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Critical review of methodological tools and trends for assessing the performance of inclusive circular cities

Susana Toboso-Chavero [a,b,*], Filippos K. Zisopoulos [f], Martin de Jong [a,c,d], Daan Schraven [e]

[a] Rotterdam School of Management, Erasmus University Rotterdam, Rotterdam, the Netherlands
[b] Integral Design and Management, Department of Materials, Mechanics, Management & Design, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands
[c] Erasmus School of Law, Erasmus University Rotterdam, Rotterdam, the Netherlands
[d] Institute for Global Public Policy, Fudan University, Shanghai, China
[e] Department of Management in the Built Environment (MBE), Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, the Netherlands
[f] Independent Researcher, Amsterdam, the Netherlands

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ABSTRACT

The comprehensive sustainability assessment of urban waste management systems (UWMSs) is crucial for understanding the impact of current and future city strategies aimed at improving circularity and inclusion in cities. In this study we propose a framework for conceptualizing the inclusive circular city (ICC), and we review specifically scientific literature on methodological tools and trends in integrated sustainability assessments (ISAs) of UWMSs. Of the 145 publications reviewed, only 10 % concurrently evaluated social, environmental, and economic aspects, and just 2 % incorporated circularity and inclusion metrics. Publications focusing simultaneously either on social and environmental dimensions or economic and environmental dimensions accounted for 3 % and 17 % of studies, respectively, while 70 % adopted a single-dimensional approach. A notable proportion of studies focused exclusively on environmental impact assessment, predominantly employing life cycle assessment or indicators such as carbon footprint. Social assessments were notably less prevalent, comprising only 20 % of studies. Stakeholder engagement and inclusion metrics were considered in 20 % and 5 % of the publications, respectively. In terms of R strategies, 65 % of the studies concentrated on recycling and recovery, targeting mainly municipal solid waste. To advance our knowledge on ISAs of UWMSs and improve our understanding of their embeddedness in ICCs, future research should: (a) focus on multidimensional, transdisciplinary assessments with an emphasis on strong sustainability-oriented methodologies by including circularity and inclusion metrics; (b) prioritize inclusion and active stakeholder participation in collaborative knowledge creation; and (c) shift the focus from conventional waste recycling and recovery to ambitious circular strategies that retain resources in closed-loop systems.

1. Introduction

Urban waste management systems (UWMSs) traditionally focus on the processes of waste generation, collection, and disposal which are inextricably linked and intertwined with the social, economic, and environmental spheres (Liu et al., 2023). This conventional approach has far-reaching effects on different facets of a city related to infrastructure, land use planning, and access to facilities and services (Seadon, 2010; Zaman and Lehmann, 2011). Waste generation is driven by a consumption-oriented society (Boyden and Dovers, 1992), global population growth, and ongoing urbanization trends (Lu et al., 2024) which may explain why waste management strategies are at the forefront of current municipal policies (Awasthi et al., 2021; Wilson, 2023). Currently, annual global waste generation is around 2.01 billion tonnes (0.11–4.54 kg per capita) (Kaza et al., 2018). Meanwhile, projections indicate a significant surge (+22 %) by 2030 (2.59 billion tonnes/year) and (+59 %) by 2050 (3.40 billion tonnes/year) (Kaza et al., 2018). To tackle this issue, the circular economy has gained prominence as a transformative economic model by following strategies for reducing resource consumption and waste generation (Homrich et al., 2018). In its efforts to become circular, a city incorporates the principles of the circular economy throughout the urban area (Ellen MacArthur

* Corresponding author. Rotterdam School of Management, Erasmus University Rotterdam, Rotterdam, the Netherlands
E-mail addresses: tobosochavero@rsm.nl, susana.toboso@uab.cat (S. Toboso-Chavero).

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Foundation, 2017). Circular cities prioritize the efficient use of resources through the implementation of a range of strategies. They focus on narrowing loops by using less primary raw materials, on slowing down the circulation of materials by adopting extended-use strategies, on closing loops by reusing materials, and on regenerating them with the use of renewables (Ellen MacArthur Foundation, 2013; Ndiribe, 2023). By adopting these circular economy principles, cities may gain several advantages, such as decreasing ecological footprints, enhancing urban resource security, improving urban population health, and reducing greenhouse gas emissions (Prendeville et al., 2018; Williams, 2019).

Besides offering functions that are relevant from a socio-metabolic perspective, UWMSs have the capacity to take a pivotal role within a circular economy by facilitating the transformation of cities into more inclusive environments. This potential is exemplified in the context of the informal waste sector (Zisopoulos et al., 2023). Cities may benefit not only from the enhancement of associated environmental issues resulting from circular strategies, but also by the promotion of inclusion and democratization of urban development (Liu et al., 2023). To achieve these inclusive and circular cities (ICC), UWMSs require an inclusive perspective, encompassing various aspects such as citizen involvement in waste management decision-making (Vasconcelos et al., 2022), integration of informal waste pickers into UWMSs (Fergutz et al., 2011; Marello and Helwege, 2018), active engagement of institutions, citizens, and businesses in the higher levels of the 10R ladder (reduce, reuse, etc.) (Liu et al., 2023), inclusion of marginalized or vulnerable groups, and the incorporation of a gender perspective (Buckingham et al., 2005, 2021), among others. These priorities should be a top concern for any city, focusing not only on environmental responsibility but also on social equity and participation.

To enable cities to transition to sustainable, inclusive, and circular UWMSs, their comprehensive understanding and assessment is essential. The intricate nature of UWMSs becomes apparent when considering the numerous interconnections among their constituent elements, which encompass a diverse range of flow types, legal frameworks, infrastructural components, stakeholders, and other influencing urban factors (Seadon, 2010). Consequently, UWMSs are instrumental in facilitating the transition towards ICCs. Past literature indicates that assessment frameworks frequently concentrate on specific sustainability dimensions (environmental, social or economic) while often failing to comprehend the dynamic and complex structure of an urban system (McPhearson et al., 2016). Current criteria for assessing waste management performance lack precision in measuring multifaceted impacts, including the environmental, economic, social, and cultural costs, and there is a lack of research that captures all relevant components of UWMSs (Campitelli and Schebek, 2020). Several literature reviews have been carried out, focusing on environmental (Balkau and Bezama, 2019; Cobo et al., 2018; Iqbal et al., 2020) and/or circularity approaches (Bakan et al., 2022; Corona et al., 2019; Joensuu et al., 2020; Neri et al., 2021; Osobajo et al., 2022; Ranjbari et al., 2022), but none have methodologically reviewed how to capture the transition to circular and inclusive UWMSs. Table S1 in the supporting information elaborates the gaps that this research has addressed.

Given the accountability that UWMSs have for the transition towards ICCs, as previously indicated, it is necessary to comprehend current and future performance approaches for cities by conducting a scientific literature review. While recognizing that there are many different methodologies, methods, and indicators which could potentially be used to assess UWMSs, this literature review focuses on integrated sustainability assessments (ISAs) which consider simultaneously sustainability, circularity, and inclusion aspects. In theory, such ISAs are ideal for comprehensive analysis of UWMSs; however, in practice, this can vary considerably. The aim is to provide a complete overview of the tools and trends presented in scientific literature on ISAs of UWMSs and how they can capture their performance within ICCs. In other words, it is essential to understand how scientific research addresses and measures UWMSs from an environmental, social, and economic perspective while also considering their performance in terms of circularity and inclusion. In light of the intricate interconnections and dynamics inherent to UWMSs, it is imperative to consider all relevant dimensions simultaneously. Failure to do so may result in an incomplete understanding of their underlying system dynamics and a constrained assessment of their impacts, potential rebound effects, and trade-offs (Cristiano et al., 2020). In order to achieve the objective of this research, the following research question was posed: what are the key methodological tools and trends used to capture simultaneously the social, environmental, and economic performance of UWMSs considering that they are key socio-metabolic processes embedded within ICCs? And two sub-questions: 1) In what ways do ISAs evaluate the sustainability, circularity, and inclusion of UWMSs? and 2) How are the concepts of circularity and inclusion considered in academic literature on ISAs of UWMSs?

This paper is structured as follows: Section 1.1 presents the theoretical background, where we develop the conceptual framework of ICCs and ISAs. Section 2 presents the methodology for the literature review (i. e., bibliometric analysis and content analysis). Section 3 elaborates on the results of the literature review which consists of two different subsections: the main findings related to the different bibliometric indicators and the in-depth content analysis of the peer-reviewed papers. Section 4 discusses the main findings, offers an overall impression of ISAs, and proposes a future vision for measuring the multidimensional aspects of UWMSs within ICCs. Section 5 concludes by summarizing the most relevant parts of the study.

1.1. Background of the study

1.1.1. Inclusive circular city

Inclusion, sustainability, and resilience of future urban environments are the main priorities of the Sustainable Development Goals (SDGs), particularly SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable) (Independent Group of Scientists appointed by the Secretary-General, 2023), and the New Urban Agenda, (UN-Habitat, 2020). Their aim is to guarantee that urban areas are able to accommodate an increasing population while simultaneously ensuring the provision of high quality of life for all residents and the safeguarding of the natural environment. To attain this vision, it is necessary to design and develop cities in a manner that encompasses all the different dimensions of an ICC (Fig. 1). It is essential to distinguish each of these dimensions – environmental, social, economic or spatial – while acknowledging their intrinsic interconnectivity and mutual reinforcement. This holistic approach guarantees that advancement in one domain reinforces and amplifies progress in others. By adopting this integrated perspective, cities can effectively address complex challenges, thereby creating a future in which all citizens flourish within a balanced and regenerative urban ecosystem (Zhao et al., 2023). In consideration of the aforementioned factors, we have put forth a conceptual framework for an ICC. The proposed ICC draws upon the work of Liang et al. (2022) who proposed five dimensions for urban inclusion: i. e., the environmental, spatial, social, economic, and the political dimension. Furthermore, we embedded aspects from the work of Liu et al. (2023), who introduced the circular economy into this equation, in order to consider the three dimensions of sustainability (environmental, social, and economic) and the 10R hierarchical circular strategies, [i.e., short loops: R0: refuse, R1: rethink, R2: reduce, medium loops: R3: reuse, R4: repair, R5: refurbish, R6: remanufacture, R7: repurpose and long loops: R8: recycle, R9: recovery (Potting et al., 2017)].

