24	25	3	IAP

Urban metabolism of Curitiba — Per capita value.

Material category	Unit	2000	2010	%	Source
Population	Inhabitants	1,587,315	1,751,907	10	IBGE
Inputs					
Food intake	kg/cap/yr	317	324	2	IBGE
Electricity consumption	kWh/cap/yr	2155	2419	12	
Residential	kWh/cap/yr	788	855	8	COPEL, IPPUC
Industrial	kWh/cap/yr	586	603	3	COPEL, IPPUC
Commercial	kWh/cap/yr	565	750	33	COPEL, IPPUC
Public services	kWh/cap/yr	208	204	−2	COPEL, IPPUC
Other	kWh/cap/yr	7.84	6.59	−16	COPEL, IPPUC
Energy consumption	kWh/cap/yr	10,149	12,087	19	
Natural gas	kWh/cap/yr	345	1070	210	COPEL
Fossil fuels	kWh/cap/yr	8255	8393	2	ANP
Coal (mineral + vegetable)	kWh/cap/yr	0.97	52.32	5316	COPEL
Biomass/biofuels	kWh/cap/yr	1548	2572	66	COPEL
Construction materials (use)	kg/cap/yr	2660	4172	57	
Cement	kg/cap/yr	234	359	53	SNIC/CBIC
Steel	kg/cap/yr	93	137	48	IABr
Aggregates (sand, gravel)	kg/cap/yr	2333	3676	58	ANEPAC, DNPM
Water consumption	l/cap/day	157	162	3	SANEPAR
Outputs					
Solid waste	kg/cap/yr	443	416	−6	
Domestic and public waste	kg/cap/yr	335	264	−21	PMC, IPPUC
Recyclable waste	kg/cap/yr	83	110	33	PMC, IPPUC
Healthcare waste	kg/cap/yr	2.40	1.54	−36	PMC, IPPUC
Toxic waste	kg/cap/yr	4.6	4.8	6	PMC, IPPUC
Tree and junk waste	kg/cap/yr	17	35	101	PMC, IPPUC
Sewage	l/cap/day	101	142	40	SANEPAR
GHG emissions	t-CO_{2eq}/cap/yr	2.00	2.01	0	ECOWOOD, 2008

Table 3
Selected indicators for livability and quality of services.

Indicator	Unit	2000	2010	%	Source
Livability					
Population	Inhabitants	1,587,315	1,751,907	10	IBGE
Fleet	veh/cap	0.42	0.68	62	DETRAN
Employment (people employed/EAP)[a]	%	85.9	95.1	11	IBGE
Formal education (Literate over 15 yrs)	%	96.6	97.9	1	IBGE
Under-five mortality rate (per 1000 births)	ratio	17.5	10.2	−42	SESA
Violent deaths (100,000 population)	ratio	21.1	43.5	106	SESA
Transport fatalities (100,000 population)	ratio	26.8	17.9	−33	SESA
Monthly average income	US$/cap	624	922	48	IBGE
Gini coefficient	index	0.59	0.57	−3	IBGE
Educational attainment	avrg. yrs.	7.3	8.3	14	IBGE
Quality of service					
Population with access to internet[b]	%	20.15	52.90	163	IBGE
Population with mobile phones[b]	%	54.47	92.22	69	IBGE
Households without direct access to water	%	0.27	0.10	−63	IBGE
Households without sewage[c]	%	1.71	0.62	−64	IBGE
Wastewater subject to treatment	%	80.91	98.71	22	SANEPAR
Households without public waste collection	%	0.7	0.0	n/a	SNIS
Households without grid electricity connection[c]	%	0.63	0.05	−92	IBGE

Table 14: *Urban metabolism of Curitiba e gross value, Source, (Conke,2015)*

Table 14 reflects in the number of materials and energy used. All livability indicators in Curitiba increased, indicating social progress, however, they remain below recommended levels.

Life expectancy increased from 70 years old in 2000 to roughly 74 years old, and there was a significant decrease in under-five mortality (49%) (2010). Although literacy rates are among the highest (99.7% and 95.1%, respectively), and the value of 97.9% indicates a high level of human development.

The availability of utilities has increased; nearly all households have access to electricity and water (99.90% and 99.95%, respectively). The public administration, which oversees the water and energy industries, has improved the infrastructure so that 99.38% of homes now have access to sewage. Although internet usage has increased at commendable rates (69% and 163%, respectively), it has not yet reached the anticipated level.

4.1.3.4 The Case of Denver, USA

A Demand-Centered,Hybrid Life Cycle Methodology for City-Greenhouse Gas Inventories

Background of Study Area. Denver, which is also the name of the state's capital, is located in the east-central region of Colorado. City has a land area of 155 square miles. The Denver Regional Council of Governments, or DRCOG, which covers a larger area of 5100 square miles and includes 9 counties in addition to Denver, is a regional planning organization in which Denver and the local governments of neighboring counties take part. Population figures for Denver and the DRCOG region in 2005 were 579,744 and 2,641,753. Denver serves as a commercial hub for this much wider region, as they all do.

Figure 24: *The location of the case study, Denver, USA.*

Source:Wikipedia

Main Inventory Categories and Inclusions

The hybrid LCA-based city-scale GHG inventory method developed in this paper includes GHG emissions from three main categories:

- **direct (end-use) energy** consumed in buildings and facilities, including homes, commercial, industrial, and government buildings and facilities.
- **direct (tailpipe) emissions** related to transportation, including surface and air travel, with a special spatial allocation procedure applied to allocate such travel within and across city buildings.
- **indirect (internal) emissions** associated with waste management and disposal, including the production of methane and other (e.g., landfill). Food,

water, fuel, and concrete are the main urban resources taken into account based on how cities work.

As the leading GHG-emitting residential construction material and the third source of CO2 emissions in the United States, cement (in concrete) is used as a stand-in for construction.
The carbon dioxide equivalents (CO2e) of the three main GHGs (CO2, CH4, and N2O), which account for more than 98% of U.S. GHG emissions, are inventoried and published collectively.

	sector/use	community-wide annual urban material/energy flows (MFA) (benchmarks)	data source for MFA {data type}[a]	GHG emission factor (EF)	EF data source {data type}[a]	total GHG emitted = MFA x EF
A. "direct" emissions in conventional city-scale GHG inventory [WRI Scope 1,2]	buildings electricity use	6,659 GWh (568 kWh/hh/mo[b]) (27 kWh/sf./yr[c])	Xcel Energy {L, MD}	0.8 kg CO2e/kWh	Xcel (*20*) {L, ME}	5.3 million mt-CO_2e
	buildings natural gas use	404 million therms (63 therms/hh/mo[b]) (1.5 therms/sf./yr[c])	Xcel Energy {L, MD}	5.6 kg-CO2e/therm	ICLEI (*9*) {N, ME}	2.3 million mt-CO_2e
	surface vehicle miles traveled, VMT	5 billion VMT (25 miles/person/day) average fuel econ. = 15 mpg	DRCOG (*25*) {L, ME} CDPHE (*28*) {L, MD}	gasoline PTW= 9.3 kg-CO_2e/gal diesel PTW= 9.5 kg-CO2e/gal	ICLEI (*9*) {N, ME}	3.5 million mt-CO_2e
B: "indirect" or out-of-boundary emissions to supplement "direct" GHG inventory [WRI Scope 3]	airline travel PTW (22% allotted to Denver)	86 million gallons jet fuel (19.5 gallons jet fuel per enplaned passenger)	DIA (*29*) BTS (*26*) {L, MD}	jet fuel PTW= 9.4 kg-CO_2e/gal	EIA (*32*) {L, ME}	0.9 million mt-CO_2e
	fuel production	fuel flow in million gallons jet fuel: 86 diesel: 52 gasoline: 326	ICLEI (*9*) {N, ME}	gasoline WTP= 2.5 kg-CO_2e/gal diesel/jet fuel WTP= 2 kg-CO2e/gal	GREET(*33*) {N, ME}	1.1 million mt-CO_2e
	cement use	total flow: 301,000 mt cement (0.52 mt /capita)	Denver-Aurora economic census (*35*)	0.97 - 1.05 mt CO2e per tonne cement	EPA (*37*) PCA (*38*) {N, ME}	0.3 million mt-CO_2e
	food purchases at home	$3,000/home/yr (1997-$) (240,000 homes)	Denver-Aurora consumer expenditure (*36*)	2 kg-CO_2e/$ (1997-$)	EIO-LCA (*12*) {N, ME}	1.4 million mt-CO_2e

Table 15: *Annual Community-Wide Material and Energy Flows with Associated Benchmarks and GHG Emission Factors (EF).*
Source: (Ramaswami, 2008).

Direct Energy Use in Buildings and Facilities. Denver's local utility company provided data on the total amount of electricity and natural gas used by all households, businesses, and industrial buildings in Denver (Xcel Energy). To confirm the broad range and magnitude of the numbers, community-wide energy use data were normalized and compared to comparable data provided from other state and national studies.

Direct Surface Transportation Energy. Daily vehicle miles traveled (VMT) derived from DRCOG's regional transportation model were used to estimate direct tailpipe (pump-to-wheels, PTW) GHG emissions from the road transportation sector (25). 16,450 road linkages connect 2,664 traffic analysis zones in the DRCOG road network model (TAZs). For local air quality modeling, DRCOG calculates VMT within each TAZ, measured traffic volume counts at different points.

Embodied Energy of Key Urban Materials and End-of Life. Indirect energy use and GHG emissions for the essential urban materials—water, fuel, food, and cement—were calculated based on how well city's function. The embodied energy and GHG emissions were calculated by combining a material flow analysis (MFA) of these materials through the city with an emissions factor (EF), as shown in Table 2. The annual transportation fuel flows required by the community were derived using vehicle miles. Denver Water's billing information was used to track water use within its boundaries. Moreover, its annual reports were used to calculate the amount of energy required to create water upstream of Denver. Cement and food material flows were estimated using data from the Denver-Aurora Metropolitan Statistical Area (MSA). The CACP software from ICLEI was used to calculate end-of-life GHG emissions from municipal solid waste.

Table 15 shows the material and energy flows, as well as the accompanying LCA-based emission factors for all flows. Important metrics for comparing these flows also shown in Table 2.

Community-Wide Summary. Denver's community-wide GHG emissions totaled 14.6 million metric tons CO2e in 2005, using the demand-centered LCA hybrid approach. These were split across the following three sectors: (1) community-wide energy consumption in residential structures and industrial/commercial facilities (52%); (2) tailpipe GHG emissions from transportation (30%); and (3) community-wide use of critical materials and waste disposal (18%).

Figure 25 shows the 2005 GHG contributions made by Denver by activity. The estimated embodied energy of food and transportation fuels accounts for more than 15% of the inventory, although the usage of urban cement alone accounts for only 2%, which is comparable to the effect of energy use in all Denver City Government buildings (including Airport Buildings).The model's parameter inputs have an impact on Denver's annual per capita GHG emission. Figure 26 illustrates the per capita GHG calculation's sensitivity to a 10% change in the most important modeled parameters. Changes in the emissions factor have the greatest impact on the volume of community-wide emissions.

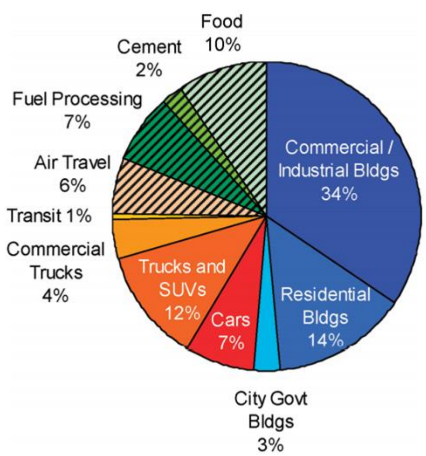


Figure 25: Denver's GHG emissions summary by activity in 2005.

Source:(Ramaswami, 2008).

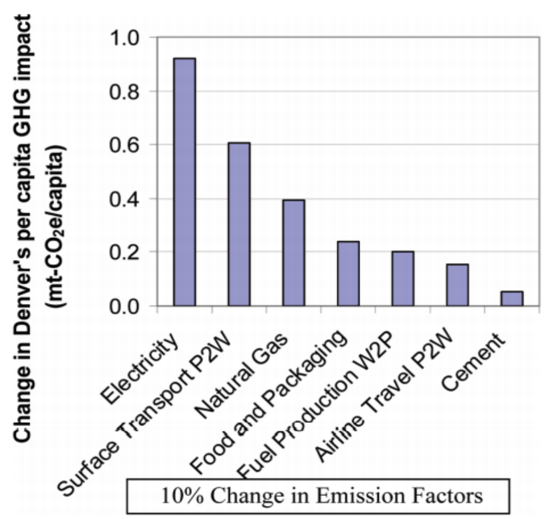


Figure 26: *Variation in the magnitude of Denver's per capita GHG emissions in response to a 10% change in the modeled parameters.*

Source: (Ramaswami, 2008).

Findings for Denver thus suggest that the demand-centered hybrid LCA-based approach described in this paper can be used to create a more comprehensive and scale-consistent GHG inventory for American cities.

4.2 SECOND PHASE - Analysis Results

Results of the methodologies through a SWOT analysis give clear understanding which methodologies are the most advantageous/ disadvantageous.

4.2.1 SWOT of Footprint methodology

Figure 27 shows the summary diagram of the strengths, weaknesses, opportunities, and threats presented below.

STRENGTHS

- **Highlights the problem areas**

Footprint also illustrates which sector performs better or worse than the other by highlighting the problem area.

- **Hazard warning indicator**

It is a tool warning that humanity is currently exceeding the carrying capacity of the Earth. This indicator acknowledges that there are biophysical boundaries and that current consumption patterns are not long-term sustainable. Expansion on all levels cannot remain an objective.

- **Snapshot of the current situation**

Using EF, it is feasible to get a snapshot of current situations that is readable by non-experts and comparable to recent research about the influence of humans on the environment. A footprint is a "snapshot" estimate of biocapacity supply and demand, usually based on data for one year (Stefen et al., 2015; Vanham et al., 2019).

- **Support for decision makers and sustainable city management**

Each decision on any level must be consistent with the concept of sustainable

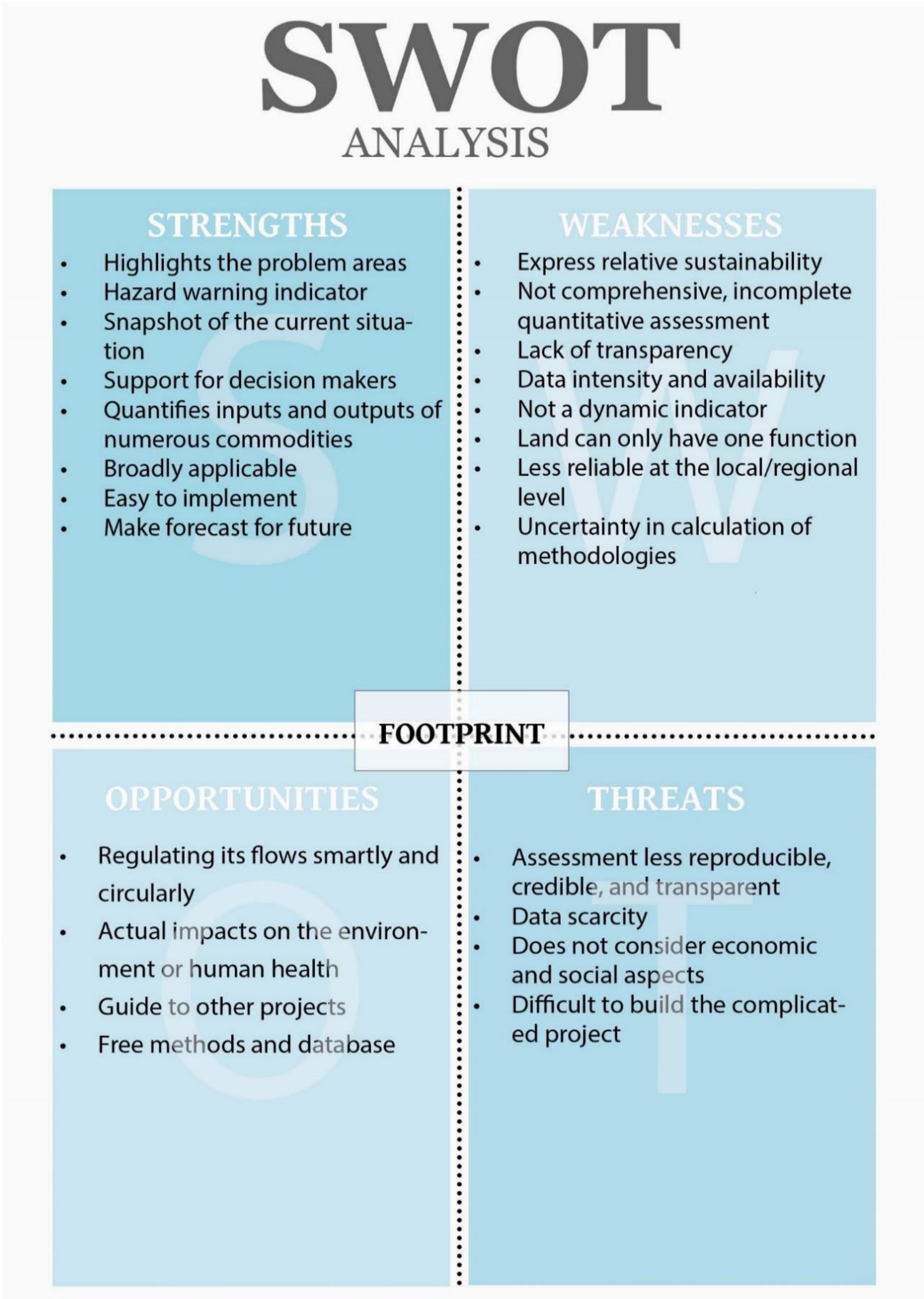


Figure 27: *SWOT Analysis of The Footprint methodology.*

Source: Author, 2022.

development. The ecological Footprint facilitates discussions and decision-making processes by providing a solid knowledge base and an easily applicable calculation method. The ecological footprint can be used in different stages of the decision-making processes (Stoeglehnera et al., 2007).

