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A HOLISTIC SELF-ASSESSMENT TOOL FOR CIRCULAR ECONOMY TRANSITIONS IN CITIES AND REGIONS

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Abstract. In the European context, cities and regions play a key role in boosting circularity and achieve the European Green Deal action plan ambition to 'boost the efficient use of resources by moving to a clean, circular economy'. To this end, cities and regions will be instrumental in promoting circularity through engagement with key actors and integration of circular economy (CE) goals within their policies and spatial plans. To support this effort, it is essential to develop appropriate metrics and tools for evaluating the progress and transition towards a circular economy. Although numerous new assessment methodologies have been suggested (Corona et al., 2019), they generally focus on quantitatively assessing how circular a project, system, or business is, or on evaluating the extent to which circular strategies align with the principles of a circular economy. Current metrics rarely extend beyond material sustainability assessments, which means they often do not capture the complexity of the CE transition and lack a comprehensive, integrated perspective. In particular, what they omit are the spatial (Williams, 2020), the governance (Korhonen et al., 2018) and the social dimensions (Pitkänen et al., 2020). In this paper, we propose a holistic transition assessment tool developed and tested across several metropolitan regions, including Amsterdam, Naples, Łódź, Hamburg and Pécs, being at different stages of the circular economy transition. The final version of the tool was applied in two cases, the Amsterdam Metropolitan Area and the city of Tomaszów Mazowiecki. The tool focuses on five dimensions: (1) governance structures, (2) awareness, comprehensiveness of the sustainability assessment, (3) tools for measuring material stocks and flows as well as (4) for co-creation of solutions and strategies with stakeholders, and (5) circular built environment. The results of applying the tool in a series of workshops with regional CE stakeholders

allow for exploring the following questions: What is the state of the transition towards CE in European urban regions from a holistic perspective? What hinders these transitions? And how to identify means to overcome those barriers? The assessment tool is of interest for regional and urban policy-makers, planners and stakeholders engaged in development of CE strategies and policies. What is more, the results presented in the paper allow for comparative insights into the state of transition towards CE and for drawing lessons on what it takes to nudge the development of regions and cities towards circularity.

Keywords: circular economy, circular transition, governance, awareness, sustainability assessment.

Introduction

In the wake of the climate crisis and a growing recognition of human activities' disastrous and unsustainable resource consumption around the world (Circle Economy, 2021), the circular economy (CE) has emerged as a new paradigm for sustainability. Geirsdoerfer et al. (2017) defined CE as a regenerative system designed to minimize resource input, waste, emissions, and energy leakage by slowing, closing, and narrowing material and energy loops.

This can be accomplished through strategies such as long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. Since then, many variations of this definition have been added. CE research is booming, and we are witnessing a flurry of policies and strategies supporting a shift away from the linear economy based on the most common make-use-waste model. Thus, the European Union has put CE at the heart of its sustainability ambitions (EC, 2015), while many countries have followed suit with national CE policies and targets. At the same time, cities, and to a lesser extent, regions, seem to be leading the 'circularity' debate. Many of them see the CE as a new foundation and compass for their sustainability policies. They are setting ambitious targets for reducing waste generation with the ambition to go 'fully circular' within two or three decades.

An OECD study (2020a) showed that most cities and regions, at least in developed countries, already plan to create and implement CE policies, even though they are at a very early stage of a transition to circularity. Moreover, the strategies and ambitions of cities and regions for a shift towards a CE often ignore the socio-ecological, governance, or spatial implications of such a radical shift (see, e.g. Obersteg et al., 2019; Williams, 2019; Friant et al., 2021). They also tend to overlook the potential that CE offers to drive social, economic, and environmental sustainability (Savini, 2021; Williams, 2021), by limiting the focus to waste management and fostering symbiotic relationships between different branches of industry to close material cycles. To exploit these opportunities and overcome the numerous barriers for CE development (see Obersteg et al., 2019), cities and regions need integrated, place-based and inclusive circular policies.

The recently published methodology for implementing a CE at the local and regional scale (CCRI, 2022) states that implementing a CE at those scales necessitates a comprehensive, stakeholder-centric methodology incorporating economic, environmental, and social considerations. Navigating a change towards a CE thus requires debate and careful consideration of those implications to identify the place-specific barriers to change and opportunities arising from the characteristics of the local or regional context.

It also requires decision-support and evaluation tools to assess the status quo and progress towards sustainable circular futures. In recent years, in parallel to the rise of CE as a policy goal, a growing number of frameworks for the assessment of CE has been proposed in the academic literature and in policy practice (for reviews, see Moraga et al., 2019; Parchomenko et al., 2019; Saidani et al., 2019).

Assessment of progress towards CE, ideally, should also involve a variety of local and regional stakeholders (Korhonen et al., 2018) who can contribute a diversity of knowledge, resources and ideas. Initially, engaging all relevant stakeholders, from local businesses to governmental entities, is vital to ensure their active participation through consultations and workshops. The phase of securing stakeholder engagement is often followed by baseline assessment, often with a limited focus on the flow of resources, economic structures, and environmental impacts within the region (CCRI, 2022). Moreover, there is often a gap between securing stakeholder engagements and the long and data-intensive baseline assessment process. Therefore, we present in this paper a Circular Economy Transitions Self-Assessment (CETSA) tool for cities and regions that aims to use and build stakeholder engagement on the one hand and shape and make the baseline assessment more complete as well as context-specific. We first provide an overview of basic transition theory and elaborate on the need for an additional assessment framework, then introduce the framework, provide guidance on how to use it, and report on the first tests.