Combining these two comprehensive studies, the conceptual framework of an ICC relies upon four distinct dimensions (Fig. 1). The first dimension is the *inclusive and circular environment* which encompasses local designs for keeping resources circulating at their highest value in cities, economic or otherwise, while engaging stakeholders across all the phases. The second dimension is the *inclusive and circular society*. This is a broader concept incorporating all stakeholders in the design and decision-making process of all types of circular and sustainable

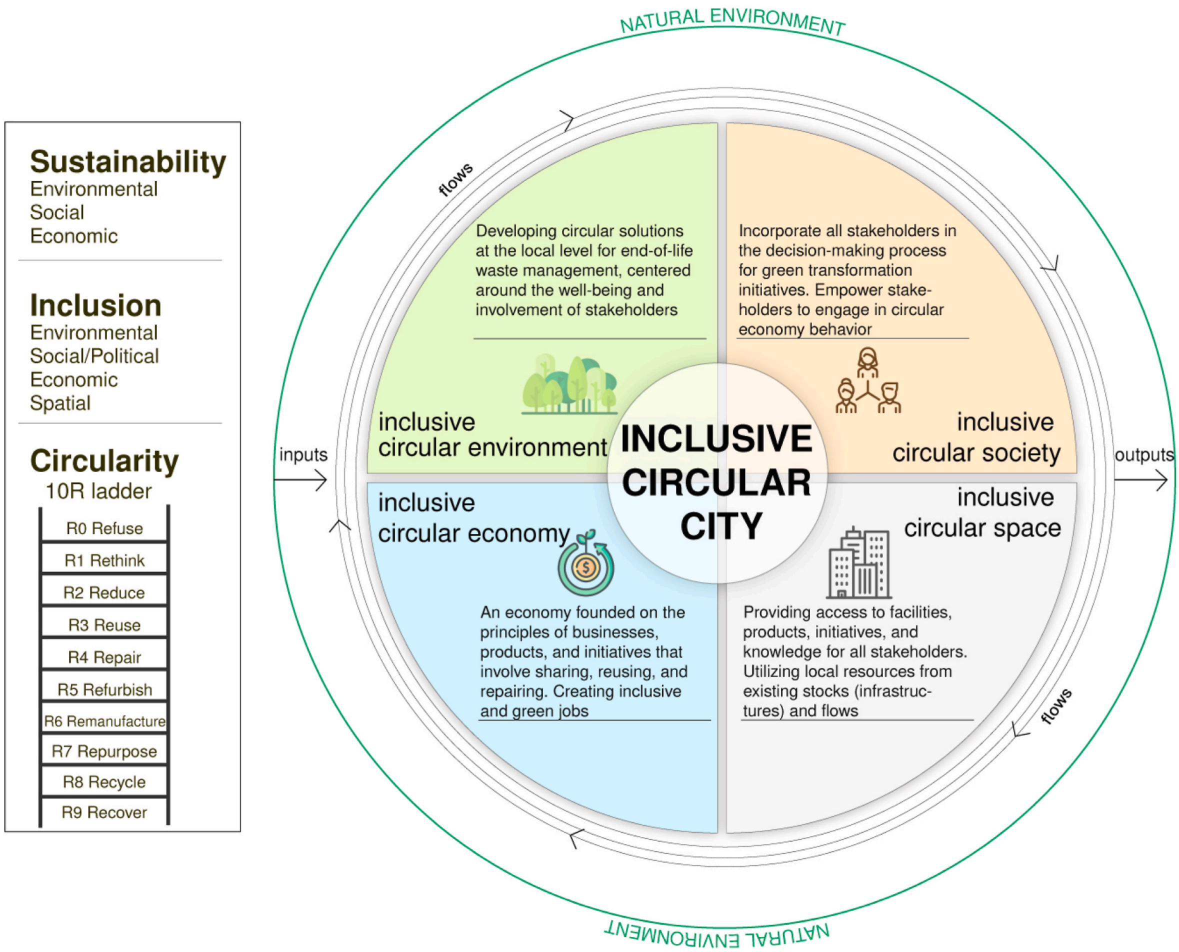

Fig. 1. Conceptual framework of an inclusive circular city (ICC). Adapted from Liang et al. (2022); Liu et al. (2023).

transformations in urban systems, empowering them, and boosting an inclusive and circular behavior. The political dimension proposed by Liang et al. (2022), is also embedded here, as in principle the same methodological tools can be used for assessments. The third dimension is the *inclusive and circular economy* which is not based on the extraction of new materials but rather on initiatives, businesses, services, and products involving sharing, reusing, repairing, and recycling while creating circular and inclusive jobs and offering equal access to the labor market. The last dimension is the *inclusive and circular space*, which refers to improve accessibility of all individuals to local and circular resources, facilities, and infrastructures, having no barriers or restrictions.

To comprehensively measure the multidimensional performance of UWMSs within ICCs, it is necessary to apply robust assessments, methodologies, indicators, and other evaluation tools which may be quantitative and/or qualitative. The four dimensions of an ICC will assist in the classification and analysis of the methodologies employed by peer-reviewed papers, thereby facilitating an understanding of their capacity to capture the performance of UWMSs within ICCs, or alternatively, a dimension, or conversely, to fail to do so.

1.1.2. Integrated sustainability assessments

This literature review focuses on ISAs by incorporating a multifaceted framework to provide a more nuanced understanding of sustainability issues (Sala et al., 2015). ISAs have different characteristics. Firstly, they offer a comprehensive and integrated analysis of environmental, social, and economic dimensions. Secondly, they are transdisciplinary, aiming at obtaining a holistic understanding that transcends disciplinary boundaries. Thirdly, they provide direction through visions and goals. Fourthly, they foster co-production of knowledge with different stakeholders, deepening stakeholder engagement by involving diverse perspectives, including local communities, businesses, governmental and non-governmental organizations. Consequently, they are inherently inclusive. Finally, they incorporate uncertainty assessments for robust decision making (Sala et al., 2015). ISAs can assist in the evaluation of the performance of UWMSs in ICCs. This is due to their capacity to encompass the full range of dynamics, interconnections and dimensions, thereby offering a comprehensive view of the system under examination.

ISAs are linked to the concept of strong sustainability through their focus on assessing the long-term viability and comprehensiveness of environmental and socio-economic systems (Sala et al., 2015). Strong sustainability is a theory which argues that natural capital provides functions which cannot be substituted by man-made capital, so that any natural resources and ecological processes are irreplaceable and must be safeguarded (Pearce et al., 1994). Strong sustainability advocates for the human well-being within the planetary boundaries and cannot be compromised for the sake of economic development (Turner, 2005). ISAs offer a holistic evaluation with a long-term perspective, and are instrumental in implementing strong sustainability principles, providing decision-makers with sound insights considering dynamics and interdependencies with ecosystems, as well as a systemic perspective (Escobar Cisternas et al., 2024). The definitions of the methodological tools used in the literature review are defined by following Sala et al. (2013). Fig. S1 in the supporting information defines each element (i.e., framework, methodology, method, model, tool, and indicator/index) in a hierarchical manner.

2. Materials & methods

2.1. Research design

The research design is shown on Fig. 2. For the search and selection of scientific literature the Preferred Reporting Items of Systematic reviews and Meta-Analyses (PRISMA) framework was followed (Page et al., 2021). A mixed methods approach was used to analyze scientific publications and answer the research questions. A quantitative analysis was employed for the bibliometric analysis while a qualitative assessment was utilized for a more thorough and specific analysis of ISAs applied in UWMSs.

2.2. Data selection

To reduce bias in literature data selection and to promote transparency throughout the review process we applied the data selection steps described in the PRISMA guideline (Page et al., 2021). In essence, these steps encompass a four-phase flow diagram comprising identification, screening, eligibility, and inclusion along with a 27-item checklist (Fig. 3).

The first phase (identification) was carried out in May 2023 and updated until 1st January 2024 by using Scopus databases for literature collection (only in English), as it is one of the world's largest databases of scientific literature, with more than 90.6 million records (Schotten et al., 2017). The timespan was from 2011 to 2023 (see general overview of publications in Table S4 in the supporting information). We tested various queries during the identification process and to refine our search, we selected the most pertinent keywords for our research questions. The query string comprises five distinct criteria: 1) circular economy, 2) assessments, 3) ISAs, 4) waste, and 5) urban scale. The titles, abstracts, and keywords were searched for these terms because this is where typically authors articulate the specific focus of their research (Schraven et al., 2015). A modified query string was added excluding the term *"wast*"*, to broaden the array of different studies from the previous query string. The resulting query strings can be seen in Fig. 3.

The second phase (screening) consisted of selecting research relevant to our study. The inclusion and exclusion criteria were based on the aforementioned criteria (1–5). The majority of the papers were related to circular economy, waste management and urban areas, and they mentioned the terms *"assessment" or other "sustainab*" "integr*"or "comprehensive"* yet did not conduct any kind of assessment. This was the primary reason for the exclusion of numerous papers in this phase. The screening was performed in different steps: firstly, duplicates from the two different query strings were eliminated (84 papers), secondly, the titles and keywords were read, excluding those that had nothing to do with the scope of the literature review (59 papers); thirdly, the abstracts were read (83 were excluded), including only articles of direct relevance, especially those conducting an assessment, which is the focus of this literature review, finally, the full texts were read (53 were excluded and 5 were not available) (see the Excel file in the supporting information with all the included and excluded papers divided by phases).