- **Quantifies inputs and outputs of numerous commodities**

The main goal of input-output analysis is to measure the interdependence of different activities within the economy. It tracks all direct, indirect, and, where necessary, induced resource use that is included in consumption using simple mathematical methods (Leontief, 1970, Miller and Blair, 1985).

- **Broadly applicable**

Despite being a complex metric to measure, EF is nonetheless a simpler way to transfer a final impact to a larger audience, particularly for the purposes of environmental education. Ecological Footprint is becoming more and more important for all ecological footprint specialists to adopt a standard technique to enable comparisons between countries and local areas (T. Wiedmann & Barrett, 2010, Collins et al., 2018).

- **Easy to implement**

Footprint is simple indicator to use and calculate, making it a usable indication for non-scientists. This is significant because it is governments and businesses that must become aware of and drastically reduce their ecological footprints in order to improve the unsustainable situation on our planet. If indicators are too technical and complicated, governments and businesses will continue to avoid them.

- **Make forecast for future**

The EF application undoubtedly provided the knowledge of how cities affect the environment and served as the basis for future decision-making processes.

OPPORTUNITIES

- **Regulating its flows smartly and circularly**

EF concept typically uses a top-down approach and provides insights in the local reality through inventory of the flows into and out of the city. The method furthermore does not allow to provide a clear insight in what happens inside the city.

- **Actual impacts on the environment or human health**

Carbon emissions generally have an effect on public health. First, breathing in high CO2 concentrations immediately damages the respiratory system, resulting in headaches, confusion, and other symptoms. If everyone was aware of their ecological footprint, today's there would be less environmental problem with issues like carbon emissions, a lack of clean air, increased desertification, global warming, and increased environmental contamination.

- **Guide to other projects**

Ecological footprint calculators are useful tools to guide users on the path to knowledge and action, as well as educate people and encourage more sustainable lifestyle choices.

- **Free methods and database**

There are numerous free databases and tools for CF quantification. Several countries and international organizations make their resources and guidance available for free on registration (GHG Protocol, 2014).

TREATS

- **Assessment less reproducible, credible, and transparent**

A certain lack of transparency in the calculations in the development of the ecological footprint can lead to inaccurate result and false information.

- **Data scarcity**

The lack of data availability to make an assessment could be the main threat. To determine an area's footprint, a lot of data is required. It is possible that the necessary data doesn't exist in the needed form or for the subject under consideration.

- **Does not consider economic and social aspects**

The ecological footprint has been criticized for just looking at demands made on the environment and focusing only on human needs. Therefore, EF does not consider the social or economic dimensions of sustainability.

- **Difficult to build the complicated project**

Nowadays the Footprint “cannot handle the complexity of sustainability” and still cannot be considered comprehensive measure of sustainability to build the complicated project which consider different sectors of the city.

WEAKNESSES

- **Express relative sustainability**

It only uses the portions of the earth that are directly beneficial to people when calculating the biocapacity of the planet. The outer reaches of the oceans and some 36 billion hectares of land are not included in the EFA calculations because they are considered unproductive for human use. This land can become degraded or experience a loss of biodiversity without having a negative impact on EFA calculations. Therefore, the ecological footprint express relative sustainability and is a tool of environmental sustainability rather than a overall tool of sustainability (Venetoulis and Talberth, 2008).

- **Not comprehensive, incomplete quantitative assessment**

The EF is limited in what it measures, for example chemical pollution cannot be measured with this indicator (Scotti et al., 2009). Therefore, Footprint is not comprehensive indicator of sustainability to build the complicated project with the city boundaries.

- **Lack of transparency**

The calculations involved in putting together the indicator are complex and often not fully explained and available to those who will use the results. Therefore, there is a certain lack of transparency.

- **Data intensity and availability**

To determine an area's footprint, a lot of data is required. It is possible that the necessary data doesn't exist in the needed form or for the subject under consideration. Additionally, it's crucial to consider the cost of data collection for specific industries as well as the expense of creating, storing, and maintaining the required databases.

- **Not a dynamic indicator**

As was mentioned above the footprint is a 'snapshot' estimate of biocapacity demand and supply, based on data from a single year. Forecasting or "backcast" footprints using current data is not practicable since both sides of the equation can alter over time.

- **Land can only have one function**

The methodology's assumption that each piece of land has only one use is another drawback. Ecological Footprint assumes that CO_2 can only be absorbed by land, despite the fact that agricultural crops and oceans are also significant CO_2 absorbers.

- **Less reliable at the local/regional level**

The application of Footprint indicator at the regional/local level is significantly less precise than at the global or national level due to a lack of access to local data. Estimating conversion factors at the regional level would not only be unfeasible, but it would also be challenging to find data at such a local level.

- **Uncertainty in calculation of methodologies**

Different footprint methodologies show that the field is still under development. Contrary to what the EFA community has stated, the term "footprint" is frequently used as a indistinct term to any pressure or impact. This means that there are many different approaches and definitions for the "same" footprint.

4.2.2 SWOT of Life Cycle Assessment methodology

Figure 28 shows the summary diagram of the strengths, weaknesses, opportunities, and threats presented below.

STRENGTHS

- **Support for decision makers**

LCA allows a decision-maker to study the entire product system using LCA . LCA can measure environmental releases to air, water, and land. It may also provide a systematic evaluation of the environmental impacts (Guinee, 2002).

- **Compare and select the products that impact less**

LCA allows decision makers to compare different products and to select the product that has the lowest impact on the environment.

- **Cradle to grave concept**

LCA is a modelling tool to assess environmental impacts related to a product during its entire lifespan. LCA considers the full life cycle from cradle to grave: from raw material extraction through processing, manufacturing, distribution, consumption and disposal or recycling.

- **Support for sustainable city management**

The Lifecycle Thinking approach is promising in supporting cities towards sustainable development. LCA plays an important role, as it can help policymakers make decisions that are more transparent and supported by evidence (Reale et al., 2017).

- **Widely recognized / Broadly applicable**

The LCA is based on internationally recognized standards, used by different organizations and is widely accepted as the best approach to quantify the environmental impact of a product throughout its life cycle.

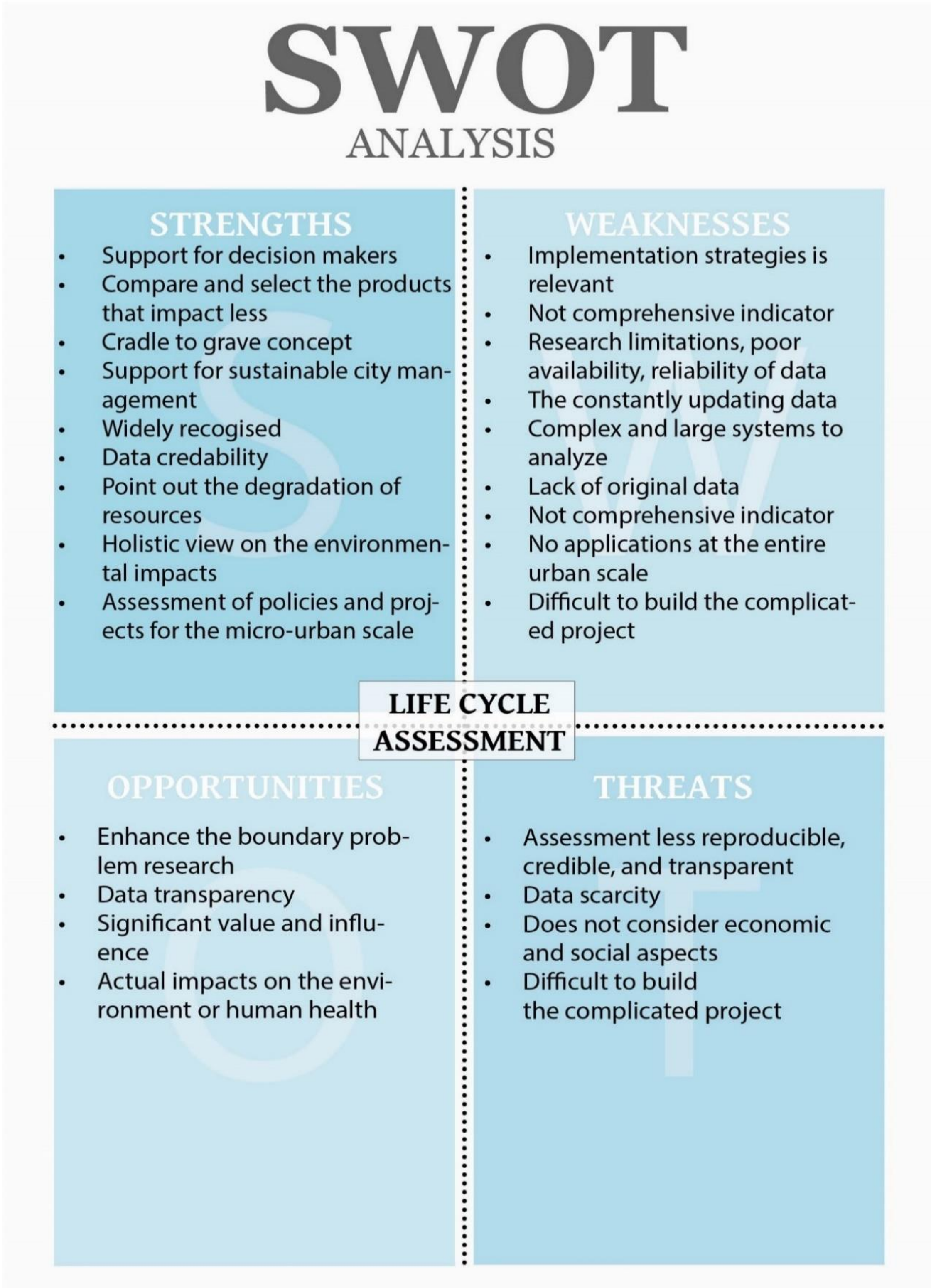


Figure 28: *SWOT Analysis of The LCA methodology.*

Source: Author, 2022.

- **Data credibility**

As more and more regulations emerge to combat greenwashing, the credible environmental data to make products being sustainable is needed. Accounting for energy and emissions over the life cycle of a product is essential to determine if it is truly sustainable. Environmental data based on the LCA study not only confirms and strengthens sustainability of the cities, but it also enhances credibility.

- **Point out the degradation of resources**

LCA provides the possibility to identify hotspots in the environmental impact and point out the degradation of resources. It provides insight in how to improve processes to achieve reduced environmental effects. Moreover, It gives insights in how to enhance procedures to reduce environmental effects on the cities.

- **Holistic view on the environmental impacts**

To avoid optimizing one environmental indicator without taking into account the (unfavorable) effects on the other indicators, LCA offers a holistic view of the environmental impacts.

- **Assessment of policies and projects for the micro-urban scale**

LCA indicator provides robust and accurate methods to quantify the built environment on both for micro-urban scale and urban scales (Anderson, Wulfhorst, & Lang, 2015).

OPPORTUNITIES

- **Enhance the boundary problem research.**

The LCA is looking for opportunities to improve environmental impact and take advantage of these opportunities through assessment. If a comprehensive LCA helps to expand the objects of study and is used for decision making, then the applicability of the LCA will be increased (Curran, 2006).

- **Data transparency**

Evidently, all LCA studies must be completely transparent about data, models in order for everyone to assess the validity of the study and its findings.

- **Significant value and influence**

LCA has significant value and influence in different areas all over the world. LCA could develop more effective communication tools to translate environmental performance into value and benefits for consumers and ultimately help consumers make the "right choice."

- **Actual impacts on the environment or human health**

LCA also assess the human and ecological impact of material consumption and environmental releases. LCA is used to compare the health and ecological impacts and have benefit for the environmental tradeoffs. LCA reduces the environmental impact of products by examining the inputs and outputs of their products, with the aim of producing a more environmentally friendly product (SAIC,2006).

WEAKNESSES

- **Implementation strategies is relevant**

LCA can assist in the selection of relevant indicators of environmental performance, including measurement techniques and marketing.

- **Not comprehensive indicator.**

The application of LCA at the urban scale is not yet a reality. Its current application is limited in scope (e. g. Only the urban waste management sector is investigated) and applied to only a geographical part of the city (e. g. Neighborhood scale).

- **Research limitations, poor availability, reliability of data**

In addition to the issue of data availability, data quality is another important factor in ensuring the accuracy of LCA results. The LCA study aims for a high degree of accuracy. Data quality requires a number of stages, including collecting the required data, third party validation of the data, review, and validation of LCA results.

- **The constantly updating data**

The results of the LCA could be affected by the constantly updating data, making them unstable. With the advancement of technology, the data already included in LCA may be updated and changed. (SAIC, 2006).

- **Complex and large systems to analyze**

It can be difficult for non- LCA experts to assess the quality of an LCA study. LCA experts may find it difficult to assess data selection unless they are experts in all subjects of study.

- **Not comprehensive indicator**

However, most of the studies did not include a comprehensive life cycle approach that took into account every stage of these systems' implementation (Porsche and Köhler, 2003;).

- **No applications at the entire urban scale**

Literature reviews show that no applications of LCA at the entire urban scale exist to date, and upscaling approaches are still on the way of development.

- **Difficult to build the complicated project**

Applying the life cycle inventory is complex tool as it covers a wide range of production activity sectors (i.e., food, durable goods, non-durable goods, services, and so on). Furthermore, the study of such complex products becomes more complicated due to lack of data.

THREATS

- **Does not consider economic and social aspects**

As LCA involves a complex and huge amount of work, a lot of manpower, material and financial resources are required. LCA needs do not take into account the economic and social benefits of environmental protection, which are difficult to assess.

- **Subjective system boundaries and thresholds**

System boundaries are often one of the biggest threats when quantifying CF. The complexity of obtaining all the data requires that the threshold of significance e, i.e. threshold criteria e, be determined and justified before evaluation. These boundaries and thresholds may vary subjectively for each analyst and therefore compromise the consistency and comparability of the results.

- **Hidden environmental impacts**

Though LCA can affect environmental quality condition, it does not mean the condition will stay unchanged over the span of the project. The hidden troubles still exist in environmental impacts.

- **Data scarcity and uncertainty in calculations**

The availability of data is and will be the main limitation for the use of dynamic LCAs. To best deal with this problem, the data should be combined from different databases, which would lead to the inherent uncertainty that occurs whenever someone combines data obtained from different sources (Cardellini, Mutel, Vial, & Muys, 2018).

- **Too professional.**

Moreover, the LCA is a professional tool for environmental impact analysis, which requires urban actors/ future researchers to have professional knowledge to help them make decisions. This puts managers in front of a professional challenge. LCA should provide urban actors with a simpler and more intuitive model for decision-making.

