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Indicators for the Circular City: A Review and a Proposal

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Abstract: The theme of the circular city is currently much debated in the literature as a possible strategy for achieving sustainability in urban areas. However, as a recent development it still has many features in the making, one of the most important being the issue concerning monitoring and the tool through which to achieve it. In the paper, therefore, the "indicator" tool is explored in depth. Metrics represent a fundamental and complex aspect that is foundational to measuring and quantifying the progress of results achieved with respect to the goals set. Currently, most existing indicators are associated with specific aspects of the circular economy; there have been few examples of indicators designed to assess the circularity of an entire city. The paper aims to identify priority themes and describe a set of indicators to be used at the urban level. In the absence of an established reference frame, themes and indicators were identified through a methodology starting with an extensive literature search and careful analysis, including statistical analysis, of the scientific literature as well as international and European strategies on the subject. A particular result of this research is the definition ofa minimum set of indicators common to all cities, which can be applied for comparative purposes.

Keywords: urban sustainability; circular cities; indicators

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1. Introduction

The topic of the circular city is currently much debated in the literature and is seen as one of the possible solutions for achieving sustainability in urban areas. The transition to circular cities is at the center of this debate. Specifically, this transition involves the creation of an integrated city in which the principles of circular economy are applied to all local government divisions, in a process facilitated by political initiative and support that through good example promotes change among residents and various stakeholders. Thus, the basis of this vision is the employment of circular economy ideals, which include in their foundational design the concepts of second use, remanufacturing, efficient use of resources, elimination of waste, avoidance of toxic materials, and improving and making sustainable waste management through the utilization of the 9Rs strategy (reduce, reuse, recycle, recover, reject, repair, refurbish, remanufacture, and reuse) [1]. It has been reported that by applying the circular city model, Europe's gross domestic product (GDP) can be increased by 7%, with yearly savings of 600 billion euros, benefits of 1.8 trillion euros each year, and the creation of 170,000 jobs by 2035 [2]. Furthermore, carbon dioxide discharges could be diminished by 48% by 2030 and 83% by 2050 [3]. Over a similar period, raw material utilization can be decreased by 32% and 53% [4]. This study framework applies analysis at the city level, discretizing it into key sectors for the transition which were identified in the Circular Economy Action Plan (electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water, and nutrients). These sectors are key because they have the greatest potential for circular innovation, the greatest environmental impact, and the greatest demand on resources. For each of these sectors, there is a need to be able to close the loop, as well as to create circular activity in general that

connects the different sectors. However, effective circular planning and decision-making requires an understanding of the flows of materials and energy that leave and enter cities, and are consumed, processed, or stored there. The ability to collect and analyze this data helps to identify where and how to intervene and which circuits to close, provides cities with information about their economic activities, and allows them to link current initiatives and their potential to make the city more circular. In this context, identifying operational indicators is a priority for cities to plan their transition to circularity, to understand what parameters can be measured and where the population and other actors in the cities can have the greatest impact [5]. Today there are several tools that have been adapted for assessing circularity in urban settings, but few that have been designed specifically for the purpose. However, this is an important area for development as the fielding of a circular model needs a tool that can take into account the multidimensional impacts involved. Above all, such a tool should include all the actors and the various sectors that are involved in the process. This requirement is fundamental [6] to oversee and weigh the positive and adverse consequences [7–9] and balance them against the commitment of every actor involved (public administration, research, merchants, companies, and population). This appraisal instrument should be able to overcome the constraints of the ongoing financial methodology [10], by "catching" social perspectives. Moreover, renewal and change of the regulative and administrative structure is expected to help the shift to circularity [11]. Cities currently play a dominant role in the world economy; they are not only the centers of present-day living and the centers of gross domestic product production, but are also greatly responsible for the consumption of natural resources, greenhouse gas production, and waste. It is natural, then, that research continues to focus on attempts to improve existing urban conditions. As previously mentioned, to try to limit such harmful effects, it would be desirable for cities to become ecosystems in which closed cycles predominate, so that no waste is produced. This would lead to improvements in several areas, including ecological footprint and greenhouse gas emissions, urban safety, and public health [12]. This goal is facilitated by the fact that cities are centers where progress, sharing, experimentation, and encounters are favored, therefore where solutions to the social, economic, and environmental problems of our time are more likely to be found [13]. However, for such progress to be called sustainable, which it should be, there is a need for cities to change and to do so quickly. Such change to date has been brought about by the enforcement of the circular economy in urban settings to achieve what is called a circular city. Underlying this concept is the need to create closed and regenerative cycles that can optimize use of available resources while avoiding production of waste: "A circular city is one that promotes the transition from a linear to a circular economy in an integrated way across all its functions in collaboration with citizens, businesses and the research community. [. . .] to improve human well-being, reduce emissions, protect and enhance biodiversity, and promote social justice, in line with the Sustainable Development Goals" [5]. At present, the concept of the circular city encompasses within it several others, most relevant of which are those of the smart city and the resilient city. The concept of resilience has been expanded from its original meaning, that is related solely to the ability to adapt to a natural event, including man-made events within the definition. This concept is taken up in the Urban Agenda and is fundamental to risk reduction. The smart city concept, on the other hand, is currently widely used and defines cities based on their ability to resolve problems such as crime, traffic congestion, inefficient services, and economic stagnation. According to the European Union's definition: "A smart city is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and businesses".