In the final phase (here considering eligibility & inclusion simultaneously), the full text of all studies was read to determine eligibility. A considerable number of papers employed the terms *"sustainab*" "integr*"*or *"comprehensive"* but did not assess all dimensions of sustainability (see section 3). Nevertheless, we included these studies in order to gain a comprehensive understanding of trends and tools related to UWMS assessment. Papers that assessed a case study or were purely theoretical but proposing an assessment framework were included in the review. All relevant information (title and year of publication, authors, abstract, journal/conference of publication, country, keywords, and full text) was then collected and all were read for further evaluation. After the screening process, 145 publications were identified, comprising 117 papers, 11 review papers, 11 conference papers, 5 book chapters and 1 editorial (Fig. 3).

2.3. Data analysis

2.3.1. Bibliometric analysis

We conducted a bibliometric analysis to obtain information on subject areas, author networks, keywords trends and co-occurrence, overall publication dynamics, and topic evolution as an initial overview of the trends and tools employed for assessing UWMSs. This type of literature review technique allows a quantitative analysis of a wide range of information (Phulwani et al., 2020), offering a first insight of the research under study. Two types of tools were used in this study, VOSViewer (version 1.6.19) (van Eck and Waltman, 2010) and Bibliometrix (Aria and Cuccurullo, 2017). The former software was used for keyword co-occurrence analysis [with a cut-off of three occurrences

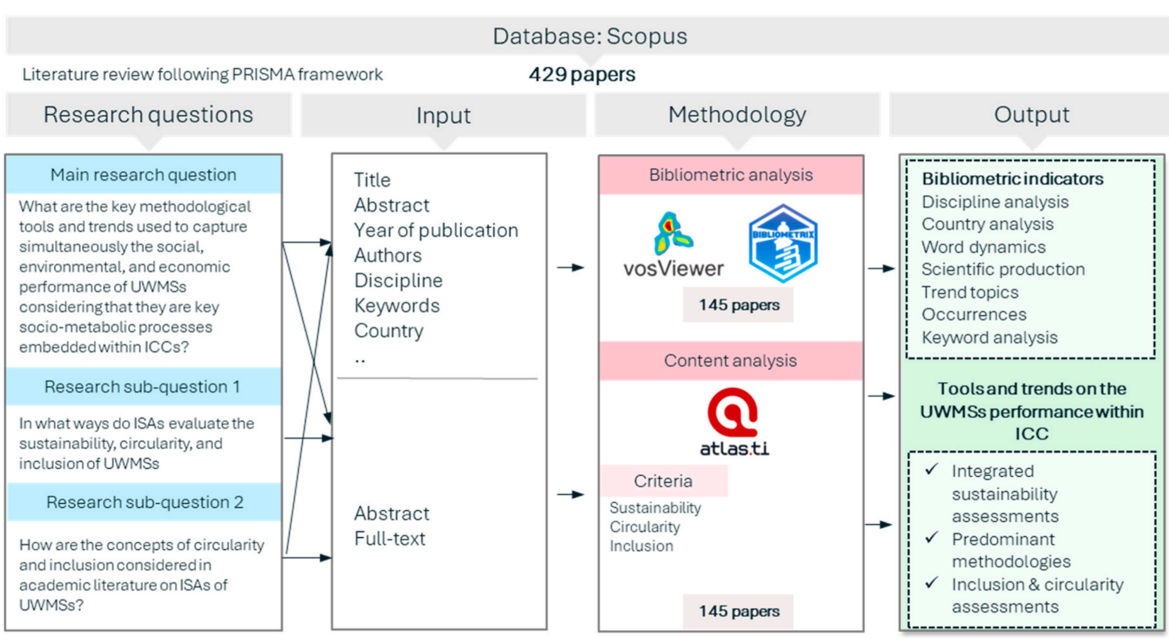

Fig. 2. Research design for the study. UWMSs: urban waste management systems; ICC: inclusive circular city; ISAs: integrated sustainability assessments.

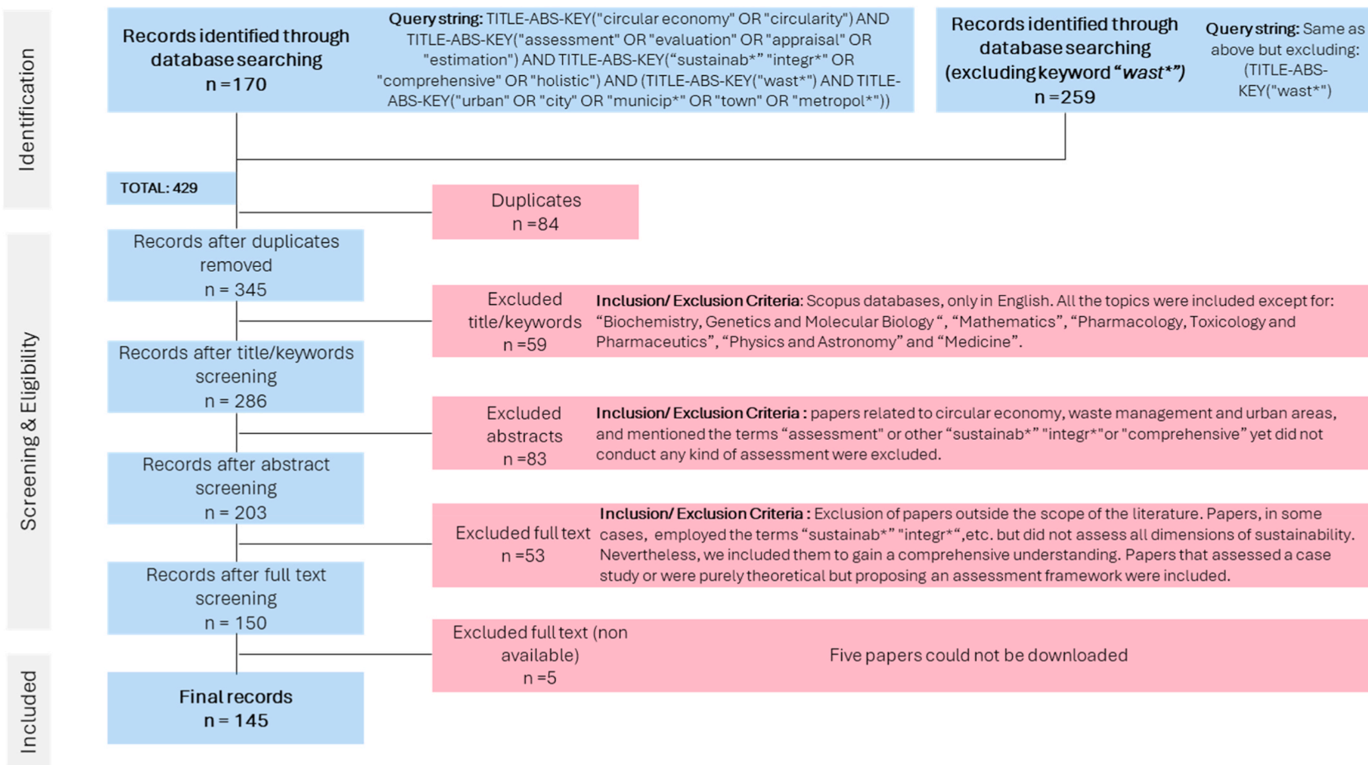

Fig. 3. Publication selection following PRISMA framework.

(Fig. 5a) and without the query term *"circular economy" (*Fig. 5b)], and the latter, which is an open-source package in R, allows for comprehensive science mapping analyses, was used for the rest of the bibliometric analysis (Fig. 4). It should be noted that only relevant analyses are shown in the main manuscript; the rest can be found in the supporting information. The reviewed publications by year are illustrated in Fig. 4a (left axis). The output was also normalized by the total number of scientific publications for those years in the Scopus database (Table S5 in the supporting information), i.e., the reviewed publications were divided by the total scientific output to analyze the growth with respect to the total. The logarithmic scale was used to better visualize these changes (Fig. 4a, right axis) to provide an overview of the relevance of the topic. The trend topics (Fig. 4b) and case study locations (Fig. 4c) were utilized to analyze which and where these studies were focused.

2.3.2. Content analysis

To gain a comprehensive insight into the tools and trends used in assessing the multidimensional performance of UWMSs, we conducted a content analysis of all the 145 papers. Content analysis is a qualitative research method that facilitates the identification of concepts, words, and themes, enabling a thorough exploration of research concepts and relationships (Stemler, 2000). The papers underwent three rounds of coding by one researcher to identify key elements related to the main objective and to ensure consistency and accuracy. For a consistent coding framework, the search was divided into specific themes (Tables S2 and S3 in the supporting information). It was constructed deductively, using a framework analysis methodology (Pope et al., 2000) that was based on the methodological tools from Sala et al. (2013) (Table S1 in the supporting information). A subsequent inductive part was completed in which additional themes were identified through meticulous reading and rereading of the papers and the refinement of the codes. The final code framework consisted of 208 individual codes located in 13 main themes (i.e., assessments, methodologies, index, indicators, assessments not applied, type of flows, 10R strategy, inclusion, scale, location, barriers, benefits, type of dataset) (Tables S2 and S3 in the supporting information). We utilized the ATLAS.ti v.23 software (ATLAS.ti, 2024), for coding, tagging, and annotation. The process was based on looking for the specific parts of the publications related to the case study, the methods, the methodological discussion and how they were articulated.

The methodologies were classified according to their purposes, which included the following categories: a) scenario analysis and development, b) impact assessment, c) prioritization methodologies, and d) indicators/indexes (Taelman et al., 2018). Then, the analysis of the components of an ICC, encompassing sustainability, inclusion and circularity, facilitated a discussion of the strengths and weaknesses associated with assessments and methodologies prone to measuring the performance of UWMSs, as well as future research directions. In particular, an examination was conducted of the integration of the methodologies with respect to each dimension of sustainability, their transdisciplinary approach, and whether they took into account inclusion and circularity.