- **Incompact and incomplete quantitative assessment**

An incomplete environmental impact assessment will lead to the fact that the project will be associated with a higher risk of negative impact. Without the introduction of a proper environmental assessment tool that could provide a holistic perspective, the environment and people could be at risk.

4.2.3 SWOT of Urban Metabolism methodology

Figure 29 below shows the summary diagram of the strengths, weaknesses, opportunities, and threats presented below.

STRENGTHS

- **Support for decision makers**

All implementation strategies provide urban decision-makers with comprehensible information on the environmental sustainability of Ums.

- **Quantifies inputs and outputs**

UM has mostly remained a tool for accounting, tracking inputs and waste flows, with limited ability to explain differences among cities or reasons for the changes in the urban metabolism of cities (Barles, 2009; Gasson, 2002; Sahely et al., 2003).

- **Quantifies the numerous commodities.**

Urban Metabolism has some characteristic as interconnect sustainability, circular economy with other related strategies, as it provides important information on resource consumption, energy efficiency, water consumption and waste management on cities (Chen and Chen, 2015; Cui, 2018; Sun and An, 2018; Wang et al., 2020a, 2020b; Voukkali et al., 2021).

- **Provide a snapshot of resource or energy use**

The majority of research on urban metabolism rely on highly aggregated data, frequently at the city or regional level, which provide a snapshot of resource or energy use.

- **Broadly applicable, relevant methodology**

UM concept is relevant tool for the multidimensional assessment of sustainability. More than 150 studies have been found using a variety of methods to evaluate the environmental performance of UMs since 1974, according to a recent search (Broto et al., 2012; Rapoport, 2011, Decker et al., 2000).

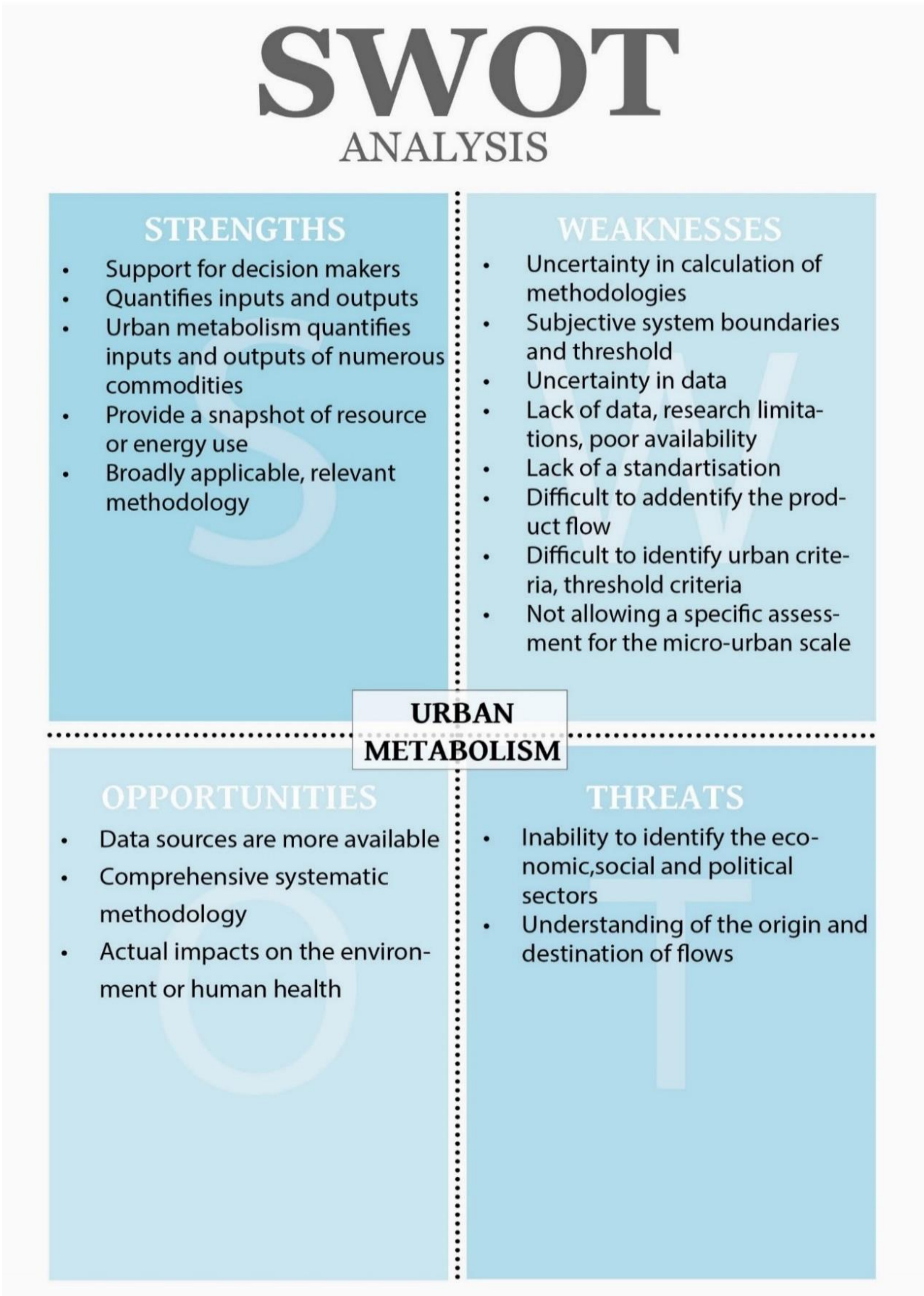


Figure 29: *SWOT Analysis of The UM methodology.*

Source: Author, 2022.

OPPORTUNITIES

- **Data sources are more available**

New data sources are becoming more accessible to better study urban systems.

- **Comprehensive systematic methodology**

The main purpose of the work presented here is to provide a comprehensive framework that. analyzes urban material flows and energy parameters of cities as well as the human, social, policy, economic, and related systems that both structure and govern specific urban metabolic process.

- **Actual impacts on the environment or human health**

The city, as a "living organism," is not only a natural space for planning and development, but also a place where metabolic activities and processes need to be monitored and controlled because of the dynamic and complex flows of raw materials, energy, waste, and water that over time affect the city's character, environmental health, wellbeing, life expectancy, and quality of life.

WEAKNESSES

- **Uncertainty in calculation of methodologies**

It is clear from the literature that there is no unified methodology in the urban studies of the MFA. Different studies use different methodologies. Without a unified methodology, urban metabolism studies can only be considered on a case-by-case basis (Kennedy et al. 2011; Niza et al. 2009; Barles 2010; Weisz and Steinberger 2010).

- **Subjective system boundaries and threshold**

Challenges lie in specifying the system's boundaries and assessing sufficient representative data to model the system network and its interactions with the environment.

- **Uncertainty in data**

Certain UM data are only available on a larger scale (national or regional) requires certain assumptions that allow the estimation of certain variables (García-Guaita et al., 2018).

- **Lack of data, research limitations, poor availability**

Taking into account the evaluation of the current Urban Metabolism methodologies, there are significant barriers and weaknesses are found such as a lack of data, omitted/hidden upstream flows, uncertainty regarding the appropriate scale of analysis continue to limit accurate accounting of urban metabolism of cities (Kennedy et al., 2011).

- **Lack of a standardization**

Lack of a standard method for examining Urban Metabolism based on a standard procedure as in an ISO 9001 (quality management system) and ISO 14001 (environmental management system) (Zorpas, 2010; Kennedy et al., 2007; Beloin-Saint-Pierre et al., 2016).

- **Difficult to identify the product flow**

One of the biggest challenges for an urban area UM relates to the difficulty in determining flow of each product within the boundaries of the economy, which ultimately leads to double-counting problems.

- **Difficult to identify urban criteria, threshold criteria**

A major drawback to categorizing and comparing sustainability outcomes in the urban sphere is the lack of agreement among researchers on how to define the idea of a sustainable municipality (or city) and the threshold standards above which an urban area can be considered sustainable (Feleki, Vlachokostas, & Moussiopoulos, 2018; Tanguay, Rajaonson, & Lanoie, 2010).

- **Not allowing a specific assessment for the micro-urban scale**

UM studies have mostly been developed on a broader regional or urban scale (Nizza et al. 2009; Barnes 2009), with few analyses on a local scale,mainly due to difficulties with data availability (Codoban and Kennedy, 2008).

THREATS

- **Inability to identify the economic, social and political impact**

UM analyze does not consider the social and political impact and flows. Nowadays determining flow of each product within the boundaries of the economy is challenging to define for UM . An inability to identify the economic sectors that are the main drivers of material consumption is gap of current urban flow accounting methodologies.

- **Understanding of the origin and destination of flows**

Having a limited understanding of the source and destination of flows inside metropolitan limits is another gap (Hammer and Giljum, 2006). In some urban MFA studies, flows that enter or leave the system are taken into account, but the life cycle phase of flows inside the system is not described, and they are not typically identified.

4.2.4 SWOT of Hybrid methodologies

Figure 30 shows the summary diagram of the strengths, weaknesses, opportunities, and threats presented below.

STRENGTHS

- **Support for decision makers**

The hybrid model approach makes the UM-LCA potentially effective tool for decision-makers in the development and evaluation of urban development strategies.

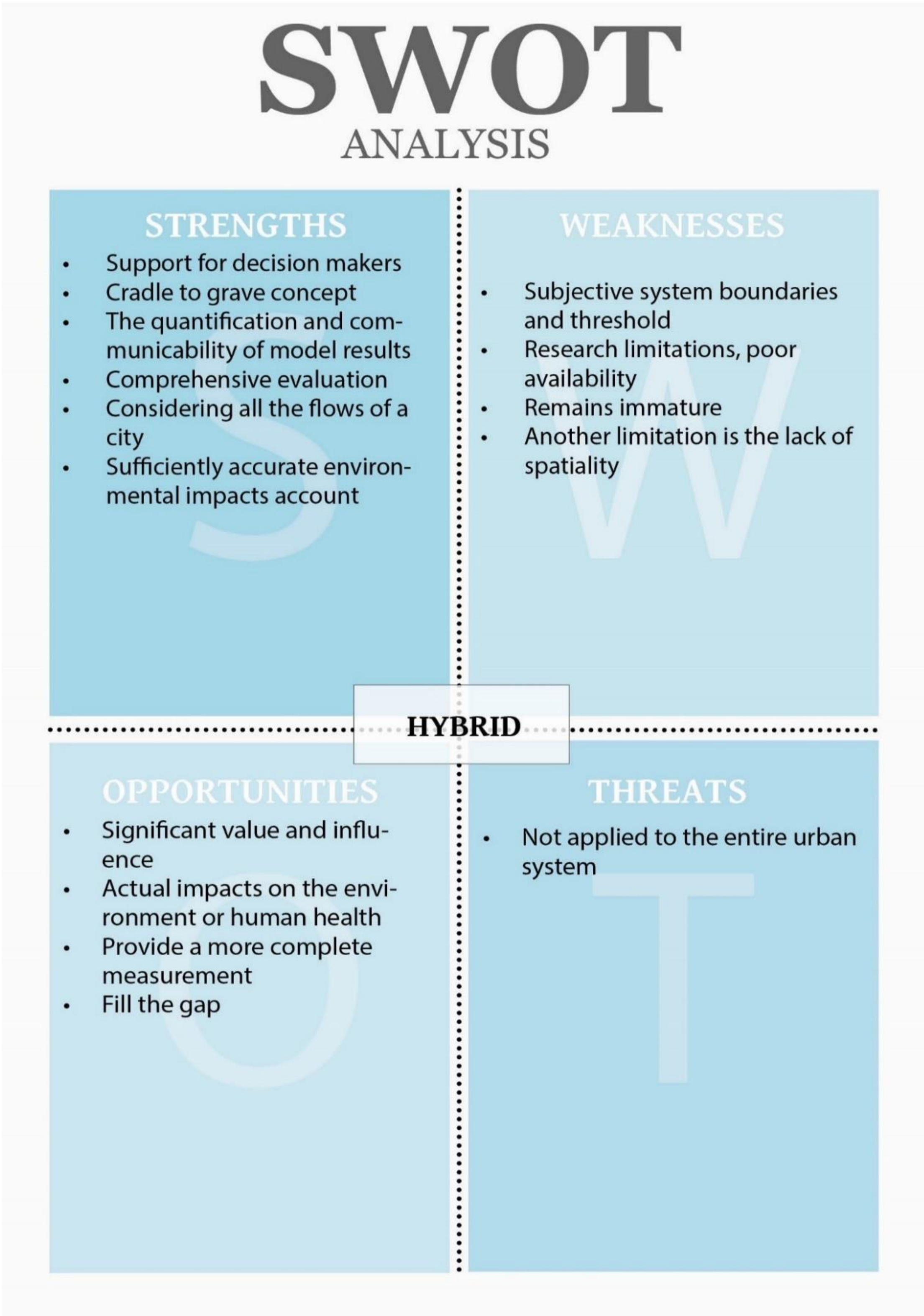


Figure 30: *SWOT Analysis of The Hybrid methodology.*

Source: Author, 2022.

- **Cradle to grave concept**

The benefits in coupling with LCA include the ability of this tool to capture embodied environmental impacts of a metabolic flow applying a cradle to grave concept.

- **The quantification and communicability of model results**

The capacity to quantify and communicate model results in terms of numerous common and prescient environmental indicators.

- **Comprehensive evaluation**

LCA requires assessment of a wide range of impacts, and its application with UM will expand the assessment of urban sustainability from its current focus on flows of energy, water, materials, nutrients and waste (including greenhouse gas emissions, GHGs) to resource depletion, damage to human health and damage to ecosystem quality. By including a wide range of impacts, more comprehensive measures will be taken to ensure the sustainability of cities, and unforeseen consequences can be better avoided (Chester et al.,2012).

- **Considering all the flows of the city**

The combined MFA-LCA methodology has proven itself well for this purpose, as it allows considering all background and forward flows associated with the metabolism of the city, then group them into certain categories of impacts and. Finally, it is possible to identify the sectors that determine the ability of these impacts to generate meaningful results.

- **Sufficiently accurate environmental impacts account**

The results of this analysis show that the considered flows in combination with the MFA-LCA methodology provide "fairly accurate" accounting of environmental impacts when additional data are not available. In addition, the results are quite disaggregated, and a comprehensive environmental strategy plan for the city can be developed.

OPPORTUNITIES

- **Significant value and influence**

Integrating existing UM and LCA frameworks can provide a deeper understanding of the physical flows and infrastructure issues that characterize any urban system, and thus can bring significant value and influence in our understanding of sustainable urban systems.

- **Actual impacts on the environment or human health**

UM and LCA are complementary frameworks that should be used in synthesis to impact on environment or human health in cities. The integrated UM and LCA approach will provide a multi-scale framework for understanding resource, human health, and environmental quality damages.

- **Provide a more complete measurement**

The hypothesis of the current study is that the UM can be integrated into the structure of a process-based LCA, resulting in a hybrid UM–LCA model that can provide a more complete measurement of the environmental pressures produced by the city.

- **Fill the gap**

The combination of LCA and MFA is essential to offer an effective sustainability policy and can also address the gaps related to UM.

WEAKNESSES

- **Subjective system boundaries and threshold**

As UM and LCA highlight environmental perspectives, they set city boundaries based on physical flows. But the boundaries of a city can vary greatly depending on the issue at hand, especially if the definition of infrastructure is of broad significance (Chester et al.,2012).

- **Research limitations, poor availability**

The problem, unrelated to the choice of method or modeling, is the limited availability of data. It is not always possible to find sufficient, high-quality data. In some situations, we have to us alternative data and assumptions to make a full assessment (Ipsen et al,2019).

- **Remains immature**

However, UM–LCA remains methodologically immature, therefore this is one of the basic barriers to its successful application.

- **Lack of spatiality**

Lack of spatiality is yet another drawback. To understand the complex metabolism of a city and to make comparisons with other studies, it is helpful to refer to the gross annual metabolic impacts at the per capital level (i.e., an average inhabitant). However, the Hybrid method overlooks the city's actual demographics. It limits the development of an ideal strategy plan since it does not allow social and economic group disaggregation.

THREATS

- **Still not comprehensive indicator**

The combination of LCA with top-down UM methods has still not been applied to the entire urban system (Pincetl et al., 2012). The proposed UM and LCA converts the city's input-output within the city in terms of environmental impacts, although it only takes into account four environmental indicators (Goldstein et al., 2013).