Circularity Transition and the need for a Self-Assessment Tool

Transition management requires identifying and translating specific transition challenges and goals to the reality of the specific urban context within multi-level and multi-actor decision-making systems (Wittmayer et al., 2014; Wittmayer & Loorbach, 2016). In recent years, we have seen the emergence of many elements needed to manage transitions towards circular cities and regions, with the proliferation of policies and strategies to promote the closing of material loops and reduce waste generation. There has also been a flurry of experimentation at the local scale, with new circular business models, eco-innovative solutions and tools to encourage and promote circular processes in the built environment, such as public procurement (Alhola et al., 2019), territorial material flow analysis (Furlan et al., 2022) or online decision support tools for circular strategy-making (Arciniegas et al., 2019).

As it is becoming apparent that cities and regions are central players in reducing climate change effects through sustainable development, the paths to achieving this objective are being explored. One of the most often-named approaches is that a deep and clear cut is needed to abandon the current linear logic in favour of circularity (Petit-Boix & Leipold, 2018), calling for a systemic urban transformation (Patterson et al., 2017). As urban regions are highly complex systems, the transformation process needs a certain degree of management to steer incremental urban sustainability transitions involving different sub-systems of the urban environment (Loorbach, 2010; Hölscher et al., 2018). Urban sustainability transitions are defined as 'fundamental and structural changes in urban systems through which persistent societal challenges are addressed' (Frantzeskaki et al., 2017, p. 1). As such, there is a high demand for governing this process, as many urban actors must jointly operate to make decisions and reach the envisioned transformation (Frantzeskaki & Rok, 2018; Obersteg et al., 2019).

The literature on (urban) sustainability transitions and transition management (Loorbach, 2010; Geels, 2011; Frantzeskaki et al., 2017; Loorbach et al., 2017) provided inspiration and a foundation for the development of this tool. There is an increasing emphasis on transitioning towards a circular economy, yet a significant knowledge gap persists, particularly regarding the question of 'how' to effectively implement these changes (Fratini et al., 2019). In other words, while the necessity of transition is recognized, there is a need to clarify how to manage it effectively. Existing literature predominantly addresses the socio-technological aspects of the circular economy, often

overlooking spatial considerations (Williams, 2019), governance (Obersteg et al., 2019) and societal aspects (Moreau et al., 2017; Pitkänen et al., 2020). We need an integrative approach to grasp the complexity of transitioning towards a circular economy.

Co-creative aspects, which facilitate the active engagement of stakeholders in developing knowledge and solutions, are crucial due to the relative novelty and complexity of the challenge. In this context, the CETSA tool is introduced as a means to address these gaps by harnessing stakeholder collaboration within a specific territory. The tool aims to provide insights into a region's progress along the path to circular economy transition, identify barriers impeding progress, and determine the necessary steps to create an enabling environment for the transition.

There are only a few circularity self-assessment tools available, one of them being the Circularity Assessment Protocol in Cities (Jambeck et al., 2024). It is a hub-and-spoke model that offers a snapshot of a city's circularity, providing data that can inform local, regional, or national decision-making. This data aids in reducing waste leakage (e.g., single-use plastics) into the environment and enhances the management of circular materials. As the description shows, it's very waste-centred and has not been applied beyond individual sectors or waste streams. The OECD framework for (self-)assessment by urban and regional level authorities (OECD, 2020b) is a scoreboard for the development of a selection of elements of CE policies, from the development of strategic visions, stakeholder engagement, and capacity-building to data and assessment.

A broader perspective on CE is included in some of the regional and urban assessment frameworks proposed by academic researchers. For instance, Cavaleiro de Ferreira and Fuso-Nerini (2019) developed an approach incorporating a more comprehensive range of indicators, considering demographics, policy environment, and some aspects of the built environment. Similarly, Silvestri et al. (2020) proposed an approach to the assessment of CE, bringing together social, health, economic and environmental indicators, while that developed by Avdiushchenko (2018) also includes some spatial and cultural factors.

Many of the existing assessment tools tend to use quantitative methods and focus on material flows (e.g. Ecorys, 2019), overlooking the social and spatial dimensions of the transition to sustainability. Most frameworks for evaluation of CE rely on the available (and often flawed; see Sileryte et al., 2022) data on waste (OECD, 2020b) and the most widely used environmental indicators such as waste recycling rates or greenhouse gases emissions, even if social (such as generation of circular jobs), economic (such as public spending on circular economy projects) or even smart city indicators are included in some of them (Bîrgovan et al., 2022). In addition, one critique of the current approaches to the assessment of CE is that they tend to ignore stocks of materials, for instance, those that are 'locked in' within the existing built environment, focusing instead mainly on flows (Harris et al., 2021), for instance, those embedded in buildings or infrastructure and potentially available for 'mining' and reuse. Another critique concerns the narrow understanding of CE that permeates the existing assessment frameworks, often limited to only the basic circular strategies of material preservation (Moraga et al., 2019), e.g. through recycling, while ignoring the more sustainable and, hence, more desirable strategies that focus on the use of products and materials and avoidance of waste generation.

Our approach is more qualitative, comprehensive and based on co-creating knowledge with regional stakeholders. In some aspects, namely governance and stakeholder engagement, our assessment tool shares features with the OECD framework for (self-)assessment by urban and regional level authorities (OECD, 2020b). While being comprehensive on governance and policy aspects, including awareness-building, this framework hardly covers spatial matters beyond promoting territorial linkages between urban and rural areas and CE actions at the neighbourhood

scale. By contrast, our tool comprises not only the means to measure the degree of awareness, the presence of the elements needed to enable governance of transition towards CE at different levels of government, and adequate data to support these efforts but also incorporates a more comprehensive perspective on the spatial dimension of CE and the sustainability of circular actions. Below, we present the core features of the tool and illustrate its application in a stakeholder workshop context.