3. Results

3.1. Bibliometric exploration of integrated sustainability assessments in urban waste management systems

The number of annual publications on ISAs of UWMSs has increased significantly over time, as has the normalized share with respect to the total scientific output (Fig. 4a and Table S5 in the supporting information). During the initial five-year period (2011–2015), the research output was three publications, therefore publications on this topic constituted a very small fraction in total and compared to the total scientific output. However, from 2015 onwards there was a notable shift with an increase in the number of publications. In 2020, the number of publications spiked, doubling from the previous year. This period (2020–2023) thus became the most prolific, although there was a slight decline in 2023, suggesting a possible stagnation in the growth rate of topic-related publications. This growth over years can be attributed to

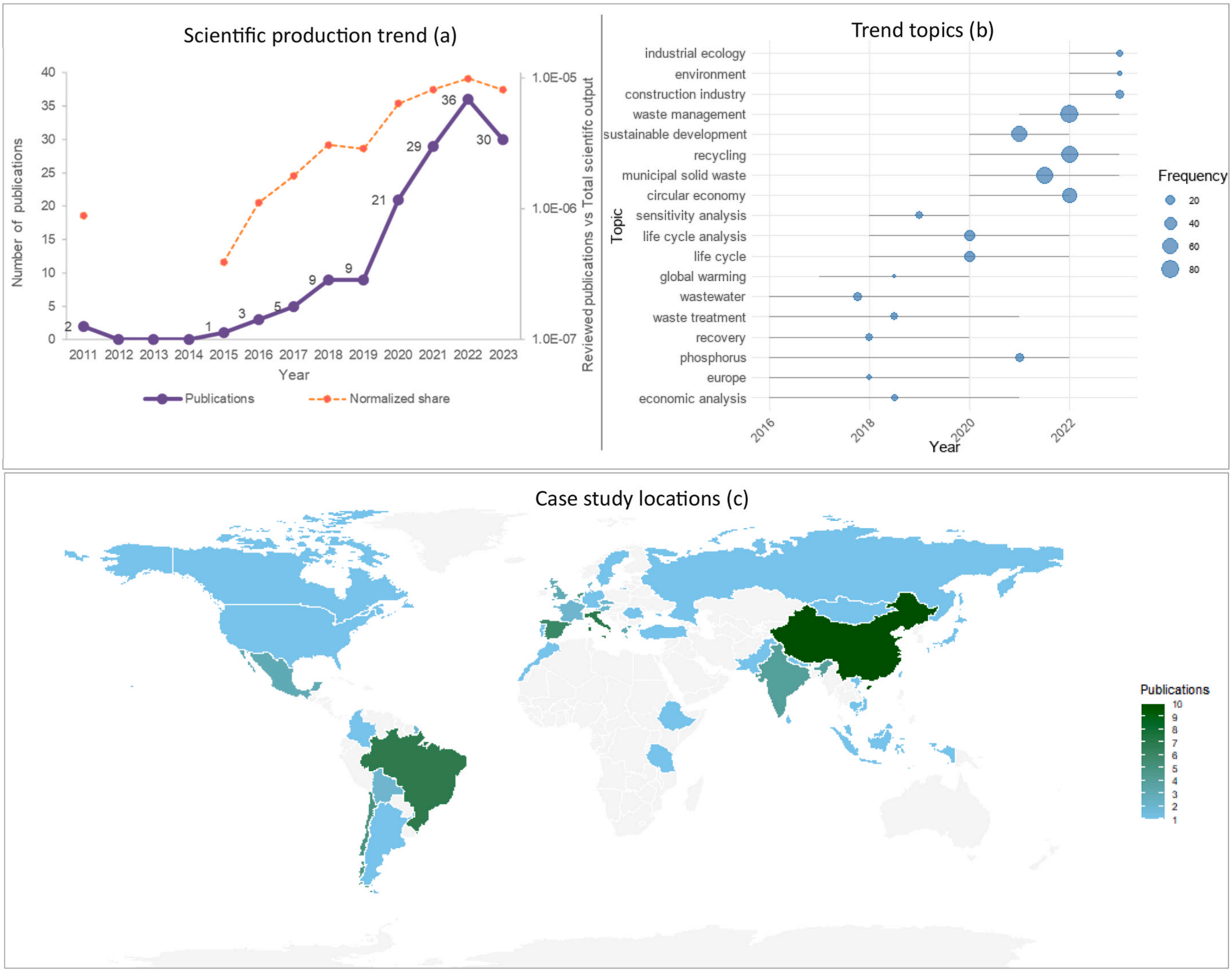

Fig. 4. Overview of the bibliometric analysis including a) scientific production (number of reviewed papers/year) and normalized share by total scientific output (logarithmic scale) b) trend topics, and c) case study locations. Case studies without a specific country were unspecified: 27, and a group of countries were European Union: 9 and Developing countries: 1.

the increase of the total scientific output but also of direct and indirect global impacts of cities [such as the increased generation of urban waste and pollution (Mills, 2007)], the emergence of the circular economy to address the resource efficiency (Geissdoerfer et al., 2017; Ghisellini et al., 2016), and the development of several international agreements. These include the Paris Agreement (COP 21) and subsequent COPs, the 2030 Agenda for Sustainable Development (Independent Group of Scientists appointed by the Secretary-General, 2023) and more recently, the European Green Deal (European Commission, 2019). Such agreements are regarded as paradigm shifts in sustainable development and environmental agreements (Weiland et al., 2021).

Trend topics revealed that the keywords which stood out were *"waste management"*, *"recycling"*, *"sustainable development"*, *"municipal solid waste (MSW)"* and, to a lesser extent *"circular economy"*. It is noteworthy that these keywords have been a sustained theme over the recent years. The early topics, such as *"waste treatment"*, *"wastewater"* (and related topics, including *"phosphorus"*, etc.) and *"economic analysis"*, indicate a long-term interest until 2020–2021. Conversely, topics such as *"construction industry", "industrial ecology" and "environment"* are more emerging topics from 2022 onwards. All these topics skyrocketed in 2019, particularly the three mentioned above (i.e., "*waste management*", *"recycling"*, and *"MSW"* (Fig. S2 in the supporting information).

The peer-reviewed publications covered 41 different countries (Fig. 4c), Europe (9 publications), and developing countries (1 publication) where case studies covered several countries. The most studied countries were China (10 publications), Brazil, and Italy (7 publications each), Spain (6 publications), Chile and the Netherlands (5 publications each), and India (4 publications). The most studied urban areas were in Europe (48 %), followed by Asia (27 %), and the Americas (22 %). Africa had only 3 studies (Campitelli et al., 2023; Kazuva et al., 2021; Misganaw, 2023) and Oceania had no publications. We also identified 27 publications with an unspecified urban area, covering either many different countries or no specific country (Iqbal et al., 2020; Joensuu et al., 2020), and focusing either on technology (Ng et al., 2016; Thomassen et al., 2022), or were theoretical (Ventura, 2022). Several studies were conducted in Europe. This is important because a greater number of case studies can lead to more comparative results and a more extensive understanding of the role of UWMSs in ICCs. Conversely, there is a significant research gap in many countries in Oceania and Africa, as well as in the Americas and Asia (except for China, Brazil and Chile). It is therefore advisable to focus research on these continents to facilitate a deeper exploration of this topic. All the different analyses offered by the Bibliometrix software were analyzed (see Fig. S2 in the supporting information), however, only the most relevant results are presented here.

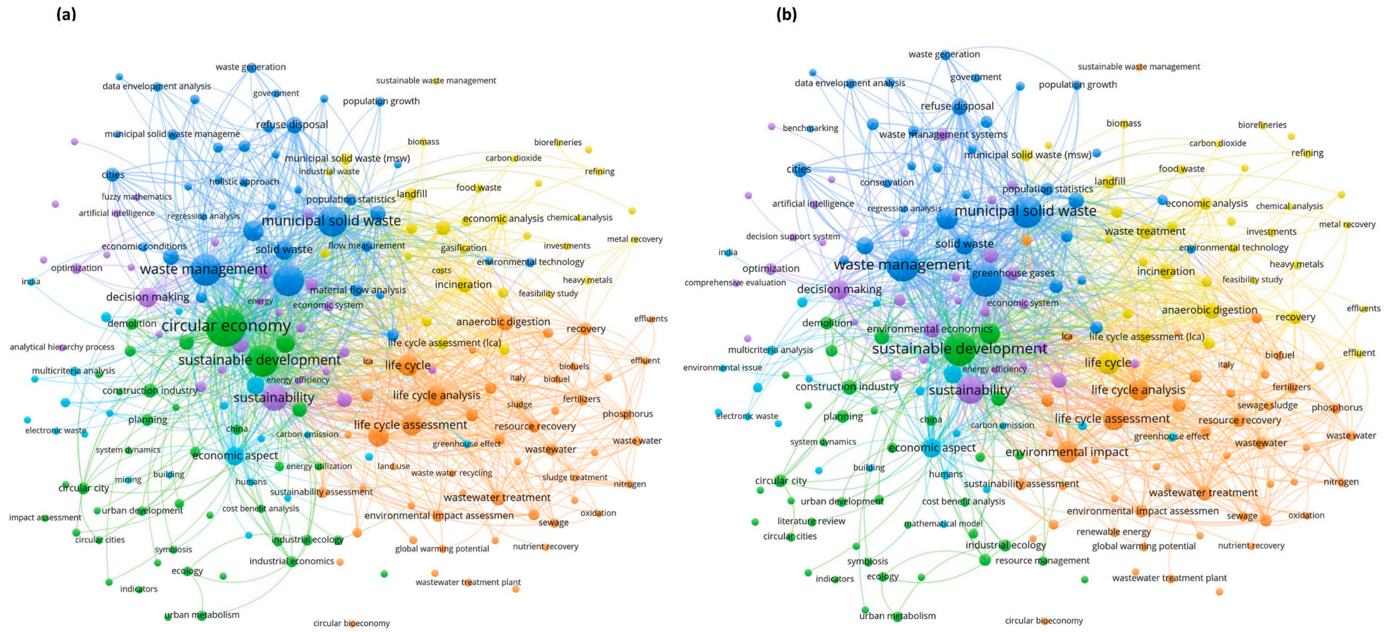

Fig. 5. Keyword analysis carried out with VOSViewer software; a) all the query terms included, b) without the query term *"circular economy"*.