4.3 THIRD PHASE - Comparison Results

Result of Comparison and key findings of analyzed methodologies through mapping are seen and the potential of each methodology are highlighted and compared. Key questions were compiled for each category such as Strengths, Weaknesses, Opportunities, Threats.

4.3.1 Comparison of Strengths

Figure 31 shows key features of the strengths of each methodology, presented below:

STRENGTHS WHAT ARE THE METHODOLOGIES BEST AT?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Support for decision makers	✓	✓	✓	✓
Compare and select the products that impact less	✗	✓	✗	✓
Cradle-to-grave evaluation	✗	✓	✗	✓
Quantifies inputs and outputs of commodities	✓	✓	✓	✓
Provide support for sustainable city management	✓	✓	✓	✓
Broadly applicable	✓	✓	✓	✓
Easy to implement	✓	✗	✗	✗
Point out the degradation of resources	✗	✓	✗	✓
Assessment of policies and projects for the	✓	✓	✗	✓
Comprehensive environmental strategy	✗	✗	✗	✓
'Sufficiently accurate' environmental impacts	✗	✗	✗	✓
Data credabilty	✗	✓	✗	✗

Figure 31: *Comparison of Strengths.*
Source: Author, 2022.

4.3.2 Comparison of Opportunities

Figure 32 shows the key features of opportunities of each methodology, presented below:

OPPORTUNITIES WHAT OPORTUNITIES ARE OPENED?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Significant value and influence	✓	✓	✓	✓
Regulating its flows smartly and circularly	✓	✓	✓	✓
CO2 emission reduction	✓	✓	✓	✓
Free methods and databases	✓	✓	✓	✓
Actual impacts on the environment or human	✓	✓	✓	✓
Guide to other projects	✓	✓	✓	✓
Regulating flows smartly and circularly	✗	✗	✗	✓

Figure 32 : *Comparison of Opportunities.*

Source: Author, 2022.

4.3.3 Comparison of Weaknesses

Figure 33 shows the key features of weaknesses of each methodology, presented below

WEAKNESSES WHAT COULD BE IMPROVED?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Uncertainty in calculation of methodologies	✓	✓	✓	✗
Subjective system boundaries and threshold	✓	✓	✓	✓
Not comprehensive indicators	✓	✓	✓	✗
Research limitations, poor availability of data	✓	✓	✓	✓
Implementation of strateges is relevant	✓	✓	✓	✓
Complex and large systems to analyze	✗	✓	✓	✓
Not allowing an assessment for the micro-urban scale	✗	✗	✓	✗
Not widely evaluated by practitioners	✗	✗	✗	✓
Express relative sustainability	✓	✓	✓	✓
Incompact and incomplete quantitative assessment	✓	✓	✓	✗
Difficult to build the complicated projectaccount	✓	✓	✓	✓
Lacks of standardization	✓	✓	✗	✗

Figure 33 : *Comparison of Weaknesses.*

Source: Author, 2022.

4.3.4 Comparison of Threats

Figure 34 shows the key features of threats of each methodology, presented below:

THREAT WHAT THREAT COULD HARM?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Diversity of evaluations	✓	✓	✓	✓
Assessment less reproducible, credible and transparent	✓	✓	✓	✗
Hidden environmental impacts	✗	✓	✗	✓
Limited funding	✓	✓	✓	✓
Not easy to communicate the results	✗	✓	✓	✓
Hard interpretation of flows	✗	✗	✓	✗
Does not consoder economic and social aspects	✓	✓	✓	✓

Figure 34 *: Comparison of Threats.*

Source: Author, 2022.

4.3.5 Comparison of Implementation Categories

Figure 35 shows the comparison of implementation categories of each methodology, presented below:

IMPLEMENTATION CATEGORIES	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	FOOTPRINT	HYBRID
Built environment	🟢	🔴	🟢	🟢
Water	🟢	🟢	🟢	🟢
Food	🟢	🟢	🟢	🟢
Energy	🟢	🟢	🟢	🟢
Material cycling	🟢	🟢	🔴	🟢
Open spaces	🟢	🔴	🔴	🟢
Mobility	🟢	🔴	🟢	🟢
Waste flow	🟢	🟢	🟢	🟢

Figure 35: Comparison of implementation categories.

Source: Author, 2022.

4.4 FOURTH PHASE - Recommendations and Guidance Results

After the research about different methodologies used in urban studies, and the development both the SWOT analysis and comparison result, the six Recommendations and Guidance on selection of methodology for use in environmental impact assessment were elaborated.This chapter result has been broken down into three steps: the first is about conducting interviews with urban experts from the Politecnico di Torino, the second is the development of six recommendations, and the third is the development of Guidance handbook.

4.4.1 Interview with Urban Experts

The Urban Experts were asked questions which are specified in Section 3.1.4, to see if they have experience applying those methodologies withing their work or expertise. During interviews, Experts shared their experience and gave an opinion about advantages / disadvantages of each assessment methods and what challenges they faced when applying one of the urban assessment indicators. Additionally, after conducting interviews the challenges of each method, pros of some tools and disadvantages were taken into account and thus, another set of SWOT is developed.

INTERVIEW 01

1.Have you ever implemented those methodologies within your work and expertise? In your opinion did I consider the most important ones? Do you have any suggestion on possible integration in the thesis?

I started my work as a researcher in the field of environmental design by reviewing papers about Urban Metabolism methodology. It resulted in a scoping review paper, in which we highlighted the possibility of applying UM for supporting decisions and guidance to micro-urban scale design. I am also doing research in the framework of UM within a national project, in which we are focusing on quantifying the so-called vertical and horizontal flows (Kellett et al., 2013) at neighborhood scale (i.e., GHG emissions and waste), intended as major outputs of an urban system, to which we should primarily be paying attention. As for my future works, I am about to start deepening my knowledge about Life Cycle Assessment, which is considered to be the most robust and sound methodology for assessing impacts of processes and products with respect to the planet by the European Commission (Commission of the European Communities, 2003), too. Finally, I am not really an expert on the field of Footprint calculations. However, as far I got from your synthesis, I think you certainly did consider the most solid and acknowledged methodologies. As for possible integration of the thesis (or, may be better, mainly for your personal knowledge), I would suggest you to consider the possibility of looking at the "Social LCA" (UNEP, 2009), which is recently growing as a complementary approach for establishing impacts of products and processes with respect to the social dimension of sustainable development. However, many scholars are still working for better defining thresholds and proper methods for its calculation. I would finally suggest to have a look at this important and acknowledged framework for sustainability assessment (Sala, Ciuffo and Nijkamp, 2015) representing a spectrum of criteria for assessing the capability of different methods to address sustainability, in which LCA and FT are discussed, too.

2.What in your opinion are the opportunities and weaknesses of these three methodologies?

According to me, the greatest merit of UM methodology is more a concept one, as it is related to the emphasis it put on the urban dimension of sustainable development, that is strictly the pressure of an urban system on the surrounding natural peripheral ecosystems (Castan Broto, Allert, and Rapaport, 2013). I think UM is mostly related to processes and the connection between these and their environmental effects, rather than analyzing impacts. However, many (or may be, almost all) UM research are accounting exercise or they can turn out to be conducted considering the system analyzed as a "black box", with no attention to the relationships among phenomena occurring but just considering inputs-outputs. Is that how a complex ecosystem like a city do work? Not really. Indeed, their main limitation is to focus on the "pressure" measurement stage, without considering final impacts with respect to certain thresholds. This is actually what is covered by LCA, which, in a way, could be considered the step after UM measurement. Indeed, its greatest advantage is to have certain boundaries (as it happens with FT) against which product and process sustainability could be assessed. LCA comes with an established, transparent, and accessible method for its evaluation, too, with respect to UM and FT. Finally, LCA is not so easy to communicate to non-experts, while FT is much more effective when it comes to its mainstreaming.

3.What are the strong points and limitations of Hybrid methodologies? Why do we need to integrate them? (E.g., LCA & FT, LCA & UM, UM & FT)

I am not an expert in hybrid methodologies and I am looking forward to read more from your results. However, I guess that, among the strong point of them, there is the possibility to combine the positive elements of each methodology, thus trying to minimize limits. Just as an example, I guess that combining LCA or UM with FT could turn into more communicable and easy-to-understand results. LCA and UM combination could actually ease the application of LCA in urban and territorial assessment, which is nowadays very limited. To conclude, I see LCA at the basis of any sustainability assessment process, that, combined with other methodologies, could in turn become more and more appliable at all scale and for all sustainability assessment domains.

4.By what criteria do you choose currently available methods? When I have to use LCA rather than Footprint or Hybrid one? What are the main differences between them?

I am not an expert in hybrid methodologies and I am looking forward to read more from your results. For the moment, I have been applying UM, I started studying LCA, while I only theoretically know FT, although never directly applied. However, LCA is widely used for measuring sustainability of companies and / or their products. Besides, it must be used for scientific reporting, such as, for example, on the "Do not significant harm" principle, with respect to environmental protection. Finally, I guess that choosing a specific methodology mainly depends on two factors, namely the purpose of the study and the scale of application. As for measuring the pressure of certain phenomena that occur at urban, regional, territorial or even national scale, UM and FT are more appropriate. If you need to benchmark processes or products with respect to certain upper thresholds (e.g., the Planetary Boundaries) and for sustainability certification, you will be needing LCA.

INTERVIEW 02

1.Have you ever implemented those methodologies within your work and expertise? In your opinion did I consider the most important ones? Do you have any suggestion on possible integration in the thesis?

The methodologies you have chosen for the thesis I believe are the most important ones for determining environmental impact at the urban scale. In the past, I have been mainly concerned with the Urban Metabolism approach because I believe it is better suited to consider the complexity of urban phenomena and the possibility of scaling the analysis from local to global. In particular, I used it to conduct a study on urban green waste. In that case, I tried to combine UM with MFA (material flow analysis) to compare the potential recovery of energy and matter (compost) from urban green waste.

2.What in your opinion are the opportunities and weaknesses of these three methodologies?

Environmental assessing of a product or process is fundamental. LCA and CF have the advantage (in my opinion) of clearly and directly communicating the results making them understandable even to non-experts. On the other hand, both disciplines run the risk of not considering the heterogeneity of effects. >In my opinion, this approach risks simplifying the nature of the problems. For UM, it is difficult to determine pros and cons because since now it is still discussed on a theoretical level, concrete experiences are extremely limited.

3.What are the strong points and limitations of Hybrid methodologies? Why do we need to integrate them? (E.g. LCA & FT, LCA & UM, UM & FT)

Certainly a hybrid approach allows for better investigation of the actual impact of the product/process. On how to integrate, I think it strongly depends on the type of analysis. It is unthinkable to define an a priori analysis with so many variables as in the urban system.

4.By what criteria do you choose currently available methods? When I have to use LCA rather than Footprint or Hybrid one?

Based on the process to be analyzed, available data, timing, and the result we want to demonstrate. Generally, before each analysis, a panel of experts defines the analysis methodology and indicators to be used.

INTERVIEW 03

1.Have you ever implemented those methodologies within your work and expertise? In your opinion did I consider the most important ones? Do you have any suggestion on possible integration in the thesis? What in your opinion are the opportunities and weaknesses of these three methodologies?

I used that type of methodology at different level, I started with my Master thesis and the studies that have done with Green Team-Politecnico di Torino we evaluated the Ecological Footprint of university campus considering as a small part of the city as a small city in this case we used the ecological footprint method considering different types of categories by assessing the land that was needed to support the activities performed inside of the campus by all its communities . Then in my research I implemented another method, one of the most recent method that I have used it is called Consumption Footprint. It combines both the footprint approach,considering the impact on the environment and it is based on the LCA methodology to evaluate the impact of the consumption behaviour in general. That methodology was initially adopted to the country level to evaluate the impact of different countries in European Union and then we tried to adopt to territorialize this method using the LCA combined with general idea of Footprint analysis in the city to evaluate the impact of urban consumption behaviour.

2.What in your opinion are the opportunities and weaknesses of these three methodologies?

Opportunities: they are all quantitatives all of the has done in quantitative way , one of the opportunities that have the final set of numbers that explain the environmental effects of the cities for example. When I worked with the ecological footprint it was very interesting to see the possible using of the communicative way of this final number to explain the environmental impact in a circular way to non-experts. There are different challenges using that methodology one of the main challenges are the data collection. When we worked at the urban level the collection of the data was very difficult since there are several data base and institutions or entities in general that collect data and transform them in the different way. There are a lot of work have done to adopt the data that are available to data that are needed to perform this type of analyses so how to transform, aggregate and align this type of data with one that are needed by the methodology. Other weaknesses are also related to the fact about the difficulties in data collection,some modifications are done to specific methodologies and in this case at the end the comparability of the result is difficult. Sometimes the experimentation and studies that have done in different cities are very difficult to be compared with other case studies to see which are the differences in different geografical or socio-economic context.The comparability of results can be challenging it should be improved in future.

3.What are the strong points and limitations of Hybrid methodologies? Why do we need to integrate them? (E.g. LCA & FT, LCA & UM, UM & FT)

All of these methodologies, with the exception of urban metabolism, are not designed specifically for the urban context, so the need to hybridize and combine them is one of the strengths. Testing the most innovative aspect of each methodology makes it easier to adapt them to the urban context. since life cycle assessment itself is very difficult to apply to the whole city, because it is very accurate and is used in an industrial context to evaluate goods and products. On the contrary, I usually use footprint analysis at the level of a country, region, so the combination of different aspects can create innovative methodologies for assessing the impact of cities specifically adapted to the urban context. The limitations are similar to the ones I mentioned earlier, so even if we combine these methodologies, there will be data collection issues related to the results, because if we create this new innovative methodology, it will also be very difficult to verify the correctness of the results, because perhaps this is just an example and cannot be compared with previous studies. For example, the footprint methodology is very well defined at country level and if we create our own methodology combining footprint with LCA or UM to create any methodologies then it is very difficult to see and check how the results are correct.

4.By what criteria do you choose currently available methods? When I have to use LCA rather than Footprint or Hybrid one?

The first criterion for choosing a methodology is the purpose and purpose of your research, what you want to evaluate, and then choose the most appropriate methodology. For example, in my first study where we assessed the Ecological Footprint of the Polytechnic University campus, we decided to use EF because we wanted to evaluate the environmental impact using this index to report the result in a very simple way, given the limitations of EF, of course, the study can be conducted using other methodologies with different results. In this case, for example, the Green Team is now working on assessing the carbon footprint of the campus, since the goal has changed, we started with something that should be more communicative, now we need to do a more accurate study to determine the hot spot. so we have a different goal that is changing, so we also changed the analysis methodology. In addition, the selection is based on the availability of data that we know is available for collection, as long as it is consistent with the need for each methodology. And also time, because some methodologies are time consuming, such as LCA evaluation.

What are the main differences between them?

The differences are based on the purpose they can use to achieve different goals. If you need a single index as a result, you should be aware of the difference when using different information data that is not always available or is private, you will have to pay to get this type of data. Hybrid is the ability to mix and match the most innovative to also try to limit the problems and barriers in the overall methodology.

Figure 36: *Interview with Urban Experts.*

Source: Author, 2022.

Strengths	Weaknesses
• LCA is considered to be the most robust and sound methodology • LCA comes with an established, transparent, and accessible method for its evaluation • FT is much more effective when it comes to its mainstreaming. • LCA considers final impacts with respect to certain thresholds • Hybrid methodologies as the possibility to combine the positive elements of each methodology • Combining LCA or UM with FT could turn into more communicable and easy-to-understand results • LCA and UM combination could ease the application of LCA • LCA could become more applicable at all scale • LCA is widely used for measuring sustainability of companies and / or products • UM and FT are more appropriate for measuring the pressure of certain phenomena that occur at different scale • UM is better suited to consider the complexity of urban phenomena • UM gives the possibility of scaling the analysis from local to global • LCA and CF clearly and directly communicating the results • LCA and CF understandable even to non-experts. • Hybrid approach allows for better investigation of the actual impact of the product/process • LCA is very very precise indicator • Footprint methodology is very well defined at the country level • Hybrid is more easier to adopt them to the urban context	• UM is focusing on the "pressure" measurement stage, without considering final impacts with respect to certain thresholds • UM only considers inputs-outputs (no attention to the relationships among phenomena occurring) • LCA is not so easy to communicate to non-experts • LCA and CF run the risk of not considering the heterogeneity of effects • UM is still discussed on a theoretical level All methodologies has the difficulties in data collection • Footprint result is challenging • LCA is very difficult to apply to the entire city • Different information data which is not always available

Table 16: *SWOT Analysis based on the conducted interview with Urban Experts.*
Source: Author, 2022.