The Four Stages and Five Dimensions of the Self-Assessment Tool

As a first step towards self-assessment, four stages of the transition were determined to assess progress. The stages are:

1. **Ambition to go circular** – an early stage of the transition, at which the economy remains firmly linear, but stakeholders and policy actors express ambitions to shift towards a CE and put forward ideas, plans, and strategies to achieve this.
2. **Niche change** – as argued by Geels (2011), the transition begins with changes and experimentation in niches on the fringe of the predominant model of activity. Such experimentation is critical for identifying new solutions, new ways of doing things, and methodologies, paving the way for more widespread use.
3. **Accelerating change** – this stage corresponds to a situation where experimentation becomes widespread, institutionalised, and widely supported, reaching a critical mass that is able to drive systemic change.
4. **Mainstreamed circular economy** – in this final stage of the transition, the linear economy would be a song of the past and circular processes would be fully mainstreamed as the predominant paradigm for production, consumption, or development of the built environment.

Naturally, these stages are not precisely defined, but rather 'ideal types' and serve the purpose of assessment, animation of the debate and comparison. Subsequently, indicators for assessing the transition were divided into five dimensions. Each dimension contains three indicators, with which one is able to assess the state of play in a given territory using a four-stage scale (from ambition to move beyond the linear economy to mainstream circular economy). Moreover, we would like to acknowledge that there may, of course, be cases where no ambition at all to the transition can be observed. This stage is not included in the tables describing different dimensions. If a case did not reach the ambition phase, the value assigned for that indicator is 0.

The dimensions are the following (see Fig. 1):

1. **Governance**: arenas, agendas, and experiments supporting and steering the transition;
2. **Awareness**: corporate awareness, awareness towards policies, and everyday practices of citizens;
3. **Tools**: tools for assessment of material flows, tools for urban mining (stock), and tools for enabling co-creation (of knowledge, solutions, strategies) with stakeholders;
4. **Sustainability assessment**: availability of data on waste and materials, the degree of stakeholder involvement in assessment, and the degree of comprehensiveness of sustainability assessment (consideration of the pillars of sustainability);
5. **Built environment**: The preparedness and actions taken to regenerate wastescapes – that is, areas that were degraded by linear economic processes and remain polluted and/or underused – and transform the physical and functional built environments.

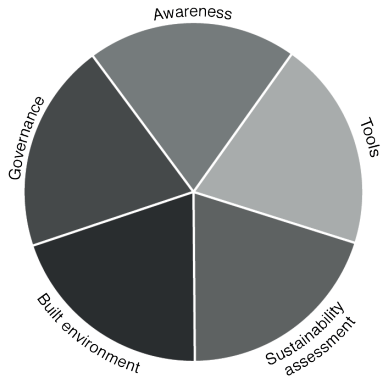

Figure 1. The five dimensions of the tool
Source: authors own elaboration.

In the following, we provide a more detailed description of the five dimensions and the related four stages of the transition for self-assessment.

The Governance dimension

The governance dimension of the CETSA tool uses three of the four levels of the transition management framework by Wittmayer and Loorbach (see Loorbach 2007; 2010; Wittmayer & Loorbach, 2016, p. 19). We adapted it for our CE focus. The three levels that are used in the CETSA tool are:

Transition Arena includes strategic-level activities which encompass long-term endeavours focused on collective deliberation in envisioning the future. Activities such as visioning, long-term goal formulation, and establishing collective goals and norms are encompassed here. This dimension emphasises the policy dimension, territorial coverage, and the nuances of vertical and horizontal coordination, spanning boundaries, policy domains, and societal dimensions.

- **Transition Agendas** are characterised by tactical-level actions designed to foster changes in established structures, institutions, regulations, and physical or financial infrastructures over the midterm and long term. These activities are closely linked to creating an enabling environment for the transition, considering various territorial levels and the extent of territorial coverage.
- **Transition Experiments** involve operational-level activities aimed at short-term objectives. These activities involve experimenting with and implementing alternative ideas, practices, and social relations.

The fourth level, **'Transition Monitoring and Evaluation'**, which is provided by Wittmayer and Loorbach (2016), is not included in the governance dimension of the CETSA tool, as monitoring and evaluation elements can be found respectively in the tools dimension and the awareness dimension of the CETSA tool. Transition Monitoring and Evaluation, according to Wittmayer and Loorbach (2016), comprise reflexive-oriented activities aimed at acquiring insights into the current state and dynamics of the system, potential future states, and the path from the present to the future. These activities involve collective learning derived from ongoing operational, tactical, and strategic endeavours. Additionally, we have introduced distinctions regarding territorial levels and incorporated the concept of co-creation into this dimension. See Table 1.

Table 1. The indicators of the governance dimension

Indicator	Description
Arenas – Long-term-oriented strategic activities and policies	Ambition: *...are being discussed by a small group of stakeholders*.
	Niche: *...begins to be implemented at some territorial levels ...and cover only parts of the relevant territory ...are not yet integrated vertically or horizontally ...are not yet integrated with spatial strategies*.
	Accelerating: *...are implemented at all territorial levels ...and cover most of the relevant territory (municipalities) ...are integrated vertically across government levels OR horizontally across administrative boundaries OR across policy sectors AND in collaboration with knowledge and private sectors.*
	Mainstreamed: *...are in place in all territorial levels ...and cover all the relevant territory, integrated vertically across those levels AND horizontally across administrative boundaries ...AND across policy sectors in collaboration with knowledge and economic sectors AND citizens.*
Agendas	Ambition: *...are being discussed (emerging)*.
	Niche: *...are in place at some territorial levels and cover some of the relevant territory, their impact remains limited to selected policy sectors*.
	Accelerating: *...are in place at all territorial levels and cover most of the relevant territory ...but they cover only some of the relevant policy sectors*.
	Mainstreamed: *...are in place at all territorial levels ...and cover all the relevant territory, creating an enabling environment for the transition.*
Experiments/ Eco-Innovative Solutions	Ambition: *...are isolated, most innovations are concerned with the improvement of waste management*.
	Niche: *...are emerging based on the R-strategies, predominantly in the form of industrial symbiosis*.
	Accelerating: *...are reaching a 'critical mass'...emerge in the form of circular urban and regional development initiatives (e.g. spatial planning integrating CE, like circular business parks or neighbourhoods*.
	Mainstreamed: ...are spatially integrated and considered as standard (beyond experimental character) ...have reached a critical mass cutting across material flows AND are integrated with spatial strategies cutting across scales.