The analysis of the performance of the UWMS highlights an imbalance in the investigated topics, as revealed by the keyword co-occurrence analysis using VOSViewer (Fig. 5a and b). The dominant themes are related to one type of circular economy strategy: *"recycling"* (as seen above), then to a general theme: *"sustainable"*, and *"sustainable development"*, and finally to one type of methodology: *"life cycle assessment (LCA)"* and its analogues focusing on environmental accounting (i.e., *"environmental impacts"*, *"life cycle"*, and *"life cycle analysis"*). Additionally, the keyword *"economics/economic analysis"* also stood out as a related keyword to methodologies, albeit to a lesser extent. Consequently, revealing a primary focus on environmental accounting, with a less emphasis on economic accounting, and minimal attention given to ISAs.

In terms of waste streams, the keywords *"municipal solid waste"*, *"waste management"*, *"solid waste",* etc. and, to a lesser degree *"wastewater"* and analogues stood out. Consequently, scholars have primarily concentrated their efforts on the evaluation of recycling strategies as a means of enhancing the effectiveness of UWMSs and as seen in the previous section, on MSW. While recycling represents a significant strategy of the circular economy, there is still considerable untapped potential for the transition to more advanced circular economy strategies. These include short loops, such as refuse (R0), rethink (R1), and

Methodologies/ Indicators	Assessment					
	Sustainability	Environmental	Social	Economic	Circularity	Inclusion
Scenario analysis: MFA, spatial analysis, system dynamics, agent-based model etc.	7	45	13	26	8	3
Impact assessment: LCA, LCC, SLCA, LCSA, TEA model, DEA, DPSIRO, etc.	18	79	32	42	9	11
Prioritization: MCDA, game theory, MIVES, etc.	13	44	17	33	11	6
Indicators/Indexes: Carbon footprint, cost, recycling rate, etc.	16	73	33	48	39	12

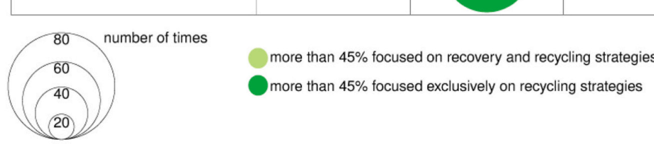

Fig. 6. Mapping of all the publications concerning to assessments, methodologies, indicators/indexes and circular strategies. The numbers within the bubbles represent the number of times these methodologies/indicators have been employed in the publications related to assessments. MFA: Material Flow Analysis, LCA: Life Cycle Assessment, LCC: Life Cycle Costing, SLCA: Social Life Cycle Assessment, LCSA: Life Cycle Sustainability Assessment, TEA: Techno-economic assessment, DEA: Data Envelopment Analysis, DPSIRO: Driver, Pressure, State, Impact, Response, Outcome, MCDA: Multi-criteria Decision Analysis, MIVES: Integrated Value Model for Sustainability Assessment.

reduce (R2) as well as medium loops, such as reuse (R3) and repair (R5). These higher orders of the circular economy prioritize the reduction of waste generation at source and the prolongation of the useful life of materials and products.

3.2. Comprehensive content analysis

3.2.1. Types of assessments and methodologies applied in the peer-reviewed publications

Most publications employed methodologies and/or indicators and indexes to assess the environmental dimension while putting less emphasis on the economic dimension (Fig. 6). Conversely, social assessments and ISAs were the least utilized. A similar trend was observed for assessments related to inclusion and circularity.

The most common methodologies were related to environmental impact assessment such as "*Life cycle assessment (LCA)*", but also indicators such as "*carbon footprint*" were widely used in these publications. Economic assessments were also widespread, although no specific methodologies were applied, except for LCC (only in six studies), and a variety of indicators were used (e.g., "*total cost", "net present value (NPV)*", etc.), lacking homogenization for comparative purposes. Regarding social assessments, "*SLCA*" (UNEP et al., 2020) was applied in five studies and behavior analysis (i.e., the factors which influence behavior in a context of change) in two studies (Delgado-Antequera et al., 2021; Ramos et al., 2023), while the remaining studies used a combination of different indicators and indexes.

In the context of scenario analysis methodologies, a total of 17 out of 145 publications employed spatial assessment techniques such as Geographic Information System (GIS) to locate specific waste management facilities (Rufí-Salís et al., 2020), to map the eco-efficiency scores of municipalities in Chile for the provision of MSW services (Llanquileo-Melgarejo et al., 2021), or to identify structural building products from the building stock for future reuse (urban mining) (Ajayebi et al., 2020), while others performed dynamic spatiotemporal modelling of the building stock (Yang et al., 2022). Other widely employed methodologies in the peer-reviewed publications were "*Material flow analysis (MFA)*" for scenario analysis and "*Multi-criteria decision analysis (MCDA)*" as a prioritization methodology.

For the assessment of circularity, indicators and indexes were used instead of specific methodologies, such as "*recycling rate", "MSW generation", "material circularity index", "waste circularity index",* etc. Concerning the type of circular strategies assessed in these publications, more than 65 % referred to "*recycling*" and "*recovery*", whereas "*landfilling*" had a similar or even higher number of publications than "*reuse*", "*reduce*" or "*refurbish*". This means that research focused on the longer loops (recovery and recycling) for the transition to a circular economy. These strategies were mainly applied to MSW (35 %), waste management systems (10 %), then to a variety of flows such as construction (11 %), circular economy without mentioning a specific flow (10 %), and wastewater and organic fraction (9 % each). Our literature review revealed a scarcity of studies dealing with textiles, cardboard (or paper), glass, plastics, and waste of electrical and electronic equipment (WEEE) (Table S6 in the supporting information). Consequently, the existing body of literature is predominantly focused on MSW, leaving a gap in the assessment of individual waste streams.

The assessment of inclusion aspects was marginally conducted (8 publications) using various indicators/indexes (e.g., *"accessibility", "stakeholder involvement degree",* etc.).

3.2.2. How integrated sustainability assessments evaluate urban waste management systems in terms of sustainability, circularity and inclusion

The studied sample (145 papers) demonstrated a limited representation of ISAs. As previously discussed, ISAs are well-suited to comprehensive analyses, but in practice, few publications have utilized them. Only 15 papers (10 %) addressed all three dimensions of sustainability (environmental, social, and economic). Four papers (3 %) addressed both environmental and social dimensions, while 25 papers (17 %) focused on environmental and economic dimensions. In terms of assessing circularity, 15 publications (10 %) used indicators and only 8 publications (5 %) used indicators to assess inclusion; however, 30 publications (21 %) included stakeholders in the decision-making to some extent.

A total of 15 publications were identified addressing ISAs (Table 1). These publications employed a **range of methodologies for measuring all three dimensions of sustainability** and were related mainly to the life cycle thinking family including LCA, SLCA, and LCC (Nocca and Angrisano, 2022; Tarpani and Azapagic, 2023). The impact categories selected in these publications were midpoints, and climate change impact category was used in all of them. In the case of SLCA and LCC, greater variability was observed in the absence of standardized impact categories. In the former, local employment (Voss et al., 2022), water, energy and food security (Tarpani and Azapagic, 2023), occupational health, and so forth were employed. The LCC impact categories were related to operating, investment, construction and infrastructure costs (Tonini et al., 2020). With regard to indicators, the publications in question proposed a considerable degree of variability, with carbon footprint and energy-related indicators being the most frequently used (Nadal et al., 2018; Zhou et al., 2022). Additionally, two publications put forth the proposal of developing indexes, one of which was a UWMS index [i.e., a composite of 19 indicators and 51 sub-indicators based on five groups: environmental, operational, social, educational and political-economic (Moraes et al., 2023)], and the other a sustainability index [i.e., 28 sub-criteria organized in four different criteria: environmental, technological, social and economic (Ozturk and Topuz, 2023)]. Different criteria were employed across different publications. The remaining publications opted for using both quantitative and qualitative criteria, encompassing social aspects, environment, and health (Pamucar et al., 2021), economic productivity, and other factors. These criteria were then evaluated by a group of experts or stakeholders, and a multi-criteria decision-making (MCDA) approach was employed for the decision-making process (Della Spina et al., 2023; Kokkinos et al., 2020)

The most frequently employed **circular economy strategies** were reuse (R3), recycling (R8), and recovery (R9), followed by circularity in general without the specification of a particular strategy proposed. The remaining 10 R circular strategies were not assessed or were only marginally assessed in a single case study. The aforementioned strategies were subsequently applied to construction waste (4 case studies), and to MSW, waste management systems (WMS), wastewater and the organic fraction (with 2 cases each). A total of seven publications assessed circularity to some extent. Piñones et al. (2023) developed the CIROAD framework (Circularity Indicator for Urban Road Projects) which includes specific circularity metrics such as the fractions of recycled materials (%) and locally sourced materials (%). Nocca and Angrisano (2022) proposed three distinct indicators for measuring circularity, waste generation, and reuse of materials and buildings. Similarly, Zhou et al. (2022) used the waste generation indicator in combination with recycling and landfill rate indicators. Other publications employed a more qualitative approach, evaluating factors such as the local promotion of the circular economy or the existence of action plans.