4.4.2 Recommendations

After a post assessment of the learnings and outcomes from the three above Phases, six recommendations were elaborated. Recommendations address the need to provide valuable information on how to better integrate and implement different environmental assessment methodologies in order to support urban actors and future researchers in reducing the environmental impact of cities.

4.4 Fourth Phase – Recommendations and Guidance Results

Based on the cons identified, the recommendations suggest a pragmatic shift in the focus of urban sustainability assessment from theory development to more of application. Methods must quickly move beyond the experimental phase to practical application. Moreover, based on the key findings of the SWOT analysis and comparison of different approaches, recommendations may also be also applicable to other projects at the EU level and on a broader scale.

Therefore, elaborated recommendations are aimed at involving European and local urban actors in the use of these recommendations, thereby allowing them to contribute their experience and perspectives to the future project.

The six recommendations are:

1. Use the Ecological Footprint analysis with the Urban Metabolism framework to tackle a wide range of sustainability issues at a metropolitan, regional scale.
2. Use Integrated methodology (UM-LCA) for comprehensive and sufficiently accurate environmental impact analysis.
3. Use the LCA method to obtain reproducible, credible and transparent assessment.
4. Integrate different methodologies to accelerate the learning process of the urban sustainability assessment and help in the improvement of both theory and practice.
5. Use the Footprint indicator to provide urban actors/future researchers with a simpler and easier indicator to apply at different stages of the decision-making processes.
6. Consider a new method with respect to social or economic dimensions of sustainability.

4.4 Fourth Phase – Recommendations and Guidance Results

As a result, the six recommendations are detailed below, following the six structured points explained in Section 3.1.4:

- Name of the Recommendation
- Scale of Applicability – Neighborhood, Urban, Regional scale
- Linkage with the 17 Sustainable Development Goals (SDGs) outlined by the United Nations General Assembly

- Background information and justification
- Description of the Recommendation
- Examples and/or references related to the recommendations to reflect the concept behind it

4.4 Fourth Phase – Recommendations and Guidance Results

01 Recommendation:

Use The Ecological Footprint analysis with the Urban Metabolism framework to tackle a wide range of sustainability issues at a metropolitan, regional scale.

Scale of Applicability: Metropolitan/Regional scale

Linkage with SDGs:

Background and justification:

Since LCA is indicator which is very difficult to apply to the entire city or regional scale, the integration of UM and EF is solution while applying for wider scale. Effective measures taken at sub-national level could assist us in addressing global environmental challenges at the global scale (Bulkeley and Betsill, 2005; Wilbanks and Kates, 1999). The application of a bottom-up ecological footprint analysis using an urban metabolism framework at a metropolitan, regional scale can be more effective in addressing urban actors concerns and interests.

Description:

Urban actors/Future researchers should use the Urban Metabolism framework and The Ecological Footprint study to address a variety of sustainability issues at a metropolitan and regional level. The use of a bottom-up ecological footprint study within an urban metabolism framework at a metropolitan, regional scale can be an effective tool to quantify flows consumed by cities.

Examples and/or references:

Moore et al. (2013) introduce a detailed, bottom-up urban metabolism and ecological footprint analysis for a North American metropolitan region. It aims to demonstrate the application of a bottom-up ecological footprint analysis using an urban metabolism framework at a regional scale. The authors show why and how the methodological approach for subnational ecological footprint research is based on economy-wide input-output estimates, which is standard in Europe.

02 Recommendation:

Use Integrated methodology (UM-LCA) for comprehensive and sufficiently accurate environmental impact analysis.

Scale of Applicability: Urban/Neighborhood

Linkage with SDGs: 

Background and justification:

The application of LCA at the urban scale is not yet a reality. Its current application is limited in scope and applied to a geographical part of the city (e. g. Neighborhood scale). Therefore, an incomplete environmental impact assessment will lead to the fact that the project will be associated with a higher risk of negative impact. Without the introduction of a proper environmental assessment tool that could provide a holistic perspective, the environment and people could be at risk. Thus, LCA requires assessment of a wide range of impacts, and its application with UM will expand the assessment of urban sustainability from its current focus on flows of energy, water, materials, nutrients, and waste (including greenhouse gas emissions, GHGs) to resource depletion, damage to human health and damage to ecosystem quality. By incorporating a wide range of impacts, urban actors can take more comprehensive measures to ensure urban resilience, and unforeseen consequences can be better avoided (Chester et al., 2012).

Description:

Using Integrated methodology (UM-LCA) by urban experts for comprehensive and sufficiently accurate environmental impacts analysis. Both methods can ensure the sustainability of cities through intelligent and circular harmonization of flows.

Examples and/or references:

Some studies developed the UM-LCA model in the past. For example, UM–LCA model was applied to five case cities: Beijing, Cape Town, Hong Kong, London, and Toronto. Findings report that the considered flows, in combination with the UM-LCA, provide a "sufficiently accurate" environmental impacts account when no further data is available. (Goldstein et al.,2013).

4.4 Fourth Phase – Recommendations and Guidance Results

03 Recommendation:

Use the LCA method to obtain reproducible, credible and transparent assessment.

Scale of Applicability: Urban scale

Linkage with SDGs:

Background and justification:

As more and more regulations emerge to combat greenwashing, the credible environmental data to make products being sustainable is needed. The evaluation of the current urban methodologies remains methodologically immature and continues to limit accurate accounting of urban flows of cities. Taking them into account there are significant barriers and weaknesses such as a lack of data, omitted/hidden upstream flows, uncertainty regarding the appropriate scale of analysis. A certain lack of transparency in the calculations in development of the ecological footprint can lead to inaccurate result and false information. However, the use of the environmental data based on the LCA study can make the life cycle of a product truly sustainable (Kennedy et al., 2011).

Description:

Despite the fact that most assessment methodologies are currently immature, the use of a LCA method can be used to obtain reproducible and transparent assessment. The use of accurate data based on the LCA study not only confirms and strengthens sustainability of the cities, but it also enhances credibility.

Examples and/or references:

Currently, there are many studies devoted to the LCA method that provide a reliable result of data evaluation. For example, Loubet et al. (2016) developed framework and an associated modeling tool to perform LCA for urban water system. The model WaLA applied to a real-world case study, the urban water system of the Paris suburbs (France). The innovative and comprehensive strategy is supported by credible primary and secondary data (measurement flow meter, calculation from an external model or mass balance result).

4.4 Fourth Phase – Recommendations and Guidance Results

04 Recommendation:

Integrate different methodologies to accelerate the learning process of the urban sustainability assessment and help in the improvement of both theory and practice.

Scale of Applicability: Local, Regional

Linkage with SDGs: 

Background and justification:

There is still a significant gap between assessment theories and assessment practices. Cooper (1997; 1999) refers to this fact and argues that the practice of assessment lags well behind development of methodological theories. New assessment approaches are still mostly experimental, with limited practical uses. A simple example of this is the current scenario in which most widely used assessment methods fail to make evaluations that sufficiently address most challenges underlying the sustainable urban development process. (Adinyira et al., 2007). To improve the current situation, it is necessary to identify those aspects of urban activities and challenges at various geographical scales that are poorly covered by existing evaluation methods. Based on identified gaps, urban actors should integrate main assessment methods to develop hybrid one which may be able of addressing most of urban sustainability issues at different scale.

Description:

By combining different methodologies that currently exist it will be possible to develop methods that will capture most if not all urban activities and spatial scales, accelerate the learning process of the urban sustainability assessment and aid in the improvement of both theory and practice.

Examples and/or references:

Currently, there are several hybrid proposals for quantifying environmental impacts. For example: 1) the integration of LCA and EF; 2) UM, MFA and LCA; 3) UM and EF. These results in a more precise and detailed modelling allow for a clearer identification of hotspot and opportunities for efficient environmental performance of cities. Combining UMA with EFA can enhance strengths of both methods (Curry et al., 2011). The EFA, based on the UMA framework, adds an additional layer of insight to the already robust analysis of energy and material flows in a city (Mirabella et al., 2018).

4.4 Fourth Phase – Recommendations and Guidance Results

05 Recommendation:

Use the Footprint indicator to provide urban actors/future researchers with a simpler and easier indicator to apply at different stages of the decision-making processes.

Scale of Applicability: At all scale

Linkage with SDGs: 

Background and justification:

Taking into account that LCA is too professional, complex and large tool to analyze, thus requiring urban actors to have professional knowledge to help them make decisions; footprint is simpler indicator to use and calculate, making it a usable indication for non-scientists. If indicators are too technical and complicated, most urban practitioners and future researchers will continue to avoid them. Therefore, the environment assessment Indicator should provide them with a simpler and more intuitive model for decision-making. The Ecological Footprint can be applied at all scales, ranging from single products to humanity as a whole by providing a solid knowledge base and an easily applicable calculation method (Wackernagel et al., 2006). Not surprising the footprint is the only indicator that can communicate results to a wide audience (Thomas Wiedmann and John Barrett, 2010).

Description:

Urban actors/Future researchers when choosing an environment assessment indicator should consider the Footprint indicator since it is simpler and easier indicator to use and apply in different stages of the decision-making processes.

Examples and/or references:

There are several EF approaches now available, differing in the underlying methodology. “A Review of the Ecological Footprint Indicator «by Thomas Widman (2010) provided a comprehensive overview of perceptions and practices regarding the Ecological Footprint. That review is based on a survey of more than 50 international EF stakeholders and a review of more than 150 original papers on EF methods supporting the idea of the ease of using the Footprint indicator (Thomas Wiedmann and John Barrett, 2010).

4.4 Fourth Phase – Recommendations and Guidance Results

06 Recommendation:

Consider a new method with respect to social or economic dimensions of sustainability.

Scale of Applicability: Urban/Neighborhood

Linkage with SDGs:

Background and justification:

The ability to address economic, social and environmental interdependencies within policies, plans, legislations and projects has become the basic requirement of all urban sustainability assessments methods. Most currently available methods still fail to demonstrate sufficient understanding of the interrelations of social, economic and environmental considerations (Adinyira et al.,2007). For example, Urban Metabolism does not consider the social and political impact and flows. Ecological Footprint does not count as well the social or economic dimensions of sustainability. To overcome these challenges, 'Social LCA' method was suggested to be considered by one of the urban actors (from conducted interview) as an important and acknowledged framework for sustainability assessment. Taking these points into consideration, the importance of a new social and socio-economic assessment tool in moving towards sustainable development is undeniable (Guideline for Social Life Cycle Assessment,2020).

Description:

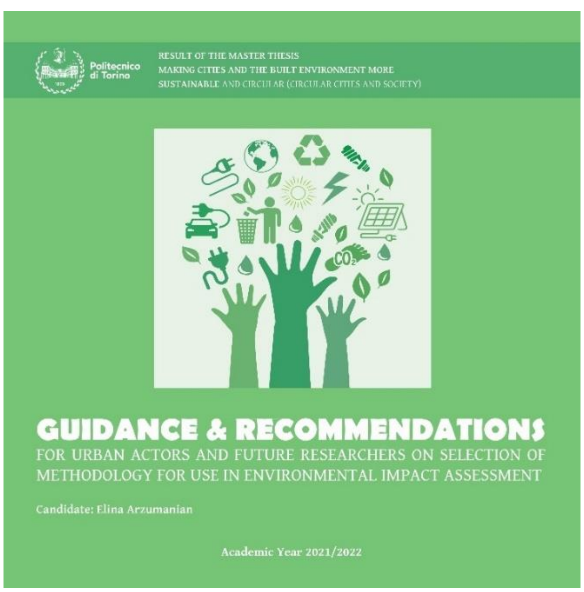
Urban Actors/ Future Researchers should consider another recently growing quantitative tool for assessing the positive and negative impact of products and processes with respect to the social or economic dimensions. In this way it can support urban actors in improving their overall socio-economic performance and strategies to achieve sustainable urban growth.

Examples and/or references:

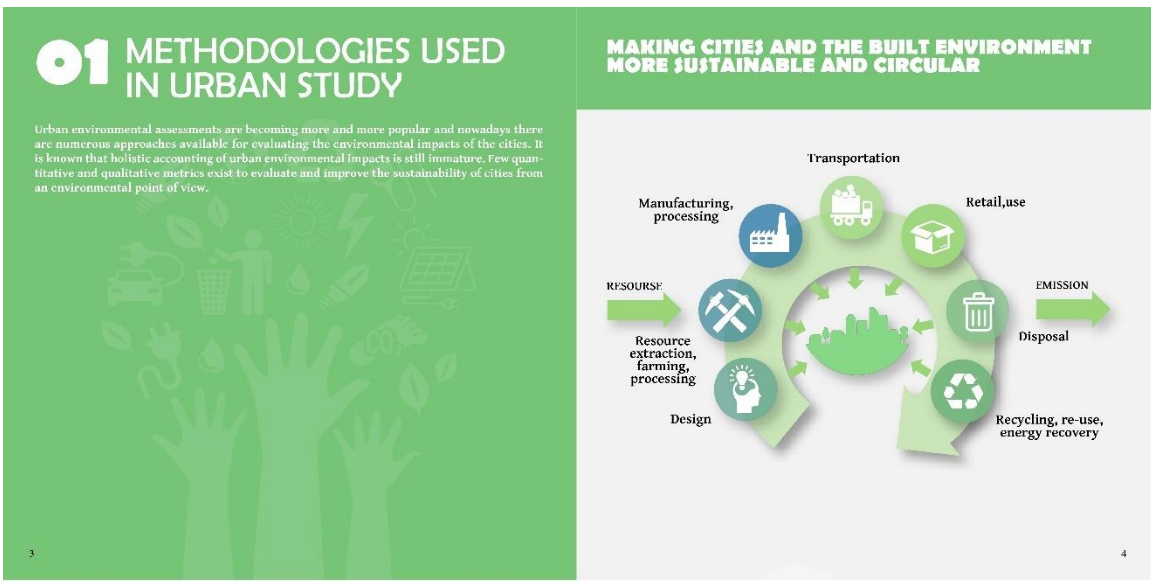
The Guidelines for Social Life Cycle Assessment (S-LCA) present a methodology to assess the social impact of products using a life cycle perspective. Moreover, it covers new methodological and provides a key and unique feature of Social-LCA practical developments. Therefore, that innovative methodology can be applied to calculate a social impact, social footprint, identify social hotspots (location or activity with high risk/impact), social hand printing, etc. (Guideline for Social Life Cycle Assessment,2020).

4.4.3 Guidance

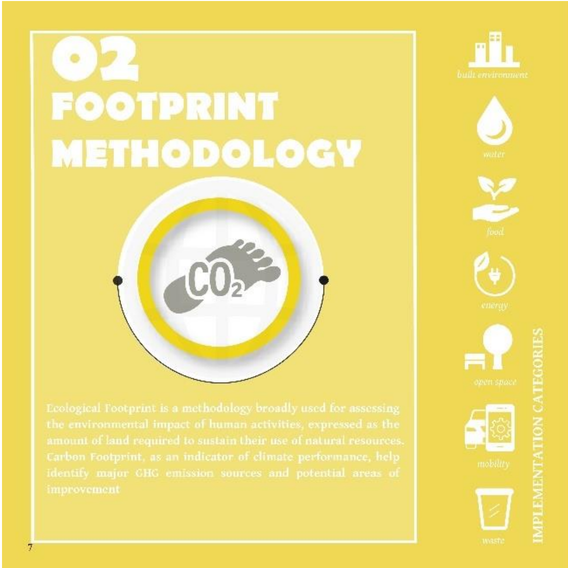
The guidance handbook is divided into seventh main parts:The first part is an introduction part which presents fourth methodologies used in urban study. It gives the general idea about four approaches recently used by experts.The second, third, fourth and fifth parts of the Guidance present: the Footprint, the Life Cycle Assessment, the Urban Metabolism and the Hybrid methods and explain the definition and the main key features, namely the concept, the major characteristics, the major viewpoints and etc. Moreover, results of those methods through a SWOT analysis give clear understanding about advantageous, disadvantageous, opportunities and threats of each method. Finally, the overviews of the main urban approaches are presented. The six part shows the key findings regarding those four methods. It highlights and compare the feasibility and potential of each approach. Finally, the seventh part is dedicated to six recommendations to provide valuable information on how to better integrate and implement different environmental assessment methodologies in order to support urban actors and future researchers in reducing the environmental impact of cities. The following handbook is annexed to the thesis.