The Awareness dimension

The awareness dimension includes three aspects: corporate awareness, awareness towards policy implementation and awareness towards daily life practices (see Table 2).

'Corporate environmentalism' refers to a company's awareness of green thinking/circularity, which involves recognising and integrating environmental concerns, specifically circularity concerns, into a firm's decision-making process. This represents one way in which a business entity can address environmental issues or the circularity of flows (Banerjee, 2002). Firms' awareness can take two forms. One is regulated and overseen by external bodies, such as meta-governmental, governmental, or local governmental organisations. The other is a self-regulatory mechanism (Lyon & Maxwell, 2004), often demonstrated through the use of environmental management systems, such as the EU's Eco-Management and Audit Scheme (EMAS) and the International Organization for Standardization's ISO 14001 quality management system (Neugebauer, 2012). ISO 14001:2004 specifies requirements for an environmental management system to enable an organisation to develop and implement policies and objectives that consider legal requirements and other subscribed-to requirements, along with information about significant environmental aspects. ISO 14001:2015 updated this management system, introducing stricter regulations for firms seeking certification.

Table 2. The indicators of the awareness dimension

Indicator	Description
Corporate	Ambition: ...*Little responsibility in separate waste collection can be found at corporate levels (e.g. one or a maximum of two separation possibilities available for employees).*
	Niche: ...*In most companies, separate waste collection is available for employees, and the majority of companies have a voluntary 'green strategy' and a related education program.*
	Accelerating: ...*Most companies are working on reducing packaging and looking for low-waste technologies ...service provider companies mainly use paperless and distant services.*
	Mainstreamed: ...*Most companies integrate reused parts in production and work on the extension of product life cycles ...paperless services ...companies mainly use renewable sources for electricity, heating and transport.*
Policy Implementation	Ambition: ...*Citizens are interested in CE rules and opportunities.*
	Niche: ...*Citizens are partially able to be informed and to experiment with CE opportunities.*
	Accelerating: ...*Citizens start making use of policy implementation on CE.*
	Mainstreamed: ...*Citizens are able to use CE rules and solutions and to suggest new challenges for policies.*
Ordinary Life Practices	Ambition: ...*People start thinking about the potential of discarded objects ...most people are satisfied with separate collection.*
	Niche: ...*Experiments are done in the recycling of materials/objects and in the field of education ...people are trying to reduce their packaging use.*
	Accelerating: ...*Groups of people start reusing disused materials/objects, and NGOs work in this field.*
	Mainstreamed: ...*People are actively involved in CE practices and open to new challenges...people mostly buy durable consumer goods ...repair and refurbishment are priorities.*

Towards Policy Implementation

Awareness towards policy implementation pertains to citizens' understanding of what the policy framework on circular economy enables for them. In the context of CE, there is an observable 'gap between policies and the city' (Balducci & Ferrara, 2018), highlighting how institutions often disregard innovations from local contexts and how institutional measures and tools are frequently little-known and underutilised by citizens. This gap, more pronounced in certain urban regions in Southern Europe, can serve as a lens through which to interpret CE awareness across European regions in general. Elevating awareness forms the foundation for promoting local transitions (Ellen MacArthur Foundation, 2019), as social and behavioural aspects of the transition are under-researched and present a barrier to circular processes (Jonker et al., 2018).

If citizens are initially primarily interested in the CE framework's rules and measures made possible by public policies, some subsequently become informed and adept at seizing CE opportunities within policy-making. Developed awareness can alter customs and habits, eventually fostering shared circular processes that bridge the gap between policies and the city, with each actor assuming their respective role.

Towards Ordinary Life Practices

A significant portion of environmental problems can be attributed to human behaviour. Consequently, much research is directed at understanding the motivations and background

of environmental/circular-related actions. Attitude and awareness represent 'psychological tendencies expressed by evaluating a particular entity with varying degrees of favour or disfavour' (Eagly & Chaiken, 1993), or by documenting the actions taken (Varjú et al., 2018). Both interviews and questionnaires are employed for 'measuring' (environmental) awareness.

The Tools dimension

Understanding the flows and stocks within a city or region and its potentially global hinterlands is crucial for devising and supervising circularity strategies and in general, assessing the sustainability of cities. This idea is anchored in the field of (urban) metabolism studies. Urban metabolism, a conceptual framework, depicts cities as dynamic organisms that evolve, adapt, and change over time. Lucertini & Musco (2020) underscored the portrayal of cities as such vibrant entities. The genesis of the urban metabolism concept can be traced back to Theodor Weyl's work in 1894 for Berlin. It was later advanced by Wolman (1965) and significantly enriched by Kennedy et al. (2007). They elucidated how urban metabolism covers the entire breadth of technical and socioeconomic processes operative within cities. These processes are crucial in dictating growth trajectory, energy synthesis, and waste management within urban confines.