A total of five publications employed some form of indicator to assess **inclusion**, while seven publications included stakeholders. Tonini et al. (2020) incorporated indicators of public acceptance and accessibility. Piñones et al. (2023) included indicators of citizen participation [as did Nadal et al. (2018) and Moraes et al. (2023)] and of social cohesion [as did Bote Alonso et al. (2022)]. The sole publication to consider the informal sector, such as waste pickers, was that of Moraes et al. (2023). The inclusion of stakeholders in the research process was undertaken in 46 % of the publications, albeit to varying degrees of participation and including different types of stakeholders. The highest level of participation was observed in the study conducted by Tonini et al. (2020), in which a co-creative living lab was established for the purpose of

Table 1
Analysis of publications dealing with all three dimensions of sustainability (environmental, social and economic), circularity, and inclusion. LCA: Life Cycle Assessment; MFA: Material Flow Analysis; MCDA: Multi-criteria Decision Analysis; SLCA: Social Life Cycle Assessment; LCC: Life Cycle Costing; SWOT: Strengths, Weaknesses, Opportunities, and Threats; LCSA: Life Cycle Sustainability Assessment; GIS: Geographic Information System; UIS: Urban and Industrial Symbiosis. DPSIR: Driving Forces-Pressures-States-Impacts-Responses Framework.

Source	Waste stream	10R ladder	Sustainability			Circularity	Inclusion	Integration
			Environmental	Social	Economic			
Tarpani, R. R. Z. et al. (2023)	Wastewater	**Reuse (R3), recycling (R8) and recovery (R9).** Different treatments	**LCA** for impact assessment, (Recipe method; 18 impact categories (midpoints))	**SLCA,** a group of indicators (11) related to **water, energy and food security, technology adoption** and **human health** were adopted	**LCC** includes **construction, infrastructure replacements, operating, waste management** and **transport costs**	**No** methodology or indicator were applied	**No** methodology or indicator were applied	**MCDA** for decision-making, in particular the multi-attribute value theory **(MAVT)**
Tonini, D. et al. (2020)	Organic waste	**Recycling (R8) and recovery (R9).** The status quo and five household food waste management scenarios	**LCA** for impact assessment, (Recipe method; 11 impact categories (midpoints))	**SLCA,** a group of indicators (10) related to **human health** and **well-being**	**LCC** includes 4 different indicators: **CAPEX, OPEX, and OELEX** and **revenues**	**No** methodology or indicator were applied	Specific SLCA indicators: **public acceptance, accessibility** and **stakeholder involvement**	Integrated into 5 areas of protection**: natural resources, ecosystem and human health and wellbeing and prosperity. A MCDA** for decision-making, in particular the **ELECTRE II** method. **Uncertainty analysis** was also performed
Piñones, P. et al. (2023)	Construction	**Circularity** (in general)	Score of different indicators related to **circular materials, design, construction, operating and deconstruction**	Score of different indicators related to **social value creation**	Score of different indicators related to **economic performance** such as **net present value**	Score of different indicators related to **circular materials, design, construction, operating and deconstruction**	Score of different indicators related to **social value creation** such as **citizen participation** and **social cohesion**	**MCDA** for decision-making, in particular the analytic hierarchy process **(AHP)**
Voss, R. et al. (2022)	MSW	**Recycling (R8)**	**LCA** for impact assessment, 3 impact categories: **climate change, terrestrial acidification and fossil resource scarcity**	**SLCA**, one indicator: **local employment**	**LCC**, one indicator: **system costs**	**No** methodology or indicator were applied	**No** methodology or indicator were applied	**Agent-based model** to link the different dimensions
Nadal et al. (2018)	Urban Metabolism: greenhouses for local food production	**Circularity** (in general)	Indicators related to: **site conditions, infrastructure, passive energy improvement** and **active energy savings**	Indicators related to: **school, family and architectural integration** and **participation potential**	Indicators related to **investment, operation costs** and **food production**	**No** methodology or indicator were applied	Indicators related to: **school** and **family integration** and **participation potential**	**Integrated Value Model for Sustainability Assessment (MIVES)** and **Sensitivity analysis**
Zhou et al. (2022)	MSW	**Recycling (R8), recovery (R9)** and **landfill**	2 indicators: **controlled treatment and disposal rate of MSW** and **per capita GHGs emissions**	1 indicator: **adequacy of national waste management framework**	1 indicator: **per capita financial input for the MSW sector**	3 indicators: **MSW generation per living expenditure, recycling rate, landfilling rate**	**No** methodology or indicator were applied	**No** methodology or assessment were applied
Della Spina et al. (2023)	Construction	**Reuse (R3)** for abandoned buildings	Four criteria (Strengths, Weaknesses, Opportunities, and Threats) (**SWOT** methodology) and subcriteria	Four criteria **SWOT** methodology and subcriteria	Four criteria **SWOT** methodology and subcriteria	**No** methodology or indicator were applied	**Inclusion of stakeholders** in decision-making	**MCDA** for decision-making, in particular the **AHP**
Kokkinos et al. (2020)	Organic waste	**Recovery (R9),** bioenergy transition	Different criteria related to **environment and health,** and **technological aspects**	Different criteria related to **social aspects**	Different criteria related to **economics**	**No** methodology or indicator were applied	**Inclusion of stakeholders** in decision-making	**Fuzzy Cognitive Map**

(*continued on next page*)

Table 1 (*continued*)

Source	Waste stream	10R ladder	Sustainability			Circularity	Inclusion	Integration
			Environmental	Social	Economic			
Pamucar et al. (2021)	Urban mobility	Circularity (in general)	Different criteria related to health and environment, and transportation	Different criteria related to social infrastructure, cultural and policy	Different criteria related to economic productivity	No methodology or indicator were applied	Group of experts	A hybrid MCDM model – DIBR-D'CoCoSo model
Bosone et al. (2021)	Construction	**Reuse (R3)**, cultural heritage adaptive reuse	Impact assessment framework with different criteria structured into three groups: the **re-generative** capacity, the **symbiotic** capacity in the context area and **generative** capacity of the heritage system	Impact assessment framework with different criteria structured into three groups: the **re-generative** capacity, the **symbiotic** capacity in the context area and **generative** capacity of the heritage system	Impact assessment framework with different criteria structured into three groups: the **re-generative** capacity, the **symbiotic** capacity in the context area and **generative** capacity of the heritage system	Impact assessment framework with different criteria structured into three groups: the **re-generative**, the **symbiotic** capacity in the context area and **generative** capacity of the heritage system	**Group of experts**	**Multi-criteria analysis methods** (not specified)
Nocca et al. (2022)	Construction	**Refurbish (R5) and reuse (R3),** cultural heritage reuse and renovation projects	**LCA** for impact assessment (impact categories such as **climate change, energy use**, **water consumption.**) and **health and comfort and wellbeing**	Thematic areas of **social value, intrinsic value** and **state of conservation** measured with different indicators	Thematic area of **cost, value and risk. LCC** was used for 2 different indicators	Thematic area of **resource efficient** and **circular material life cycles** using indicators such as **construction and demolition waste and materials, reuse of materials and buildings**	**Inclusion of stakeholders** in decision-making	**No** methodology or assessment were applied
Bote Alonso et al. (2022)	Urban Metabolism	**Circularity** (in general)	Reference map with 27 goals and **155 indicators** with 5 different dimensions: **Environmental and Spatial**	Reference map with 27 goals and **155 indicators** with 5 different dimensions: **Social and Governance**	Reference map with 27 goals and **155 indicators** with 5 different dimensions: **Economic**	Circularity is integrated into the 5 dimensions: **Environmental, Spatial, Social, Governance and Economic**	Inclusion is integrated into the 5 dimensions, such as **social inclusion, citizen participation and awareness**	**No** methodology or assessment were applied
Moraes et al. (2023)	Waste management systems	**Reuse (R3)** and **recycling (R8)**	Development of an urban solid waste management **(USWM)-index** divided into five groups of indicators: **Environmental and Operational**	Development of an **USWM-index** divided into five groups of indicators: **Social and Educational**	Development of an **USWM-index** divided into five groups of indicators: **Political-Economic**	Circularity is integrated into the 5 groups: **Environmental and Operational, Social and Educational, and Political-Economic**	Inclusion is integrated into the 5 groups, such as **public sector, private sector and population participation**, and **informal sector inclusion**	**MCDA** for decision-making, in particular the **AHP** was applied for the development of the **USWM-index**
Ozturk et al. (2023)	Wastewater	**Recovery (R9)**	Development of a **sustainability index** divided into four groups: **Environmental and Technical**	Development of a **sustainability index** divided into four groups: **Social**	Development of a **sustainability index** divided into four groups: **Economic**	**No** methodology or indicator were applied	**No** methodology or indicator were applied	**MCDA** for decision-making, in particular the **AHP** was applied for the development of the **sustainability index**
Taelman et al. (2018)	Waste management systems	**Circularity** (in general)	Sustainability conceptual framework based on methodologies for scenario analysis using **MFA, UIS and GIS.** For impact assessment using **LCA** and **DPSIR** for structuring	Sustainability conceptual framework based on methodologies for scenario analysis using **stakeholder analysis** and **GIS.** For impact assessment using **SLCA. DPSIR** for structuring and **Polmak** for policy making	Sustainability conceptual framework based on methodologies for impact assessment using **LCC** and **DPSIR** for structuring	Sustainability conceptual framework based on methodologies for scenario analysis using **MFA, UIS** and **GIS,** but not specific indicators for measuring **circularity**	**Inclusion of stakeholders** in decision-making	**MCDA** for decision-making, in particular the **AHP** and Constraint Optimization **(CO)**

decision-making and the development of future scenarios for organic waste. Nocca and Angrisano (2022) employed a participatory process involving a diverse range of stakeholders to delineate three design scenarios for a reuse and renovation project. The remaining publications included a panel of experts to assist in decision-making.