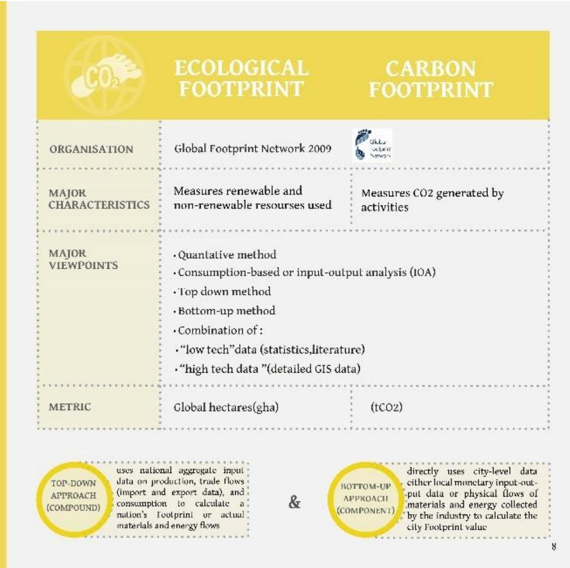


4.4 Fourth Phase – Recommendations and Guidance Results



4.4 Fourth Phase – Recommendations and Guidance Results





	ECOLOGICAL FOOTPRINT	CARBON FOOTPRINT
ORGANISATION	Global Footprint Network 2009	
MAJOR CHARACTERISTICS	Measures renewable and non-renewable resourses used	Measures CO2 generated by activities
MAJOR VIEWPOINTS	• Quantiative method • Consumption-based or input-output analysis (IOA) • Top down method • Bottom-up method • Combination of : • "low tech"data (statistics,literature) • "high tech data "(detailed GIS data)	
METRIC	Global hectares(gha)	(tCO2)

TOP-DOWN APPROACH (COMPOUND): uses national aggregate input data on production, trade flows (import and export data), and consumption to calculate a nation's Footprint or actual materials and energy flows

&

BOTTOM-UP APPROACH (COMPONENT): directly uses city-level data either local monetary input-output data or physical flows of materials and energy collected by the industry to calculate the city Footprint value

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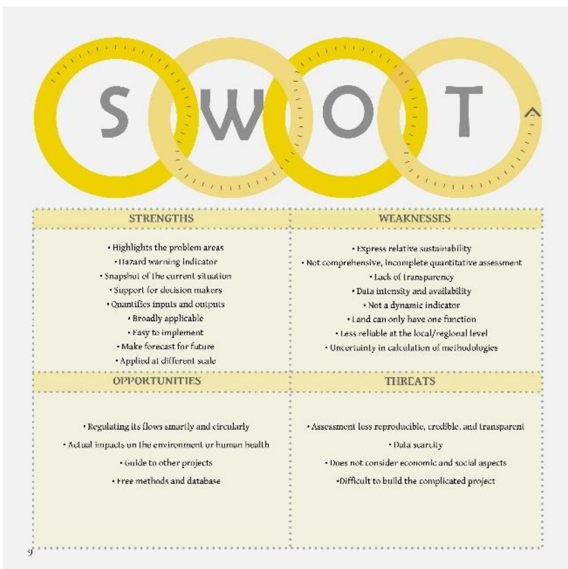

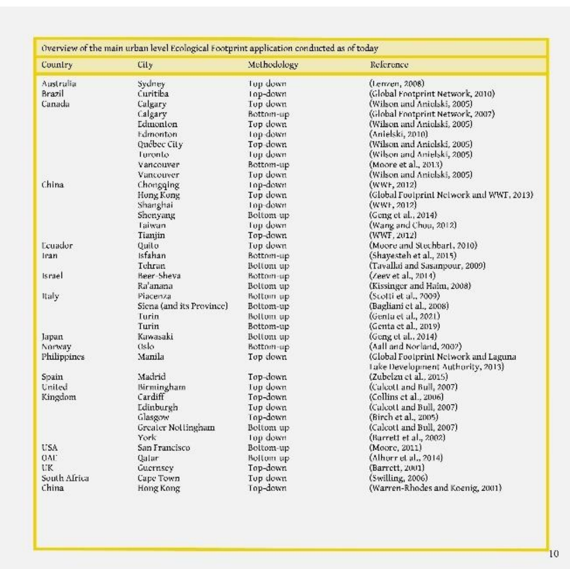

Overview of the main urban level Ecological Footprint application conducted as of today

Country	City	Methodology	Reference
Australia	Sydney	Top down	(Lenzen, 2008)
Brazil	Curitiba	Top-down	(Global Footprint Network, 2010)
Canada	Calgary	Top down	(Wilson and Anielski, 2005)
	Calgary	Bottom-up	(Global Footprint Network, 2007)
	Edmonton	Top down	(Wilson and Anielski, 2005)
	Edmonton	Top-down	(Anielski, 2010)
	Québec City	Top-down	(Wilson and Anielski, 2005)
	Toronto	Top down	(Wilson and Anielski, 2005)
	Vancouver	Bottom-up	(Moore et al., 2013)
	Vancouver	Top down	(Wilson and Anielski, 2005)
China	Chongqing	Top-down	(WWF, 2012)
	Hong Kong	Top down	(Global Footprint Network and WWF, 2013)
	Shanghai	Top-down	(WWF, 2012)
	Shenyang	Bottom up	(Geng et al., 2014)
	Taiwan	Top down	(Wang and Chou, 2012)
	Tianjin	Top-down	(WWF, 2012)
Ecuador	Quito	Top down	(Moore and Stechbart, 2010)
Iran	Isfahan	Bottom-up	(Shayesteh et al., 2015)
	Tehran	Bottom up	(Tavallai and Sasanpour, 2009)
Israel	Beer-Sheva	Bottom-up	(Zeev et al., 2014)
	Ra'anana	Bottom up	(Kissinger and Haim, 2008)
Italy	Piacenza	Bottom up	(Scotti et al., 2009)
	Siena (and its Province)	Bottom-up	(Bagliani et al., 2008)
	Turin	Bottom up	(Genta et al., 2021)
	Turin	Bottom-up	(Genta et al., 2019)
Japan	Kawasaki	Bottom up	(Geng et al., 2014)
Norway	Oslo	Bottom-up	(Aall and Norland, 2002)
Philippines	Manila	Top down	(Global Footprint Network and Laguna Lake Development Authority, 2013)
Spain	Madrid	Top-down	(Zubelzu et al., 2015)
United Kingdom	Birmingham	Top down	(Calcott and Bull, 2007)
	Cardiff	Top-down	(Collins et al., 2006)
	Edinburgh	Top down	(Calcott and Bull, 2007)
	Glasgow	Top-down	(Birch et al., 2005)
	Greater Nottingham	Bottom up	(Calcott and Bull, 2007)
	York	Top down	(Barrett et al., 2002)
USA	San Francisco	Bottom-up	(Moore, 2011)
QAE	Qatar	Bottom up	(Alhorr et al., 2014)
UK	Guernsey	Top-down	(Barrett, 2001)
South Africa	Cape Town	Top down	(Swilling, 2006)
China	Hong Kong	Top-down	(Warren-Rhodes and Koenig, 2001)

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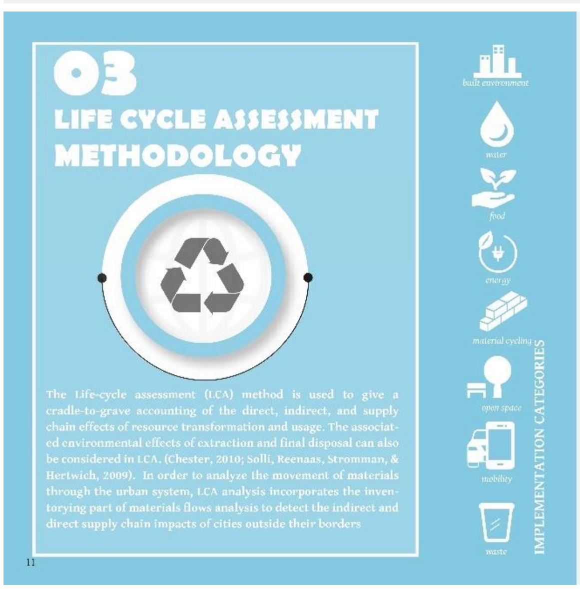

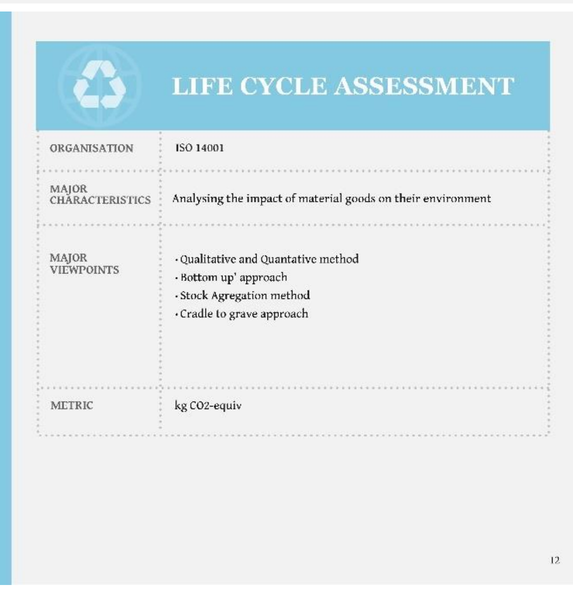

	LIFE CYCLE ASSESSMENT
ORGANISATION	ISO 14001
MAJOR CHARACTERISTICS	Analysing the impact of material goods on their environment
MAJOR VIEWPOINTS	• Qualitative and Quantative method • Bottom up' approach • Stock Agregation method • Cradle to grave approach
METRIC	kg CO2-equiv

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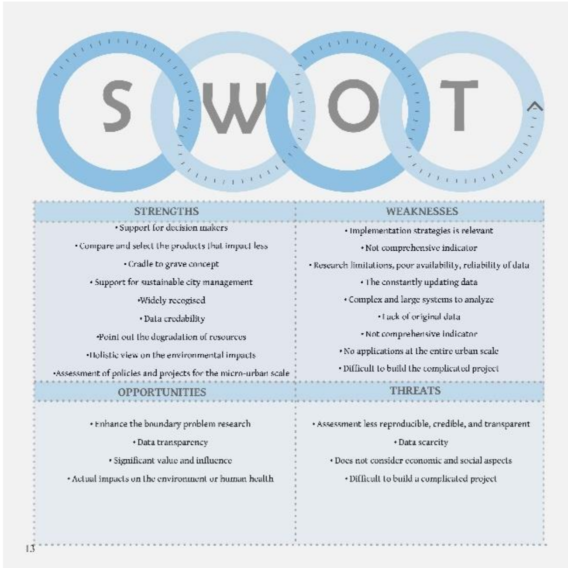
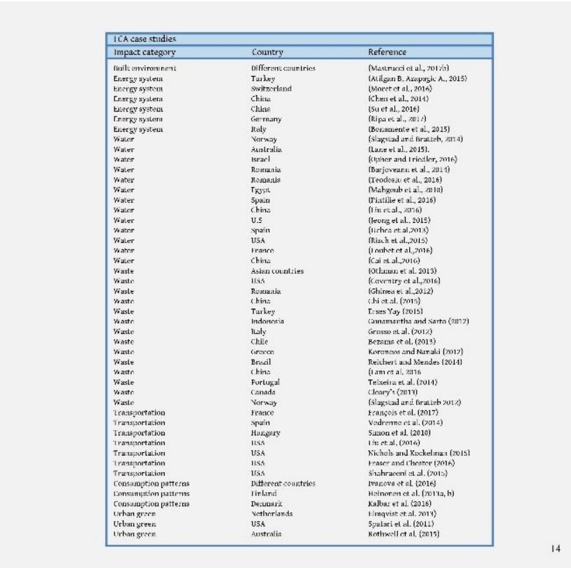
4.4 Fourth Phase – Recommendations and Guidance Results





LCA case studies		
Impact category	Country	Reference
Built environment	Different countries	(Mastrucci et al., 2017b)
Energy system	Turkey	(Atilgan B, Azapagic A., 2015)
Energy system	Switzerland	(Moret et al., 2016)
Energy system	China	(Chen et al., 2014)
Energy system	China	(Su et al., 2016)
Energy system	Germany	(Ripa et al., 2017)
Energy system	Italy	(Benamente et al., 2015)
Water	Norway	(Slagstad and Bratteb, 2014)
Water	Australia	(Lane et al., 2015).
Water	Israel	(Opher and Friedler, 2016)
Water	Romania	(Barjoveanu et al., 2014)
Water	Romania	(Teodosiu et al., 2016)
Water	Egypt	(Mahgoub et al., 2010)
Water	Spain	(Piatilie et al., 2016)
Water	China	(Lin et al., 2016)
Water	U.S	(Jeong et al., 2015)
Water	Spain	(Uchoa et al.,2013)
Water	USA	(Risch et al.,2015)
Water	France	(Loubet et al.,2016)
Water	China	(Cai et al.,2016)
Waste	Asian countries	(Othman et al. 2013)
Waste	USA	(Coventry et al.,2016)
Waste	Romania	(Ghinea et al.,2012)
Waste	China	Chi et al. (2015)
Waste	Turkey	Erses Yay (2015)
Waste	Indonesia	Gunamantha and Sarto (2012)
Waste	Italy	Grosso et al. (2012)
Waste	Chile	Bezama et al. (2013)
Waste	Greece	Koroneos and Nanaki (2012)
Waste	Brazil	Reichert and Mendes (2014)
Waste	China	(Lam et al, 2016
Waste	Portugal	Teixeira et al. (2014)
Waste	Canada	Cleary's (2013)
Waste	Norway	(Slagstad and Bratteb 2012)
Transportation	France	François et al. (2017)
Transportation	Spain	Vedrenne et al. (2014)
Transportation	Hungary	Simon et al. (2010)
Transportation	USA	Lin et al, (2016)
Transportation	USA	Nichols and Kockelman (2015)
Transportation	USA	Fraser and Chester (2016)
Transportation	USA	Shahraeeni et al. (2015)
Consumption patterns	Different countries	Ivanova et al. (2016)
Consumption patterns	Finland	Heinonen et al. (2013a, b)
Consumption patterns	Denmark	Kalbar et al. (2016)
Urban green	Netherlands	Elmqvist et al. 2013)
Urban green	USA	Spatari et al. (2011)
Urban green	Australia	Rothwell et al. (2015)

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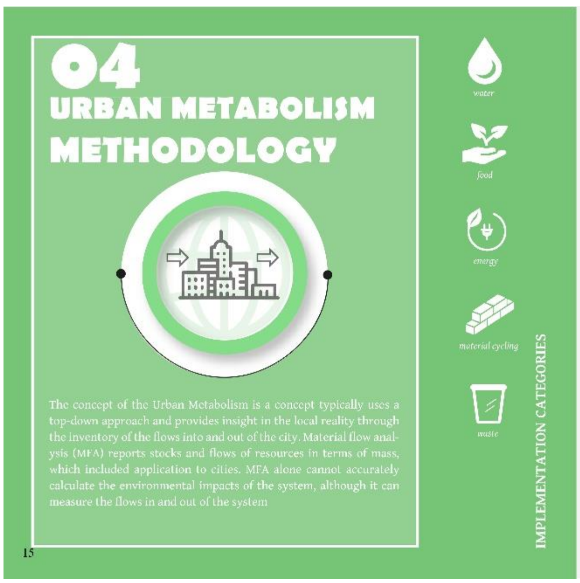