Beyond its historical evolution, urban metabolism serves as an analytical lens, allowing policymakers and researchers to assess the movement of resources holistically. Baccini & Brunner (2012) emphasised how this lens offers insights into the dynamics of consumption and production patterns in urban areas. By studying the continuous influx (like energy, materials, and water) and efflux (such as waste, pollutants, and by-products) within a delineated system boundary, stakeholders can better strategise sustainable urban planning, ensuring that cities remain resilient and sustainable in the long run. Therefore, we added to those two types of tools, also tools of co-creation, as many of the stock and flow tools stay at a dashboard level and are hardly developed in a way that they can provide interactive information for co-creative processes (see Table 3).

Tools for Flows and Stocks

The evaluation of material movements and stockpiles within a defined geographical and temporal system is traditionally known as Material Flow Analysis (MFA) (Brunner & Rechberger, 2004; Broto et al., 2012). MFA's cornerstone is the matter conservation principle (Allesch & Brunner, 2015). With the system's boundaries established, the principle of mass conservation facilitates the subsequent accounting process: inflows are equal to outflows plus alterations in stocks and depletion (Allesch & Brunner, 2015). Only more recently, methods and tools have been developed that opened up the black box of urban metabolism and provided flow analyses and mapping that include specific geographic information, allowing to understand where in the city processes and related flows are actually occurring and allowing visualising and analysing value chains spatially (Furlan et al., 2022; Sileryte et al., 2022).

Urban mining, in our context, refers to the retrieval of raw materials from products, structures, and waste within an urban environment. These secondary raw materials can substitute or complement virgin raw materials in manufacturing processes. Urban mining models enable the prediction of when, where, and in what quantities and qualities specific secondary raw materials become available (Pauliuk & Müller, 2014).

Several models and tools have been developed to support urban mining initiatives. For instance, MFA systematically assesses flows and stocks of materials within urban systems. Furthermore, Geographic Information System (GIS) based models help in spatially mapping potential resource

deposits in urban (infra-) structures and waste. Challenges remain, including technological, regulatory, and economic barriers, but the development of these models and tools signifies a growing recognition of urban areas as viable sources of valuable resources.

Co-creation Processes

Co-creation in urban planning refers to the collaborative process where diverse stakeholders, including residents, government authorities, businesses, and non-governmental organisations, actively participate in the planning, design, and implementation of urban projects (Voorberg et al., 2014). We restrict ourselves here to urban living labs (ULL). Urban Living Labs are real-life urban testbeds where stakeholders collaboratively explore, examine, and co-create solutions for complex urban challenges (Bulkeley et al.,2016). Typically characterised by a user-centred, open innovation approach, ULLs are platforms that foster iterative testing, experimentation, and learning in real-world urban settings. They have been applied in various urban contexts ranging from sustainable urban planning to smart city initiatives (Voytenko et al., 2016) and, more recently, in the transition towards circularity (Amenta et al., 2019). In contrast, other forms of collaborative planning often conclude at the stage of public consultation. Co-creation embodies a paradigm of mutual assistance and knowledge sharing, where individuals can convey their expertise and experiences (as users). The novelty of this methodology lies in its user-centric approach, combining expectations from past participatory processes while transforming users into future co-creators.

Table 3. The indicators of the tools dimension

Indicator	Description
Flows	Ambition: …*A material flow analysis for a city/region on input-output level is available for most materials and energy flows.*
	Niche: …*A more detailed MFA, either spatially or concerning qualities of materials and treatment of specific flows, are available regularly.*
	Accelerating: …*A comprehensive and detailed MFA is done regularly and used for policy assessment.*
	Mainstreamed: …*A real-time material flow information system is available that provides sufficient information to establish a secondary raw material market.*
Stocks	Ambition: …*The development of urban mining models is being discussed.*
	Niche: …*A general urban mining model for the whole city has been developed once for a selection of materials.*
	Accelerating: …*A more detailed, either spatially or concerning qualities of materials and specific stocks, model is available regularly.*
	Mainstreamed: …*Comprehensive and detailed urban mining model (supported by material passports, for example) is done regularly and used for policy assessment.*
Co-creation	Ambition: …*Only limited participatory processes are established, like, focus groups, consultation processes aimed at finding out people's expectations and their needs.*
	Niche: …*Pilot projects that include co-creational aspects are running (user-centric ensemble).*
	Accelerating: …*Many experiments based on user-centred environments with results conveyed by actual users.*
	Mainstreamed: …*Co-creational decision development of CE related policies are widely spread in management/planning processes and policy regulations.*

The Sustainability Assessment dimension

A CE strategy strives to generate value for the economy, society, and businesses while minimising resource consumption through practices like reduction, reuse, and recycling. This approach, rooted in systems thinking, seeks opportunities to close loops, whether they are biological or technical cycles, to extend the lifespan of components and materials in the market, preferably in a high-quality manner. While CE strategies often align with improved environmental sustainability, it is vital to acknowledge that this alignment only sometimes occurs.

Moreover, understanding the transition towards circularity not as a goal but as a means towards sustainable development requires embedding its assessment in comprehensive frameworks encompassing social, environmental, and economic dimensions (e.g., Taelman et al., 2020). Adopting this systemic approach allows for exploring how circularity influences resource efficiency and broader societal well-being, equity, and resilience (Raworth, 2017).

To effectively assess the sustainability of these strategies, we identified three indicators: data availability, stakeholder involvement, and comprehensive frameworks. These elements ensure a thorough and accurate evaluation of CE initiatives, revealing their impact on sustainable development.

Data availability

Data availability is a significant challenge in sustainability assessments, particularly in Life Cycle Assessment (LCA) studies, which are vital for evaluating the environmental performance of CE initiatives. Access to high-quality primary data is often limited, affecting the certainty of LCA results and hindering the effective evaluation of CE strategies (Potting et al., 2017; Harris et al., 2021). LCA is a science-based methodology that quantifies the potential environmental impacts of products, services, and business models throughout their life cycles, from raw material extraction to disposal. The accuracy of LCA relies heavily on comprehensive data covering the entire lifecycle of products and services. Therefore, improving data availability is crucial for operationalising the assessment of CE deployments and ensuring accurate sustainability evaluations.