The integration of sustainability, circularity, and inclusion into **decision-making processes** was primarily achieved through the utilization of MCDA with a particular emphasis on the analytic hierarchy process (AHP) as a prioritization methodology (Taelman et al., 2018). Four publications employed strong sustainability-oriented assessments through their focus on assessing comprehensiveness, transdisciplinarity, and knowledge co-production. Tonini et al. (2020) applied life cycle thinking with a total of 27 indicators for 25 different impact categories at the midpoint level, either environmentally, socially, or economically oriented. The authors applied a two-stage participatory process, a ranking of options using MCDA, a spatial analysis and an uncertainty assessment on organic waste. Likewise, Piñones et al. (2023) defined 25 sub-criteria and seven general criteria, comprising a set of environmental, social and economic indicators and with specific circularity metrics, while considering inclusion metrics such as citizen participation (%) and social cohesion [fraction (in %) of increase (or decrease)] and MCDA for decision making purposes. Moraes et al. (2023) developed a USWM index comprising five groups related to environmental, operational, social, educational and political-economic indicators, including different stakeholders and the informal sector, and employing MCDA. Lastly, Taelman et al. (2018) proposed a conceptual framework based on methodologies for structuring [Driving Forces-Pressures-States-Impacts-Responses Framework (DPSIR)], scenario analysis (e.g., MFA, GIS), stakeholder analysis, etc.), impact assessment (e.

Table 2
Comparison of the four dimensions that comprise an inclusive circular city in terms of sustainability, inclusion, and circularity assessments of UWMSs, along with the strengths and weaknesses of current peer-reviewed publications.

	INCLUSIVE CIRCULAR CITY			
	Inclusive Circular Environment	**Inclusive Circular Society**	**Inclusive Circular Economy**	**Inclusive Circular Space**
Sustainability	Scenarios analysis: **MFA** Impact assessment: **LCA** Prioritization: **MCDA,** in particular AHP Indicators: **Carbon footprint**	Scenarios analysis: **Stakeholder analysis** Impact assessment: **SLCA** Prioritization: **MCDA,** in particular AHP Indicators: **variety of social indicators**	Impact assessment: **LCC** Prioritization: **MCDA,** in particular AHP Indicators: **Costs, NPV, CAPEX, OPEX**	Scenarios analysis: **GIS tools** are well consolidated
Inclusion	**Stakeholder involvement** Prioritization: **MCDA,** in particular AHP Indicators: **public acceptance**, **green behavior**	**Stakeholder involvement** Prioritization: **MCDA,** in particular AHP Indicators: **social progress index, social cohesion, awareness degree**	**Stakeholder involvement** Prioritization: **MCDA,** in particular AHP Indicators: **local employment**, **informal sector inclusion**	**Stakeholder involvement** Scenarios analysis: **GIS tools** are well consolidated. Indicators: **accessibility**, **urban space consumption**
Circularity	Scenarios analysis: **MFA** Prioritization: **MCDA,** in particular AHP Indicators: **EU circularity framework, circularity index, index of zero waste city, circular material use rate, reuse/recycling rate**	Scenarios analysis: **MFA** Prioritization: **MCDA,** in particular AHP Indicators: **EU circularity framework**, **green behavior**	Scenarios analysis: **MFA** Prioritization: **MCDA,** in particular AHP Indicators: **EU circularity framework**, **total waste cost**	Scenarios analysis: **GIS tools** are well consolidated
Strength (s)	• **LCA/MFA/MCDA**: Extensive and well-established methodologies. • **Circularity**: Many different indicators/indexes.	• **Stakeholder analysis** and **involvement** using different methodologies. • Some of the publications took into consideration stakeholders in different degrees.	• **Many different indicators** to measure economic performance and **LCC** as methodology. • Different publications combined **economic and circularity indicators.**	• **GIS tools** are well established for assessing the inclusive and circular space. • **MSW** is the most analyzed flow, therefore, a large part of the data corresponds to this waste stream.
Weakness (es)	• Static view of environmental impacts. • Usually, marginal **involvement of stakeholders.** • Assessments based mainly on **recycling or recovering.** • There is no real correspondence between **environmental impacts and circularity metrics**, only 14 out of 90 studies. • **Uncertainty assessments and transdisciplinarity** are marginal.	•**Stakeholder involvement** degree is still low. • Impact assessment methodologies as SLCA are not widespread and there is a lack of databases for greater applicability and reliability of social assessments. • **Circularity**: how to measure a circular society still needs further development. • **Inclusion:** Few publications measure social inclusion.	• A **multitude of indicators** are utilized, resulting in a paucity of harmonization for the purpose of comparison. •**Stakeholder analysis and involvement** is still low.	Only a few studies considered **spatiotemporal analysis** in the reviewed publications.

g., LCA, SLCA and LCC), prioritization of options [e.g., MCDA and Constraint Optimization (CO)] and stakeholder inclusion.

4. Discussion

4.1. Strengths and weaknesses of the integrated sustainability assessments for measuring urban waste management systems within inclusive circular cities

The literature review enabled the identification of the strengths and weaknesses of ISAs in measuring the multi-faceted aspects of UWMSs within ICCs (Table 2). The four dimensions of the proposed ICC framework are analyzed in relation to the aspects of sustainability, circularity and inclusion.

Regarding the dimension ***inclusive and circular environment***, the evaluation tools of UWMSs appears to be well developed. This is due to the extensive use of the MFA as scenario analysis, LCA as impact assessment methodology, and MCDA as prioritization methodology. The LCA methodology has a long history in environmental impact accounting. Diverse software, databases, and methods are available along with an ISO standard (14040-44). The objective is to calculate the environmental impacts of all stages of a product or service. However, it was not specifically designed to analyze complex interconnected systems such as urban systems which require different types of inputs, generate diverse outputs, and which may change over time and space. Furthermore, the use of a static LCA may not fully capture the inherent dynamics of these systems. Consequently, it is strongly recommended to combine different methodologies (e.g., LCA with system dynamics, agent-based modelling, or network-based methods) to assess environmental performance of UWMSs within ICCs, such as in the works of Gao et al. (2020); Ma et al. (2022); Valencia et al. (2022); Voss et al. (2022). According to Mirabella et al. (2019), few studies have successfully applied LCA to larger-scale systems, such as cities. One potential avenue for improvement would be the incorporation of a City Environmental Footprint to facilitate a more comprehensive understanding of the dynamics inherent to urban contexts (Mirabella et al., 2019). Similarly, *transdisciplinarity* (Kehrein et al., 2020) and *uncertainty assessments* (Biancini et al., 2022) were largely absent from most published studies. Another critical aspect entails including stakeholders in the assessment process, a step which is often overlooked in environmental assessments. To understand the role of different stakeholders in urban contexts it is vital to identify and involve them in all design processes (Awasthi et al., 2021). This inclusive approach is of paramount importance for conducting sound analysis and developing meaningful and productive scenarios, such as identifying multiple stakeholders' environmental performance (Lishan et al., 2021). Given the constant interaction among citizens, waste processors, formal and informal agencies, organizations and public institutions within these systems, the exclusion of stakeholders can lead to unsustainable rather than sustainable urban systems (Joseph, 2006).

In relation to the dimension ***inclusive and circular society***, various methodologies and indicators were deployed. There was no specific trend identified for assessing the social dimension, although SLCA was the most frequently used methodology. This methodology could be effective in capturing the different sustainability dimensions in an urban context when used in combination with LCA and LCC. Yet, the extensive array of proposed ways for the simultaneous consideration of stakeholders, categories, subcategories, and indicators renders the assessment notably complex and time-consuming (Lehmann et al., 2013; Toboso-Chavero et al., 2021; Zamagni et al., 2015). The reviewed publications obtained the necessary social data relying on interviews or local statistics, assessing only some stakeholders while selecting certain indicators (Santos et al., 2019; Tarpani and Azapagic, 2023; Tonini et al., 2020). Thus, it would be more effective to reach a consensus on a set of mandatory indicators similar to LCA and then include others contingent on the context. This would enable comparison between studies and facilitate the drawing of conclusions and recommendations for policy decisions. Efforts are currently underway to develop the SLCA methodology, with the creation of an ISO standard (ISO 14075:2024(en) Environmental management - Principles and framework for social life cycle assessment). The inclusion of stakeholders was developed in some publications, however, the degree of participation (i.e., related to the selection and the method of engagement of stakeholders) still need further development. For example, only seven studies incorporated the informal sector. The informal sector significantly contributes to UWMSs by recycling and reusing millions of tonnes of waste worldwide, serving as a vital stakeholder to include in the circular economy (Zisopoulos et al., 2023). Accordingly, it is recommended to boost participation levels, considering that urban environments are primarily shaped by and for people. Co-creation living labs are excellent examples of environments where stakeholders can collaborate towards specific goals, with researchers contributing through data collection, proposing methodologies, and developing future scenarios (Tonini et al., 2020). Inclusion metrics were underdeveloped and underutilized in these publications. The focus was on indicators, with the most prevalent ones focused on social cohesion and citizen awareness. Consequently, the establishment of a comprehensive set of indicators would be advantageous, potentially concentrating on SLCA impact categories and stakeholder categories.

Regarding the dimension ***inclusive and circular economy***, a combination of methodologies, indicators, and indexes were employed in these publications. While indicators alone can only capture a small part of a complex system, the LCC methodology can provide more information on urban contexts. Nevertheless, few studies managed to perform an LCC. Their limited use may be due to a lack of availability and reliability of cost data, uncertainty for future cost estimation, lack of the understanding of the conceptual definitions and methods, lack of standards and automated calculation procedures, high complexity, and time investment (Gluch and Baumann, 2004; Goh and Sun, 2016; Kerdlap and Cornago, 2021). In this dimension, the use of many different circularity indicators makes it difficult to compare studies. To address this issue, it is advisable to develop a set of city-specific indicators, for instance, based on the EU circular framework and adapted to urban systems (European Commission, 2018). Inclusion metrics were found to be limited in scope, with a predominant focus on employment-related indicators. However, further efforts are required to comprehensively capture the concept of inclusion within a circular economy. This would entail the identification of specific types of employment, the analysis of the organizations involved, and the characterization of the workers included, with the aim of measuring the inclusion of vulnerable groups, such as those experiencing barriers to accessing the labor market, the informal sector, etc. In addition, it is imperative to assess the organizational context and policies in which these organizations operate, paying particular attention to the application of circular economy principles and the typologies of these strategies, such as repair, repurpose, reuse, etc. In essence, this necessitates a more in-depth analysis of the forms of inclusion.