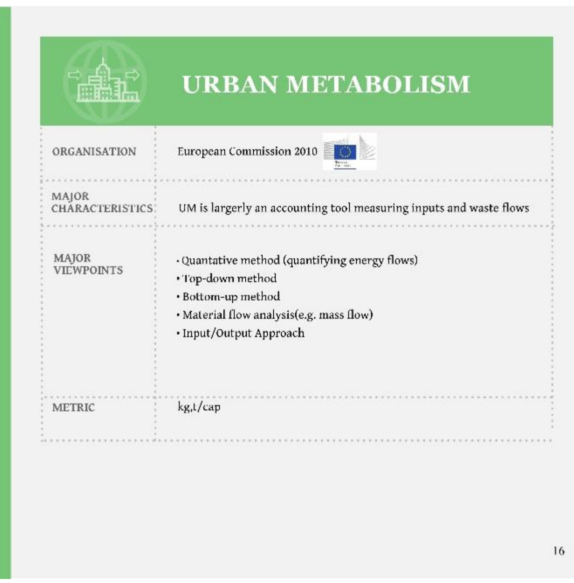

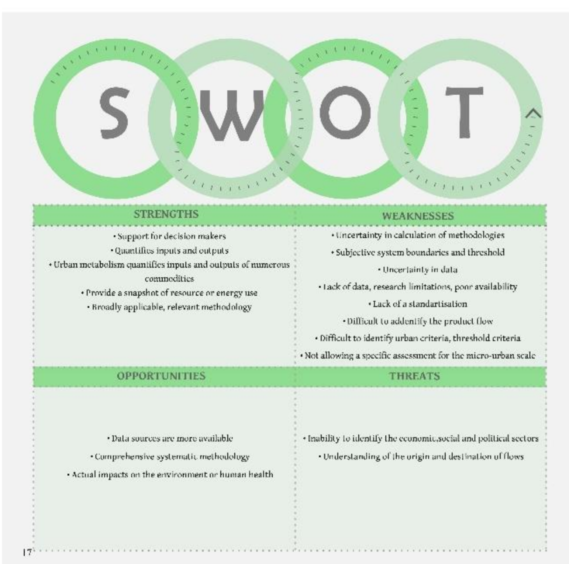

Chronological review of urban metabolism studies. Flow analysis method used in UM studies		
Notes/contribution	Country/City	Reference
Material Flow Analysis (MFA)	Berlin, Germany	(Baccini and Brunner, 2012)
Nitrogen (N) mass balance	Phoenix, USA	(Baker et al., 2001)
Material Flow Analysis (MFA)	Dalian, China	(Bao, 2010)
Material Flow Analysis (MFA)	Paris, France	(Barles, 2009, 2007a)
Materials	York, UK	(Barrett et al., 2002)
Measures product and waste flows	Paris, France	(Billen et al., 2009)
Critiqued metabolism perspective for food		(Bohle, 1994)
Material Flow Analysis (MFA)	Irish city region, Ireland	(Browne et al., 2011, 2009, 2005)
Nitrogen & Phosphorus	Stockholm, Sweden	(Burstrom et al.,2003)
Assessment of total urban metabolism	Toronto, Canada	(Codoban and Kennedy, 2008)
Assesment of metal flow	Stockholm, Sweden	(Cui et al., 2009)
Relationship between metabolism and city surface		(Deilmann, 2009)
Energy use data for Barcelona and other cities	Prague, Czech	(European Environment Agency, 1995)
Urban nutrient balance	Bangkok, Thailand	(Faerge et al., 2001)
Energy metabolism	Prague, Czech	(Fikar. 2009)
Nitrogen balance for the urban food metabolism	Toronto, Canada	(Forkes, 2007)
Water		(Gandy, 2004)
Assessment of total urban metabolism	Prague, Czech	(Garcia et al., 2009)
Recognized link to sustainable development of cities		(Girardet, 1992)
Material Flow Analysis (MFA)	Hamburg, Germany	(Hammer et al., 2003)
Assesment of heavy metals	Stockholm, Sweden	(Hedbrant, 2001)
Water		(Hermanowicz and Asano, 1999)
Assessment of the impacts of transportation	Toronto, Canada	(Kennedy, 2002)
Energy metabolism or energy flow	Austria	(Krausmann and Haberl, 2002)
Socio-metabolic transition	Czech,Slovakia	(Kuskova et al., 2008)
Mass balance for wastewater	Phoenix, USA	(Lauver and Baker. 2000)
State of the Environment report		(Lennox and Turner, 2004)
Assessment materials and energy flow, case study	Curitiba,Brazil	(Conke and Ferreira, 2015)
MFA applied for the case study	Jinchang, China	(Li et al., 2016)
MFA of inputs and outputs	Chinese Cities	(Liang and Zhang, 2011)
Assesesment water flows	Lisbon, Portugal	(Marteleira et al., 2014)
Assessment of urban metabolism	Australia	(Newman, 1999)
Flow of phosphorus	Lisbon, Portugal	(Nilsson, 1995)
MFA applied for the case study	Viena, Austria	(Niza et al., 2016, 2009)
Metal	Gävle, Sweden	(Obernosterer and Brunner, 2001)
Urban hydrology	Munich, Germany	(Paulelt and Duhme, 2000)
MFA applied for the case study	Lisbon, Portugal	(Rosado et al., 2016, 2014)
Assessment of urban metabolism	Toronto, Canada	(Sahely et al., 2003)
MFA applied for the case study	Singapore, Singapore	(Schulz, 2007)
Socio-economic metabolism	Trinket Island, India	(Singh et al., 2001)
Heavy metals	Stockholm, Sweden	(Sörme et al.,2001)
Urban metabolism to quality of life	Brisbane & Southeast Queensland, Australia	(Stimson et al., 1999)
Mercury	Stockholm, Sweden	(Svidén and Jonsson, 2001)
Water	Greater Moncton, Canada	(Thériault and Laroche, 2009)
MFA applied for the case study	Beijing, China	(Zhang et al., 2014, 2013)
Energy flow applied for the case study	Xiamen, China	(Zhao, 2012)

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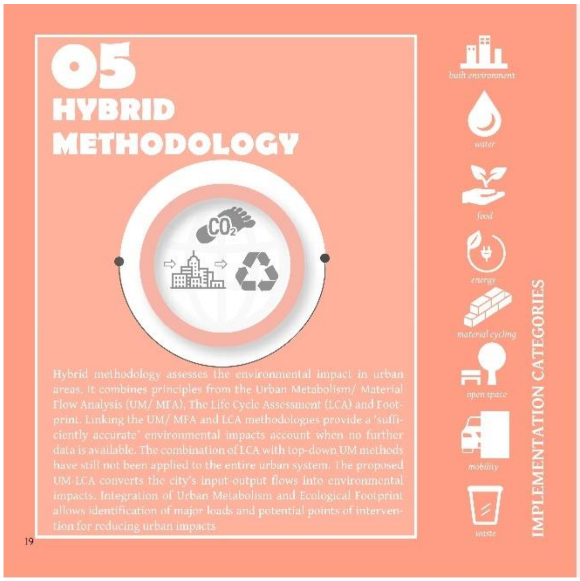
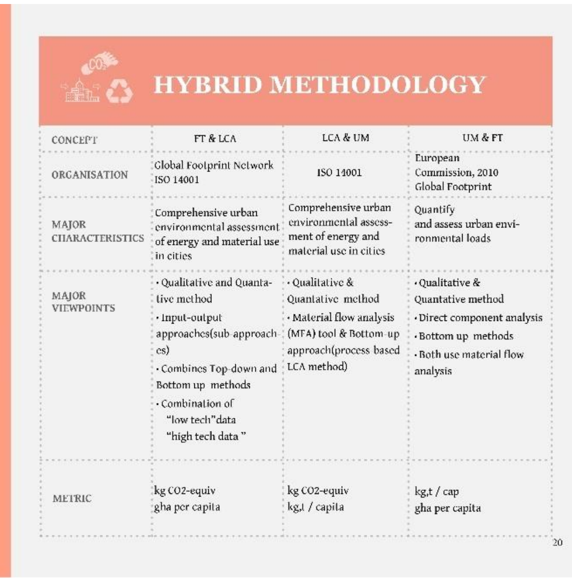
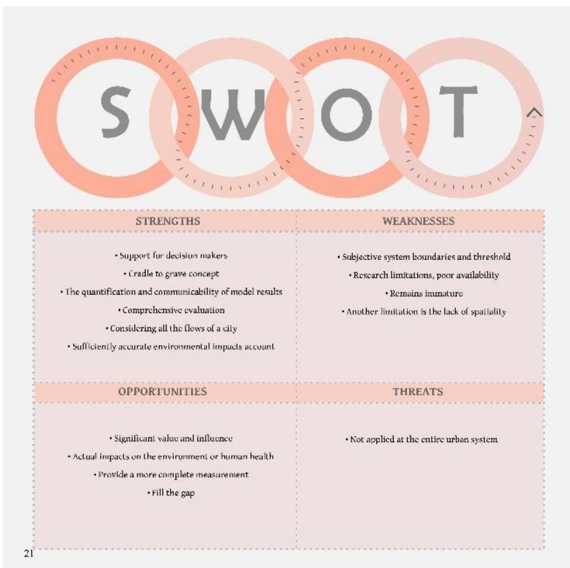
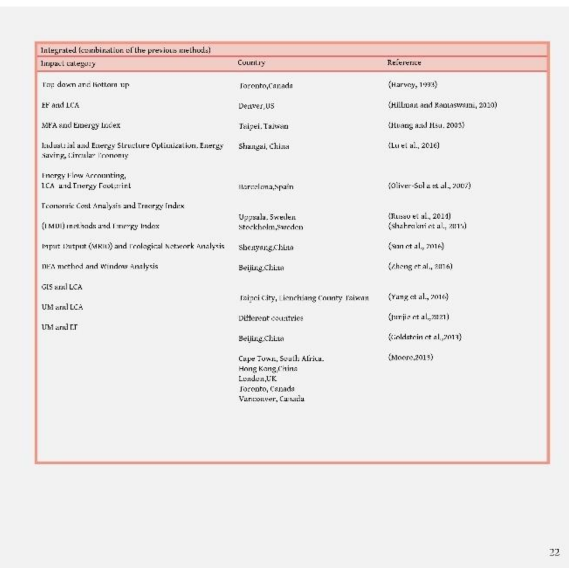
4.4 Fourth Phase – Recommendations and Guidance Results



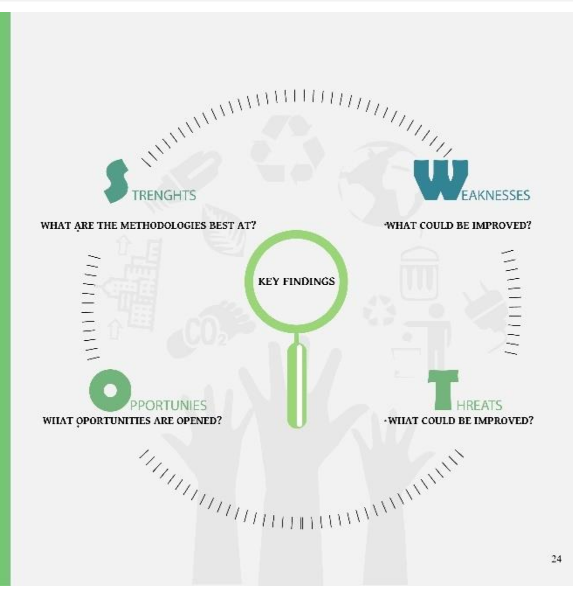


CONCEPT	FT & LCA	LCA & UM	UM & FT
ORGANISATION	Global Footprint Network ISO 14001	ISO 14001	European Commission, 2010 Global Footprint
MAJOR CHARACTERISTICS	Comprehensive urban environmental assessment of energy and material use in cities	Comprehensive urban environmental assessment of energy and material use in cities	Quantify and assess urban environmental loads
MAJOR VIEWPOINTS	• Qualitative and Quantative method • Input-output approaches(sub-approaches) • Combines Top-down and Bottom-up methods • Combination of "low tech"data "high tech data "	• Qualitative & Quantative method • Material flow analysis (MFA) tool & Bottom-up approach(process based LCA method)	• Qualitative & Quantative method • Direct component analysis • Bottom up methods • Both use material flow analysis
METRIC	kg CO2-equiv gha per capita	kg CO2-equiv kg,t / capita	kg,t / cap gha per capita





Integrated (combination of the previous methods)		
Impact category	Country	Reference
Top down and Bottom up	Toronto,Canada	(Harvey, 1993)
EF and LCA	Denver,US	(Hillman and Ramaswami, 2010)
MFA and Emergy Index	Taipei, Taiwan	(Huang and Hsu, 2003)
Industrial and Energy Structure Optimization, Energy Saving, Circular Economy	Shangai, China	(Lu et al., 2016)
Energy Flow Accounting, LCA and Energy Footprint	Barcelona,Spain	(Oliver-Sol a et al., 2007)
Economic Cost Analysis and Energy Index		
(LMDI) methods and Energy Index	Uppsala, Sweden Stockholm,Sweden	(Russo et al., 2014) (Shahrokni et al., 2015)
Input Output (MRIO) and Ecological Network Analysis	Shenyang,China	(Sun et al., 2016)
DEA method and Window Analysis	Beijing,China	(Zheng et al., 2016)
GIS and LCA		
UM and LCA	Taipei City, Lienchiang County Taiwan	(Yang et al., 2016)
UM and EF	Different countries	(Jurjic et al.,2021)
	Beijing,China	(Goldstein et al.,2013)
	Cape Town, South Africa. Hong Kong,China London,UK Toronto, Canada Vancouver, Canada	(Moore,2013)



4.4 Fourth Phase – Recommendations and Guidance Results

STRENGTHS WHAT ARE THE METHODOLOGIES BEST AT?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Support for decision makers	✓	✓	✓	✓
Compare and select the products that impact less	✗	✓	✗	✓
Cradle-to-grave evaluation	✗	✓	✗	✓
Quantifies inputs and outputs of commodities	✓	✓	✓	✓
Provides support for sustainable city management	✓	✓	✓	✓
Broadly applicable	✓	✓	✓	✓
Easy to implement	✓	✗	✗	✗
Point out the degradation of resources	✗	✓	✗	✓
Assessment of policies and projects for the	✓	✓	✗	✓
Comprehensive environmental strategy	✗	✗	✗	✓
'Sufficiently accurate' environmental impacts	✗	✗	✗	✓
Data credability	✗	✓	✗	✗

WEAKNESSES WHAT COULD BE IMPROVED?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Uncertainty in calculation of methodologies	✓	✓	✓	✗
Subjective system boundaries and threshold	✓	✓	✓	✓
Not comprehensive indicators	✓	✓	✓	✗
Research limitations, poor availability of data	✓	✓	✓	✓
Implementation of strateges is relevant	✓	✓	✓	✓
Complex and large systems to analyze	✗	✓	✓	✓
Not allowing an assessment for the micro-urban scale	✗	✗	✓	✗
Not widely evaluated by practitioners	✗	✗	✗	✓
Express relative sustainability	✓	✓	✓	✓
Uncompact and incomplete quantitative assessment	✓	✓	✓	✗
Difficult to build the complicated projectaccount	✓	✓	✓	✓
Lacks of standardization	✓	✓	✗	✗

OPPORTUNITIES WHAT OPPORTUNITIES ARE OPENED?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Significant value and influence	✓	✓	✓	✓
Regulating its flows smartly and circularly	✓	✓	✓	✓
CO2 emission reduction	✓	✓	✓	✓
Free methods and databases	✓	✓	✓	✓
Actual impacts on the environment or human	✓	✓	✓	✓
Guide to other projects	✓	✓	✓	✓
Regulating flows smartly and circularly	✗	✗	✗	✓

THREAT WHAT THREAT COULD HARM?	FOOTPRINT	LIFE CYCLE ASSESSMENT	URBAN METABOLISM	HYBRID
Diversity of evaluations	✓	✓	✓	✓
Assessment less reproducible, credible and transparent	✓	✓	✓	✗
Hidden environmental impacts	✗	✓	✗	✓
Limited funding	✓	✓	✓	✓
Not easy to communicate the results	✗	✓	✓	✓
Hard interpretation of flows	✗	✗	✓	✗
Does not consider economic and social aspects	✓	✓	✓	✓

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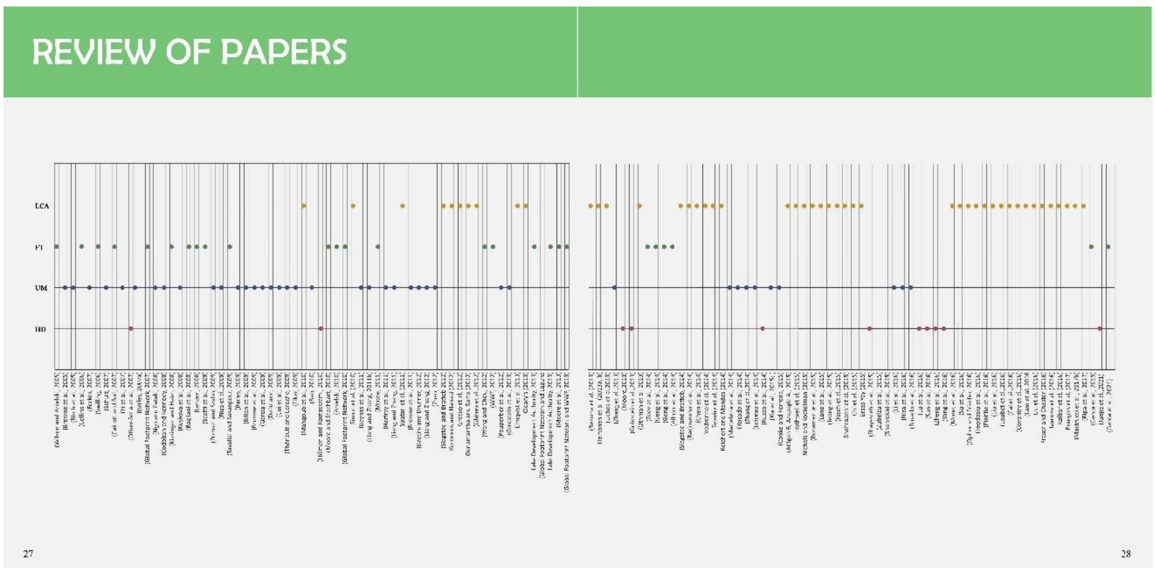

4.4 Fourth Phase – Recommendations and Guidance Results

01 USE THE ECOLOGICAL FOOTPRINT ANALYSIS WITH THE URBAN METABOLISM FRAMEWORK TO TACKLE A WIDE RANGE OF SUSTAINABILITY ISSUES AT A METROPOLITAN, REGIONAL SCALE

Scale of Applicability: Metropolitan/Regional scale
Linkage with SDGs:

Background and justification:
Since LCA is indicator which is very difficult to apply to the entire city or regional scale, the integration of UM and EF is solution while applying for wider scale. Effective measures taken at sub-national level could assist us in addressing global environmental challenges at the global scale (Bulkeley and Betsill, 2005; Wilbanks and Kates, 1999). The application of a bottom-up ecological footprint analysis using an urban metabolism framework at a metropolitan, regional scale can be more effective in addressing urban actors concerns and interests.