Stakeholder involvement

Involving stakeholders is pivotal in sustainability assessments. Their participation is essential for data collection, setting analysis goals and scope, and developing relevant indicators. Engaging policymakers, businesses, and researchers provides valuable insights and ensures that CE strategies align with broader sustainable development goals. Methodologies like monetisation, Multi-Criteria Decision Analysis (MCDA), and Sustainability Impact Assessment (SIA) facilitate the integration of diverse perspectives into a coherent evaluation framework (Rizos et al., 2017).

Comprehensive Frameworks

A comprehensive approach to sustainability assessment goes beyond merely closing loops. It embeds CE strategies within broader frameworks that encompass social, environmental, and economic dimensions (Taelman et al., 2020). These frameworks enable holistic evaluations of how CE contributes to the United Nations Sustainable Development Goals (SDGs) and reveal the complex systemic relationships involved (SRC, 2016). By considering factors like resource efficiency, societal well-being, equity, and resilience, a systemic approach helps in developing effective strategies for sustainable development (Raworth, 2017). Combining multiple assessment methods, including

social and economic indicators, ensures a thorough understanding of the local, regional, and global impacts of CE strategies (Taelman et al., 2018, 2020).

Table 4. Indicators in the Sustainability Assessment dimension

Indicator	Description
Data Availability	Ambition: …*Data on resource management not directly available …Data gaps are filled with data from the literature, databases, etc., and many approximations have been made … many problems with the confidentiality of data.*
	Niche: … *Data is available but limited …data gaps are filled with data from the literature, databases, etc., and a few approximations have been made …confidentiality issues of data might appear.*
	Accelerating: … *Data is available …data gaps are filled with data from literature, databases, etc., and a few approximations have been made …most data is open access.*
	Mainstreamed: … *Data is extensively available …data gaps are filled with data from literature, databases, etc. and almost no approximations have been made … data is open access and/or fully available.*
Stakeholder Involvement	Ambition: …*Stakeholders were not involved in the data collection.*
	Niche: …*Stakeholders were involved in the data collection, as well as contributing to the definition of the goal and scope of the sustainability study.*
	Accelerating: …*Stakeholders were involved in the data collection, brainstorm about the goal and scope of the sustainability study and were engaged in the impact assessment (developing/selecting indicators).*
	Mainstreamed: …*Stakeholders were involved in multiple steps of a sustainability assessment study (incl. interpretation of the results).*
Comprehensivess	Ambition: …*A sustainability assessment has been done for the resource management system under study for 1 pillar (either social, economic or environmental) AND for one spatial scale (e.g. local).*
	Niche: … *A sustainability assessment has been done for the resource management system under study for 2 pillars (e.g. social & economic) OR 1 pillar covering multiple spatial scales.*
	Accelerating: …*A sustainability assessment has been done for the resource management system under study for all three pillars (social, economic & environmental) OR 2 pillars covering multiple spatial scales.*
	Mainstreamed: … *There is a model and framework in place to aggregate sustainability results (3 pillars and multiple spatial scales) and eventually a single score, providing decision support for policymakers.*

The Built Environment dimension

Van der Berghe et al. (2019) concluded in their study on two Dutch circular neighbourhood developments that, contrary to the ambition to (re)balance the conflict within urban spatial planning between 'place as a location' and the 'organisation of space,' the concept of circularity is accelerating 'space as a location,' increasingly transforming urban industrial areas into circular built residential and commercial areas. To avoid the displacement of crucial functions for the circularity transition of urban areas, three indicators were included in this dimension of our assessment: the physical built environment, the functional built environment and the regeneration of wastescapes.

Remøy and Wandl (2022) pointed out that the built environment plays at least a double role in the transition towards circularity; the first is the physical built environment, which includes construction, demolishing, reconstruction maintenance and refurbishing of buildings and infrastructure, which is currently one of the most polluting dimensions. This aspect gained significant prominence in the policy discourse over the last decade. Less discussed 'is the role of the built environment

in defining the spatial playing field for all other dimensions of the economy that aim to go circular. The 'circular city' has, as the car-oriented or the pedestrian-oriented city did, a specific urban form and structure as well as a dedicated infrastructure system' (Remøy & Wandl, 2022, p. 128).

Due to industries' predominant emphasis on enhancing production efficiency and seeking material and energy synergies with other firms, there exists a limited understanding of how to effectively incorporate large-scale industrial symbiosis, reuse, sharing, and recycling practices into urban environments, all while enhancing the overall quality and liveability of these urban spaces (Remøy & Wandl, 2022).

One of the few exceptions that deal with the functional aspects of the built environment is the study of Hausleitner et al. (2022), which puts forward three ways of addressing manufacturing, and by extension, circularity, within urban areas: material flows and technology, spatial design and people and networks.