Regarding the dimension ***inclusive and circular space***, GIS tools are well established and developed for their application in ICCs. However, spatial analysis is scarcely incorporated in the reviewed publications. Future studies may introduce dynamic analysis in urban contexts to capture their intrinsic characteristics in terms of infrastructures which may change over time. GIS tools can optimize routes, locate recycling and recovery facilities, map resources for future reuse (urban mining), identify hotspots of waste generation, locate vulnerable groups, track changes in residents' perceptions (Xiao et al., 2023), and map routes of informal recyclers (Gurjar and Gaur, 2022). In essence, these tools can improve the management of urban systems. In this dimension, the emphasis of the inclusion metrics was on accessibility and the utilization of urban space. However, it would be advisable to develop more space-specific indicators of inclusion, such as the demographics of users and the nature of their access. Furthermore, it is imperative to determine whether UWMS initiatives and facilities are more accessible to different types of individuals. Consequently, more specific indicators are recommended to capture the inclusive and circular space dimension.

4.2. Vision for the future: a roadmap for integrated sustainability assessments of urban waste management systems within inclusive circular cities

Future research can focus on the recommendations suggested below as the most critical found in this literature review.

- ***Lack of integrated sustainability assessments***: ISAs for assessing the multidimensional aspects of UWMSs are scarce in academic literature. Therefore, research should focus on the development of robust, comprehensive, and policy-science aligned assessments to provide decision makers with a holistic (rather than reductionistic) view of the issues metropolises face now and, in the future (Caro, 2023). ISAs can elucidate interdependencies, synergies, trade-offs, and connections across various dimensions and aspects of a city, thereby providing a fundamental understanding of urban systems (Mirabella et al., 2019). The adoption of holistic and transdisciplinary approach is advisable for encompassing all dimensions of an ICC (environmental, social, economic and spatial) and a range of disciplines, such as urban planning, sociology, philosophy and public policy. The ICC framework can facilitate the consideration of urban futures, a process which typically necessitates a considerable degree of creativity and unconventional thinking. This entails a paradigm shift for cities and, consequently, in the methodologies that assess them which can be attained by fostering comprehensiveness and a focus on social and environmental issues rather than economic ones (Escobar Cisternas et al., 2024). Future lines of research may focus on ISAs with particular attention paid to the generation of data for social assessments since those have been the least adopted in the studied scientific literature. Existing methodologies have ample potential to improve their ability to capture the dynamics and feedback loops of UWMSs by incorporating transdisciplinary and spatiotemporal analysis, as well as methodologies with a dynamic approach such as system dynamics and agent-based modelling (Bozeman et al., 2023).
- ***Prioritize inclusion and active stakeholder engagement:*** The inclusion of all stakeholders (i.e., citizens, the informal sector, vulnerable groups, a gender perspective, etc.) should be a prerequisite for ISAs of UWMSs, as they are currently underrepresented in scientific literature. Further research may be on gathering opinions (consultation) and sharing information but also on involving affected stakeholders, empowering them across all phases of the research process to facilitate the co-creation of knowledge (Bozeman et al., 2023; Yalçın and Foxon, 2021). Participatory strategies encompass the incorporation of waste pickers' cooperatives (Buch et al., 2021), women's participation in decision-making (Kahsay et al., 2021), and citizen science in research (Pierini et al., 2021). Therefore, interaction between different stakeholders and research communities using mixed method approaches is crucial. It is also important to reach consensus on specific indicators, whether quantitative and/or semi-quantitative, related to inclusion. This is to ensure that at least some of the social complexity of cities is captured while striving for replicability and comparability. In particular, we propose the establishment of a common minimum set of indicators to be applied across cities. One potential approach to this is the adaptation of the Social Progress Index (Stern et al., 2024) which provides holistic and transparent data divided across three broad dimensions, namely basic human needs, foundations of wellbeing, and opportunity (Stern et al., 2024). Furthermore, the SLCA methodology could be developed further by adapting specific indicators for the inclusion of stakeholders. These stakeholder categories have already been proposed in this methodology and include workers, local community, society, consumers, and so forth (UNEP et al., 2020)
- ***Adopt circular strategies that extend beyond recycling and recovery*:** Despite the extensive literature on recycling (R8) and recovery (R9) strategies, they are ranked lowest on the 10R ladder and are regarded as long loops and part of the prevailing linear economy, potentially exacerbating inequalities, and increasing waste generation (Vanhuyse et al., 2021). In order for urban contexts to fully embrace the principles of the circular economy, a broader shift is required. Such a shift would entail not only optimizing existing recycling processes but also innovating and implementing strategies that extend beyond recycling. This would involve the promotion of systemic changes that address the root causes of waste generation and the transition towards an ICC. Researchers may now focus their attention on the exploration of higher-level circular strategies, such as reuse (R3), reduce (R2), rethink (R1) and refuse (R0), considering the potential of methodologies and/or indicators/indexes to more accurately capture these circular strategies through a quantitative/semi-quantitative approach. This, in turn, will facilitate data acquisition and the assessment of the evolution towards shorter loops in UWMSs. Furthermore, there is a paucity of studies that integrate sustainability and circularity assessments. The integration of circularity assessments with environmental assessments and, thus ISAs, can facilitate the generation of more precise information, which in turn enables the selection of optimal future strategies and scenarios for urban systems (Cilleruelo Palomero et al., 2024). Potential avenues for consideration are the adaptation of the Wasteaware benchmark indicators (Wilson et al., 2015) and the EU monitoring framework for the circular economy (European Commission, 2018) to urban contexts, including MSW generation per capita, MSW recycling rate, and the circular material use rate. Additionally, it would be advantageous to ascertain the current set of circular economy indicators employed in urban areas, thereby facilitating a more collaborative interaction between cities and research (Kopp et al., 2024).

5. Conclusions

The objective of this study is to advance research on the ISAs of UWMSs within ICCs. By identifying key areas for improvement, the study provided comprehensive guidance for measuring the effectiveness of UWMSs in ICCs. By employing bibliometric and content analysis techniques, the study contributes to the existing body of knowledge by elucidating trends, methodologies, indicators, circular strategies, and identifying knowledge gaps within the field. The findings suggest that current application of ISAs of UWMSs will have to evolve in order to capture the full complexity of urban contexts. For research on UWMSs to progress towards greater sustainability, circularity, and inclusion, it is essential that a more forward-thinking approach is adopted that encompasses not only a reimagining of UWMSs and their role within ICCs but also a redefinition of the metrics used to assess their success. It is evident that the current tools and frameworks need to mature towards a more holistic, transdisciplinary and knowledge co-creating approach.

In this literature review, we identified 145 scientific publications from 2011 to 2023, of which only 15 assessed the three dimensions of sustainability (but only four were classified as strong sustainability-oriented), 4 measured social and environmental dimensions, and 25 measured economic and environmental dimensions of UWMSs. The remaining publications (70 %) evaluated only one dimension (environmental or social or economic). Most of the publications were focused on European countries, China, Brazil and Chile, and began to flourish from 2020 onwards. There is therefore a need to promote more research in ISAs, involving different disciplines working together and focusing on Africa, Oceania and the Americas (except Brazil and Chile), and also on Asia (except China).

The most frequently used methodologies in these publications were from environmental accounting, such as LCA, and environmental indicators, such as carbon footprint. MFA was also extensively used in the scenario analysis. The economic and social assessments revealed a plethora of methodologies and indicators, making cross-study comparisons difficult. Moreover, most publications employed isolated methodologies, whether environmental, social, or economic, and proposals for multidimensional studies were limited. The MCDA was widely used as prioritization methodology for all dimensions. With regard to inclusion and circularity assessments, these are seldom combined with ISAs [only in three publications made this combination (Bote Alonso et al., 2022; Moraes et al., 2023; Piñones et al., 2023)].

There are several limitations to this literature review that can be addressed in future studies. Firstly, in addition to scientifically proven methodologies, there are other indicators and indexes used to measure the performance of cities in terms of inclusion (Zhao et al., 2023), circularity, and sustainability (Sáez et al., 2020). Accordingly, to broaden the scope, future research could also consider grey literature, including reports, and city rankings among other relevant materials. Secondly, as this literature review employed specific keywords, it would be advisable to propose an alternative keyword combination to include those possible articles related to assessments but not explicitly mentioning *circular economy/circularity* or/and *sustainability/integrated/comprehensive/holistic*. Despite its limitations, the results of this literature review provide a valuable and insightful analysis of the current state of research on sustainable, circular and inclusive urban contexts.

In our view, there are numerous avenues for further research, interdisciplinary collaboration, and knowledge generation related to UWMSs and their role within ICCs. Priority areas for further research include: a) multidimensional and cross-disciplinary (transdisciplinarity) assessments, i.e., the implementation of strong sustainability-oriented assessments; b) inclusion and participation of stakeholders in collaborative knowledge creation; c) incorporation of circularity and inclusion assessments in ISAs; and d) setting ambitious targets for resource retention in closed loops rather than exclusively adopting recovery or recycling strategies. Closing these gaps will equip cities to advance towards more sustainable, inclusive, and circular environments, fostering resilience and promoting long-term environmental and social well-being.

CRediT authorship contribution statement

Susana Toboso-Chavero: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Filippos K. Zisopoulos:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Martin de Jong:** Writing – review & editing, Supervision, Software, Resources, Funding acquisition, Conceptualization. **Daan Schraven:** Writing – review & editing, Visualization, Supervision, Software, Resources, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The study falls within the Sino-Dutch project “Towards Inclusive CE: Transnational Network for Wise-Waste Cities (IWWCs)” which is one of the projects of the Erasmus Initiative Dynamics of Inclusive Prosperity, and it is co-funded by the Dutch Research Council (NWO) and the National Natural Science Foundation of China (NSFC); NWO project number: 482.19.608; NSFC project number: 72061137071.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2025.100275.

Data availability

I have shared the data in the Supplementary Information

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