Description:
Urban actors/Future researchers should use the Urban Metabolism framework and The Ecological Footprint study to address a variety of sustainability issues at a metropolitan and regional level. The use of a bottom-up ecological footprint study within an urban metabolism framework at a metropolitan, regional scale can be an effective tool to quantify flows consumed by cities.

Examples and/or references:
Moore et al. (2013) introduce a detailed, bottom-up urban metabolism and ecological footprint analysis for a North American metropolitan region. It aims to demonstrate the application of a bottom-up ecological footprint analysis using an urban metabolism framework at a regional scale. The authors show why and how the methodological approach for subnational ecological footprint research is based on economy-wide input-output estimates, which is standard in Europe.

31

02 USE INTEGRATED METHODOLOGY (UM-LCA) FOR COMPREHENSIVE AND SUFFICIENTLY ACCURATE ENVIRONMENTAL IMPACT ANALYSIS

Scale of Applicability: Local/Neighborhood
Linkage with SDGs:

Background and justification:
The application of LCA at the urban scale is not yet a reality. Its current application is limited in scope (e. g. Only the urban waste management sector is investigated) and applied to only a geographical part of the city (e. g. Neighborhood scale). Therefore, an incomplete environmental impact assessment will lead to the fact that the project will be associated with a higher risk of negative impact. Without the introduction of a proper environmental assessment tool that could provide a holistic perspective, the environment and people could be at risk. Thus, LCA requires assessment of a wide range of impacts, and its application with UM will expand the assessment of urban sustainability from its current focus on flows of energy, water, materials, nutrients, and waste (including greenhouse gas emissions, GHGs) to resource depletion, damage to human health and damage to ecosystem quality. By incorporating a wide range of impacts, urban actors can take more comprehensive measures to ensure urban resilience, and unforeseen consequences can be better avoided (Chester et al., 2012).

Description:
Using Integrated methodology (UM-LCA) by urban actors/future researchers for comprehensive and sufficiently accurate environmental impacts analysis. Both methods can ensure the sustainability of cities through intelligent and circular harmonization of flows.

Examples and/or references:
Some studies were already developed the UM-LCA model in the past. For example, UM-LCA model was applied to five case cities: Beijing, Cape Town, Hong Kong, London, and Toronto. Findings report that the considered flows, in combination with the UM-LCA methodology, provide a "sufficiently accurate" environmental impacts account when no further data is available. (Goldstein et al.,2013). 32

03 USE THE LCA METHOD TO OBTAIN REPRODUCIBLE, CREDIBLE AND TRANSPARENT ASSESSMENT

Scale of Applicability: Urban scale
Linkage with SDGs:

Background and justification:
As more and more regulations emerge to combat greenwashing, the credible environmental data to make products being sustainable is needed. The evaluation of the current urban methodologies remains methodologically immature and continues to limit accurate accounting of urban flows of cities. Taking them into account there are significant barriers and weaknesses such as a lack of data, omitted/hidden upstream flows, uncertainty regarding the appropriate scale of analysis. A certain lack of transparency in the calculations in development of the ecological footprint can lead to inaccurate result and false information. However, the use of the environmental data based on the LCA study can make the life cycle of a product truly sustainable (Kennedy et al., 2011).

Description:
Despite the fact that most assessment methodologies are currently immature, the use of a LCA method can be used to obtain reproducible and transparent assessment. The use of accurate data based on the LCA study not only confirms and strengthens sustainability of the cities, but it also enhances credibility.

Examples and/or references:
Currently, there are many studies devoted to the LCA method that provide a reliable result of data evaluation. For example, Loubet et al. (2016) developed framework and an associated modeling tool to perform LCA for urban water system. The model WaLA applied to a real-world case study, the urban water system of the Paris suburbs (France). The innovative and comprehensive strategy is supported by credible primary and secondary data (measurement flow meter, calculation from an external model or mass balance result).

33

04 INTEGRATE DIFFERENT METHODOLOGIES TO ACCELERATE THE LEARNING PROCESS OF THE URBAN SUSTAINABILITY ASSESSMENT AND HELP IN THE IMPROVEMENT OF BOTH THEORY AND PRACTICE

Scale of Applicability: , Regional
Linkage with SDGs:

Background and justification:
There is still a significant gap between assessment theories and assessment practices. Cooper (1997; 1999) refers to this fact and argues that the practice of assessment lags well behind development of methodological theories. New assessment approaches are still mostly experimental, with limited practical uses. A simple example of this is the current scenario in which most widely used assessment methods fail to make evaluations that sufficiently address most challenges underlying the sustainable urban development process. (Adinyira et al., 2007). To improve the current situation, it is necessary to identify those aspects of urban activities and challenges at various geographical scales that are poorly covered by existing evaluation methods. Based on identified gaps, urban actors should integrate main assessment methods to develop hybrid one which may be able of addressing most of urban sustainability issues at different scale.

Description:
By combining different methodologies that currently exist it will be possible to develop methods that will capture most if not all urban activities and spatial scales, accelerate the learning process of the urban sustainability assessment and aid in the improvement of both theory and practice.

Examples and/or references:
Currently, there are several hybrid proposals for quantifying environmental impacts. For example: 1) the integration of LCA and EF; 2) UM, MFA and LCA; 3) UM and EF. Such combinations of hybrid results in a more precise and detailed modelling allow for a clearer identification of hotspot and opportunities for efficient environmental performance of cities. Combining UMA with EFA can enhance strengths of both methods (Curry et al., 2011). The EFA, based on the UMA framework, adds an additional layer of insight to the already robust analysis of energy and material flows in a city (Mirabella et al., 2018).

34

05 USE THE FOOTPRINT INDICATOR TO PROVIDE URBAN ACTORS/FUTURE RESEARCHERS WITH A SIMPLER AND EASIER INDICATOR TO APPLY AT DIFFERENT STAGES OF THE DECISION-MAKING PROCESSES

Scale of Applicability: At all scale
Linkage with SDGs:

Background and justification:
Taking into account that LCA is too professional, complex and large tool to analyze, thus requiring urban actors to have professional knowledge to help them make decisions; footprint is simpler indicator to use and calculate, making it a usable indication for non-scientists. If indicators are too technical and complicated, most urban practitioners and future researchers will continue to avoid them. Therefore, the environment assessment Indicator should provide them with a simpler and more intuitive model for decision-making. The Ecological Footprint can be applied at all scales, ranging from single products to humanity as a whole by providing a solid knowledge base and an easily applicable calculation method (Wackernagel et al., 2006). Not surprising the footprint is the only indicator that can communicate results to a wide audience (Thomas Wiedmann and John Barrett, 2010).

Description:
Urban actors/Future researchers when choosing an environment assessment indicator should consider the Footprint indicator since it is simpler and easier indicator to use and apply in different stages of the decision-making processes.

Examples and/or references:
There are a number of EF approaches now available, differing in the underlying methodology. "A Review of the Ecological Footprint Indicator" by Thomas Widman (2010) provided a comprehensive overview of perceptions and practices regarding the Ecological Footprint. That review is based on a survey of more than 50 international EF stakeholders and a review of more than 150 original papers on EF methods supporting the idea of the ease of using the Footprint indicator (Thomas Wiedmann and John Barrett, 2010).

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06 CONSIDER A NEW METHOD WITH RESPECT TO SOCIAL OR ECONOMIC DIMENSIONS OF SUSTAINABILITY

Scale of Applicability: Urban/Neighborhood
Linkage with SDGs:

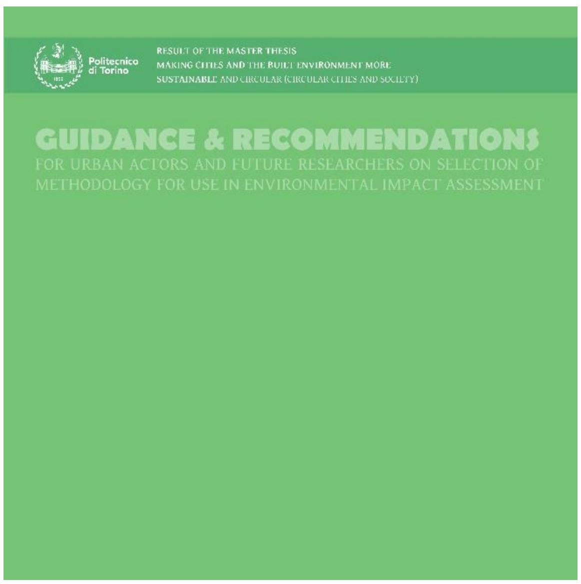
Background and justification:
The ability to address economic, social and environmental interdependencies within policies, plans, legislations and projects has become the basic requirement of all urban sustainability assessments methods. Most currently available methods still fail to demonstrate sufficient understanding of the interrelations of social, economic and environmental considerations. (Adinyira et al.,2007.) For example, Urban Metabolism does not consider the social and political impact and flows. Ecological Footprint does not count as well the social or economic dimensions of sustainability. To overcome these challenges, 'Social LCA' method was suggested to be considered by one of the urban actors (from conducted interview) as an important and acknowledged framework for sustainability assessment. Taking these points into consideration, the importance of a new social and socio-economic assessment tool in moving towards sustainable development is undeniable. (Guideline for Social Life Cycle Assessment,2020).

Description:
Urban Actors/ Future Researchers should consider another recently growing quantitative tool for assessing the positive and negative impact of products and processes with respect to the social or economic dimensions. In this way it can support urban actors in improving their overall socio-economic performance and strategies to achieve sustainable urban growth.

Examples and/or references:
The Guidelines for Social Life Cycle Assessment (S-LCA) present a methodology to assess the social impact of products using a life cycle perspective. Moreover, it covers new methodological and provides a key and unique feature of Social-LCA practical developments. Therefore, that innovative methodology can be applied to calculate a social impact, social footprint, identify social hotspots (location or activity with high risk/impact), social handprinting, etc. (Guideline for Social Life Cycle Assessment,2020). 36

4.4 Fourth Phase – Recommendations and Guidance Results

- This Guidance presents the assessment methodological approaches that have been used in previous studies to outline common strategies to evaluate the environmental impact of the cities.
- Results of the methodologies through a SWOT analysis give clear understanding which methodologies are the most advantageous/ disadvantageous in comparison with other methods.
- The recommendations for urban actors and future researchers were developed using the frameworks from the CESBA Med Commission (2019) and Restrepo Arias et al. (2020). They are focusing at promoting four assessment methodologies known in urban study and providing the advice on the use of a particular tool to decrease the environmental impact of the cities.
- Hopefully, the methodological options and development paths that Guidance& Recommendations propose will provide a solid foundation for future studies to harmonize data and analysis potential.



CHAPTER 5 – CONCLUSIONS

As cities continue to expand, modeling their behavior and assessing the environmental impact of their flows has become critical to achieving sustainable development. Cities now consume resources and generate waste in amounts that are out of proportion to their populations. Quantifying the environmental impacts of cities is essential to the sustainable urbanization of a growing world population. There are numerous methodologies available today for assessing urban sustainability. In this work, an extensive literature review is carried out to analyze, define and compare different assessment methodologies existing nowadays. Furthermore, the thesis presents the assessment methodological approaches that have been used in previous studies to outline common strategies to evaluate the environmental impact. The thesis methodology was divided in four Phases. The Phases and objectives of the thesis were:

Phase 01 - "Research"

Objective: Collection and reviewing the existing methodological approaches from different articles and journals. Review of methodologies were analyzed and discussed in the thesis.

Phase 02 "Analysis"

Objective: Provide results of the methodologies through SWOT analysis. It discusses the significance of the findings, opportunities, threats, weaknesses, and strengths in the research field. That stage provided a clear understanding of which methodologies are the most appropriate for the research topic and how the various approaches may be integrated to assess the urban environmental impacts of the cities.

Phase 03 "Comparison"

Objective: Present comparison of the key findings of analyzed methodologies. In this step the feasibility of some proposals is seen and the potential of each methodology are highlighted and compared.

Phase 04 "Recommendations and Guidance"

Objective: Elaborations of recommendations to help local urban experts and future researchers in selecting efficacious tool that can support them in transition for cities to a more sustainable path.

First Phase

In the First Phase, an extensive literature review was carried out to identify the main methodologies in urban study. Four assessment methodologies were selected: Footprint, Life Cycle Methodology, Urban Metabolism, Integrated methodology. Further, information about existing approaches were collected and the most relevant key features were identified to assist future researcher and urban actors in selection the tool for use in strategic environmental assessment. Finally, after a thorough review of the methodologies, for different case studies were selected to demonstrate the effectiveness and applicability of the indicators in the real projects.

Second Phase

In this Phase the selected papers were thoroughly scanned, analyzed and the key features of each methodology (regarding the strengths, weaknesses, opportunities, threats) are identified. To achieve goals and effective objectives of the thesis the SWOT analysis focused on Strengths, Weaknesses, Opportunities, Threats of each methodology. Results of the methodologies through a SWOT analysis gave clear understanding which methodologies are the most advantageous/ disadvantageous and find the necessity of each method.

Second Phase

In this step the feasibility of some proposals was seen, and the potential of each methodology were highlighted and compared. The key questions which were compiled for each category namely, Strength, Weaknesses, Opportunities, Threats help to define weak side and gaps of each method.

Fourth Phase

This Step aimed at elaboration of recommendations to assist local urban experts and future researchers in selecting the right tool to tackle the different environmental issues. The recommendations for urban actors and future researchers were developed using the frameworks from the CESBA Med Commission (2019) and Restrepo Arias et al. (2020). The recommendations were focusing at promoting four assessment methodologies known in urban study and providing the advice on the use of a particular tool.

Finally, Guidance Handbook presents an assessment methodology to assess the environmental impact of products through Footprint, Life Cycle Assessment, Urban metabolism, and Hybrid approaches. The main aim of this handbook was to analysis of existing approaches and tools to assist the urban actors/ future researchers use of a particular metrology in different urban context. Moreover, that guidance presents the outcome of the analyzed papers and articles, trends, and concepts of different environmental assessment methodologies. Considering the guidance context, the Handbook includes recommendations and suggestion which lays a foundation to support future work.

Furthermore, it is important to highlight some limitations while using assessment methodologies. The review emphasizes both progress and challenges in methodology and applications. The results and key findings show that, despite extensive efforts to apply one of those methods, there are still several common issues such as lack of data availability, uncertainty in calculation of methodologies, not comprehensive indicator. Further research should address the issue of data availability in order to improve the accuracy of the results obtained by primarily using local data. These findings could also be compared to those obtained through a different environmental analysis technique. Hopefully, the methodological options and development paths that Guidance& Recommendations propose will provide a solid foundation for future studies to harmonize data and analysis potential.

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