Table 5. Indicators in the Built Environment dimension

Indicator	Description
The physical built environment	*Ambition: …Modular, biobased, and other forms of circular construction of buildings are discussed and are in the planning phase.*
	Niche: *...The first buildings using circular construction methods have been built and seen as exemplary cases.*
	Accelerating: *...Circular building practices are integrated in building regulations and are becoming widespread practice; first exemplary circular infrastructure projects and open space projects are being developed.*
	Mainstreamed: *Circular construction of buildings, open spaces and infrastructure is standard.*
The functional built environment	*Ambition: .. The spatial conflict between different functions relevant for the transition towards a CE is discussed in planning processes.*
	Niche: *... Experimental zones for multifunctional areas, and circularity initiatives are provided, supported, and developed.*
	Accelerating: *...A network of places and supporting infrastructures, that provides spatial qualities and potential for synergies that are relevant for circular activities, through multiple value chains is identified, preserved, and developed.*
	Mainstreamed: *...A network of places and supporting infrastructures, that provides spatial qualities that are relevant for circular activities, through multiple value chains is established and further adapted and expanded.*
The regeneration of Wastescapes	Ambition: *...There is a discussion about the regeneration of wastescape.*
	Niche: *...Wastescapes are seen as a potential for spatial development, and discussions on regeneration projects are taking place.*
	Accelerating: *...Reappropriation and regeneration of several wastescapes are taking place*
	Mainstreamed: *...There is a program to regenerate wastescapes implemented and measures to avoid the generation of future wastescapes are in place.*

Furthermore, in the built environment dimension, we include the regeneration of wastescapes as a means to reactivate underutilised areas to integrate functions needed for circularity in a biodiverse landscape (Amenta & van Timmeren, 2018). Wastescapes emerge as outcomes of unsustainable linear growth processes and their spatial implications in urban metabolic flows and associated infrastructure. They constitute the functional framework for waste management, encompassing Drosscapes and engendering intricate interconnections with the surrounding territory and its services (Amenta & van Timmeren, 2018). Considering waste as a resource, in fact, has become a useful argument in order to move from theory to practice. While experiences taking advantage of waste flows are underway, the transition to practice appears more demanding

with respect to wastescapes. The initial step towards achieving this transition involves increasing citizens' awareness of wastescapes within their urban region and fostering their ecological sensitivity to shift their perceptions. When this adaptive awareness is widely adopted, it can stimulate shared visions of development that are instrumental in initiating wastescape regeneration processes (see Table 5).

First Applications of the Self-Assessment Tool

The self-assessment tool underwent intensive evaluation through a multi-faceted approach. Initially, it was deployed within the context of the Horizon 2020 REPAiR project in Autumn 2020, encompassing five European case study regions (Amsterdam, Naples, Łódź, Hamburg and Pécs). Before the workshops, which lasted approximately two hours, relevant stakeholders from the Peri-Urban Living Labs were engaged, ensuring their familiarity with regional circularity challenges and the specific cases of city regions. These stakeholders received pre-workshop handouts detailing dimension descriptions. Each workshop commenced with a comprehensive presentation on the dimensions and a Q&A segment. Subsequently, stakeholders provided recommendations concerning dimension definitions. A dedicated session lasting 90 minutes facilitated in-depth discussions and evaluations of city regions in relation to specific dimensions and their sub-dimensions, allocating twenty minutes per dimension. Upon concluding the discussions, consensus-based sub-dimension scores were established and visualised using a spider diagram.

Additionally, the tool's capabilities were presented at three virtual conferences to garner feedback. As a result of these engagements, the fifth dimension, termed 'built environment', was incorporated into the tool. Post this inclusion, another workshop series was conducted between July 2021 and February 2022, aimed at achieving two objectives: validating prior assessments and evaluating the newly introduced dimension with stakeholders. Both original and new stakeholders, the latter being unaffiliated with the REPAiR project, were incorporated into this subsequent workshop series. Despite the inclusion of new stakeholders, the format and approach mirrored the inaugural series, which, as the authors contend, facilitated assessment validation. We present here the results of the applications in Amsterdam (NL) on July 14, 2021, and Tomaszów Mazowiecki (PL) on April 7, 2022.

The Amsterdam Metropolitan Area workshop

The Amsterdam Metropolitan Area (AMA) workshop included 10 participants: one owner of an SME, one employee from one of the largest developing companies active in the Amsterdam Metropolitan Region, a policy maker from Amsterdam, and academics from three Dutch and one Belgium University. All participants were active in the field of circularity in their respective institutions. Figure 2 presents the aggregate self-assessment results of this workshop. Several observations made during the workshop are worth reporting. First, 8 participants is a group size, where discussions can still be organised so everybody is heard. For larger groups, we propose splitting them into subgroups and adding several rounds of discussing the results across groups, explicitly focussing on those aspects where there is disagreement. During the workshop, it became very apparent that only some participants were in the state to provide an assessment on each of the aspects, which is fine and was to be expected. We encourage the facilitators to refrain from asking participants to provide an opinion if they feel uncomfortable with it. Considering this point, it's essential

to acknowledge that the value shown in Figure 2 represents, for some of the aspects, the mean of 2 and, for others, the mean of 10 respondents. Another limitation is clearly that the representation of the mean value averages extremes. In the case of the AMA, the most significant difference in the assessment was 1.5 points for the aspect of ordinary life practices; all other aspects were scored more equally by the participants.

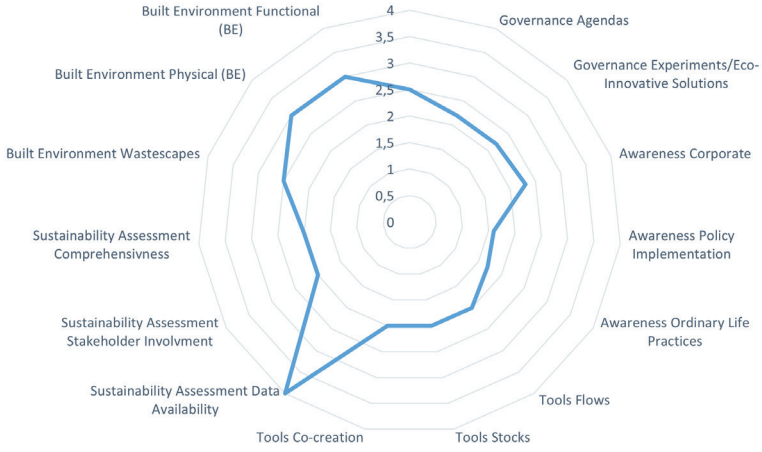

Figure 2. Visualisation of the self-assessment tool from the AMA workshop
Source: authors own elaboration.

The Tomaszów Mazowiecki-Opoczno workshop

The tool's testing in Poland occurred within the Functional Urban Area of Tomaszów Mazowiecki-Opoczno. A gathering of 13 local government representatives, collaborating under this initiative, was organised at Tomaszów Mazowiecki's City Hall. The important goal was to introduce the CE concept, covering understanding, implementation, and monitoring – a significant step as the region was beginning to adopt this concept formally. One key takeaway from the workshop was the crucial emphasis on introducing the subject despite the varying levels of familiarity among participants. This necessity became evident during the earlier tool testing phase, where a lack of shared understanding posed challenges in providing answers during an online survey conducted with institutions involved in the REPAiR project. The meeting delved into discussions on various dimensions (Fig. 3), accompanied by examples, indicators, and study stages. Another important conclusion highlighted the value of fostering open discussions and allowing for corrections when participants encountered new concepts for the first time. The methodology adopted involved discussing individual answers after representatives from each local authority had responded, allowing respondents to validate given indicators after learning from other partnership members' answers. This approach expanded comprehension, leading to more precise answers and the identification of Polish practices reflecting CE principles in everyday actions. Furthermore, it facilitated a two-dimensional self-assessment: assessing the implementation of CE ideas within local government activities and exploring potential cooperation within the partnership – a crucial aspect within the framework of the Functional Urban Area.

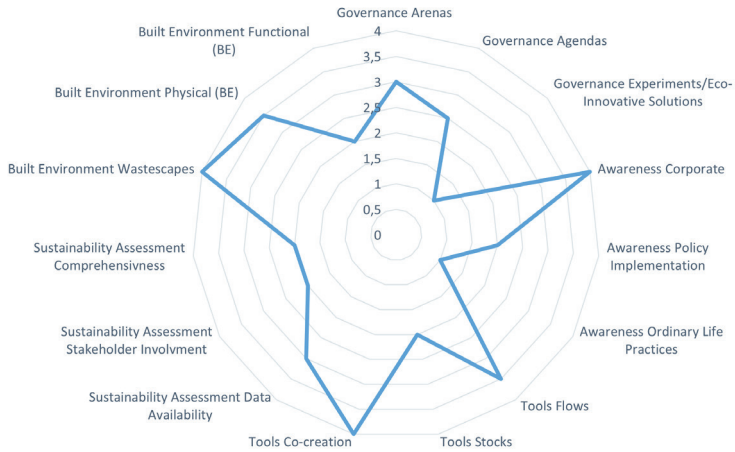

Figure 3. Visualisation of the self-assessment tool from the Tomaszów Mazowiecki-Opoczno workshop
Source: authors own elaboration.

The tool's fourth application was in the realm of online professional education. Specifically, it was utilised in the 'Spatial Circularity Strategies for Sustainable Regional Development' course offered by TU Delft on its digital education platform. Professionals working or aiming to work on circularity transitions employed the tool during preliminary studies to gauge the progress of their respective case study cities towards circularity. Course participants were given a preliminary version of this paper, a 15-minute explanatory video, and an Excel template to represent the tool's outputs visually. The culminating discussion involved the course instructor and spanned two hours in a digital environment. Although only a handful of learners could facilitate a full-fledged workshop with ample stakeholders, many employed a combination of policy analyses and interviews for their assessments. Following the course's third iteration, we have amassed results from over 20 cases spanning all continents. Several of the learners have reported that they have been using the tool in their practice afterwards.

Conclusions and discussions

During our workshops, we sought feedback from participants. Most responses indicated a positive impression, pointing towards potential areas for refining and broadening the tool's application. The primary function of the tool is to facilitate dialogue among stakeholders, allowing them to deliberate on prevailing practices, share individual activities, and identify both collaborative opportunities and potential areas of conflict. Intriguingly, many stakeholders emphasised the value of the dialogue itself, sometimes over the tool's outcomes. This revealed instances where stakeholders were unaware of the activities of their peers, underscoring potential knowledge compartmentalisation and suggesting gaps in communication across various organisational levels. Nonetheless, a consensus was often reached regarding the present state, with stakeholders recognising dimensions and elements of mutual interest for future endeavours. Concerns arose about the representativeness of workshop attendees, ensuring participants were adequately informed, and a desire for more in-depth discussions.

While we had initially contemplated using the tool for benchmarking, it became clear this approach had its pitfalls. The personal perceptions of stakeholders influenced their self-assessments. This subjective lens meant the same situation could receive varied evaluations across different contexts. Preliminary observations, though drawn from a limited sample, suggested cities perceived as frontrunners might rate themselves more favourably than cities viewing themselves as less advanced. Consequently, we advise caution if considering the tool for benchmarking purposes.

The CETSA tool aims to support decision-making processes for transitions towards more circular urban and regional models. While it offers a unique approach compared to existing benchmarks, emphasising a more integrative and co-creative perspective, its applications have limitations. It focuses on certain overlooked aspects of CE transitions, such as governance structures, public and corporate awareness levels, and the intricacies of material flows. However, a thorough critique and comparison with the established sustainability assessment methods are warranted.

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In Memoriam Prof. Konrad Czapiewski

This manuscript and numerous others within the REPAiR project are the product of a cross-national collaboration involving authors from six European countries and various academic institutions. As the Polish REPAiR team leader, Konrad was pivotal in cultivating an open academic exchange and inclusive environment. His dedication to interdisciplinary collaboration and his enthusiasm for transcultural research were cornerstones in establishing the project's collegial ethos and a lively community, which, in turn, fostered lasting collaborations and friendships. His intellectual contributions and spirit of cooperation will be enduringly cherished in our collective memory.

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