Therefore, this study paper approaches the topic of circular cities by identifying indicators common for all cities, so that they can be compared with each other.

2. Materials and Methods

2.1. The Importance of Indicators in a Circular City

The European Commission, with 75% of its citizens living in urban areas [14], has understood the potential that the circular economy can have for its cities. So, in accordance with the commitments made with the adoption of the "Action Plan for the Circular Economy" in April 2017, it launched a working group to create a set of indicators to measure the levels of "circularity" in 27 European countries. In January 2018, it adopted the "Circular Economy Observational Framework," which turned out to be well thought out for estimating progress towards a circular economy. This tool addresses different aspects at all stages of the lifecycles of renewable and nonrenewable resources (materials, water, and energy) used in products and services [15]. This model of the circular economy consists of ten indicators, some of which are themselves divided into a number of sub-indicators, divided overall into four thematic areas: Production and Consumption, Waste Management, Secondary Raw Materials, and Competitiveness and Innovation. The ten indicators have been designed to provide a general overview of some of the key elements required to succeed in increasing circularity in the EU economy [15]. The Green New Deal of January 2020 emphasized the central role of these issues by putting the circular economy at the center of its policies aiming to achieve the goals agreed in Paris in 2015. This Circular Economy Action Plan defines a future-oriented agenda to achieve a cleaner and more competitive Europe, implemented through co-creation conducted by economic actors, consumers, citizens, and civil society organizations [16].

It is therefore clear that to be successfully complete urban ecological transition through the concept of a circular city, one must consider technical and also social elements. The circular city is not only an economic model for the efficient management of resources, but offers a holistic model for the promotion of environmental sustainability and the improvement of social cooperation between the actors involved. Regarding elements of a more technical nature, as well as aspects of a purely economic nature, indicators are currently attracting particular attention. How to measure circularity in the urban context is one of the questions frequently asked in the recent literature, and the answer is by no means obvious. Indicators are invaluable both for analyzing the impact of new legislative or regulatory proposals and also for assessing the posthumous effectiveness of the measures adopted, as city populations must understand how their decisions impact both themselves and the environment around them, to assess the expected, achieved and missed targets for cycle closures [5]. Thus, circularity indicators should be considered, which although not designed for direct application to the city, can nonetheless provide a good picture of some of its areas. In the context of circular cities, we need to think about defining what we consider relevant as well as thinking about what can be measured and is worth measuring [17]. Some indicators have been made available for circular cities [18]. However, it is often not possible to apply these indicators, because of a lack of data or because similar analyses have been carried out using different indicators that do not allow for comparison and monitoring [19]. Therefore, it is essential to capture the important aspects of a city in its various areas of activity, and for each of them to identify indicators that are universal and allow comparison between different sectors and case studies [20]. The indicators described in the literature and those proposed as part of circularity initiatives cover at least environmental, social, economic and cultural aspects. However, features related to a city's circularity are not fully measurable and therefore require specific indicators which may be subjective and qualitative. Although each member state is subject to binding EU targets, there is currently no set of indicators shared on either a national or European scale. The lack of a widespread participatory implementation strategy makes these targets difficult to achieve. There is a need to create a shared base of data and knowledge, that can measure the effectiveness of actions implemented in urban areas, by measuring flows, to identify where and how action can be taken towards the closing of cycles, provide the city with a clear vision of the policies in place, and secure the involvement of relevant actors. Aiming to identify levels of

depth, steps to evaluate the level of the circular economy in a city can be developed from various analyses:

1. Quantifying the circularity of the individual proposed project with respect to the issue in which it fits;
2. then, assessing the impact of the project with respect to priority issues such as mobility, waste, energy, and reduction of inputs (land, water, and energy consumption) and outputs (waste and pollutant production);
3. finally, considering the urban neighborhood, it is essential to assess impacts on different related priority issues (waste, mobility, energy, etc.) to finally quantify the different projects implemented in the area.

Therefore, this study aims firstly to implement a reconnaissance of the existing indicators used in the literature, and secondly to propose a useful set of indicators to evaluate circularity at the urban level.

2.2. Proposed Methodology

The objective of this research paper is to identify indicators useful for monitoring actions aimed at planning a circular city. To do this we initially investigated the literature, including strategy documents, to identify indicators that are currently in use. These indicators were separated within a framework according to the different priority areas at the urban level. In particular, the review was carried out on scientific publications that dealt with the topic of circularity and referred to indicators (research carried out in 2019 by the University of Naples Federico II [21] was developed and implemented using data provided by 46 publications). Specifically, the search was conducted on scientific articles published in *Sustainability* and *Science Direct* from 2015 to 4 April 2022 by running an analysis for the keywords "circular city" and "indicators."

The approach began with investigation of the literature and the main documents and strategies, to identify the indicators currently used in relation to circularity. These indicators were categorized within a framework according to the different priority areas at the urban level. A structure was then applied through which information was gathered about these indicators, the key sector they refer to, their unit of measurement, the country of publication of the article, and number of relevant articles found. The following were identified as key sectors: Built environment, organic material and biowaste, energy, mobility, electronics and ICT, packaging and plastic, textiles, and water. Three other sectors were also identified that cut across that list; namely, the environmental dimension, economic and financial dimension, and social and cultural dimension. This database was designed to be implemented in Office or Excel as an updatable and implementable tool. An extrapolation is given below (Figure 1) and, for the purpose of providing a practical example, in the form of a table in Appendix A (Tables A1 and A2).

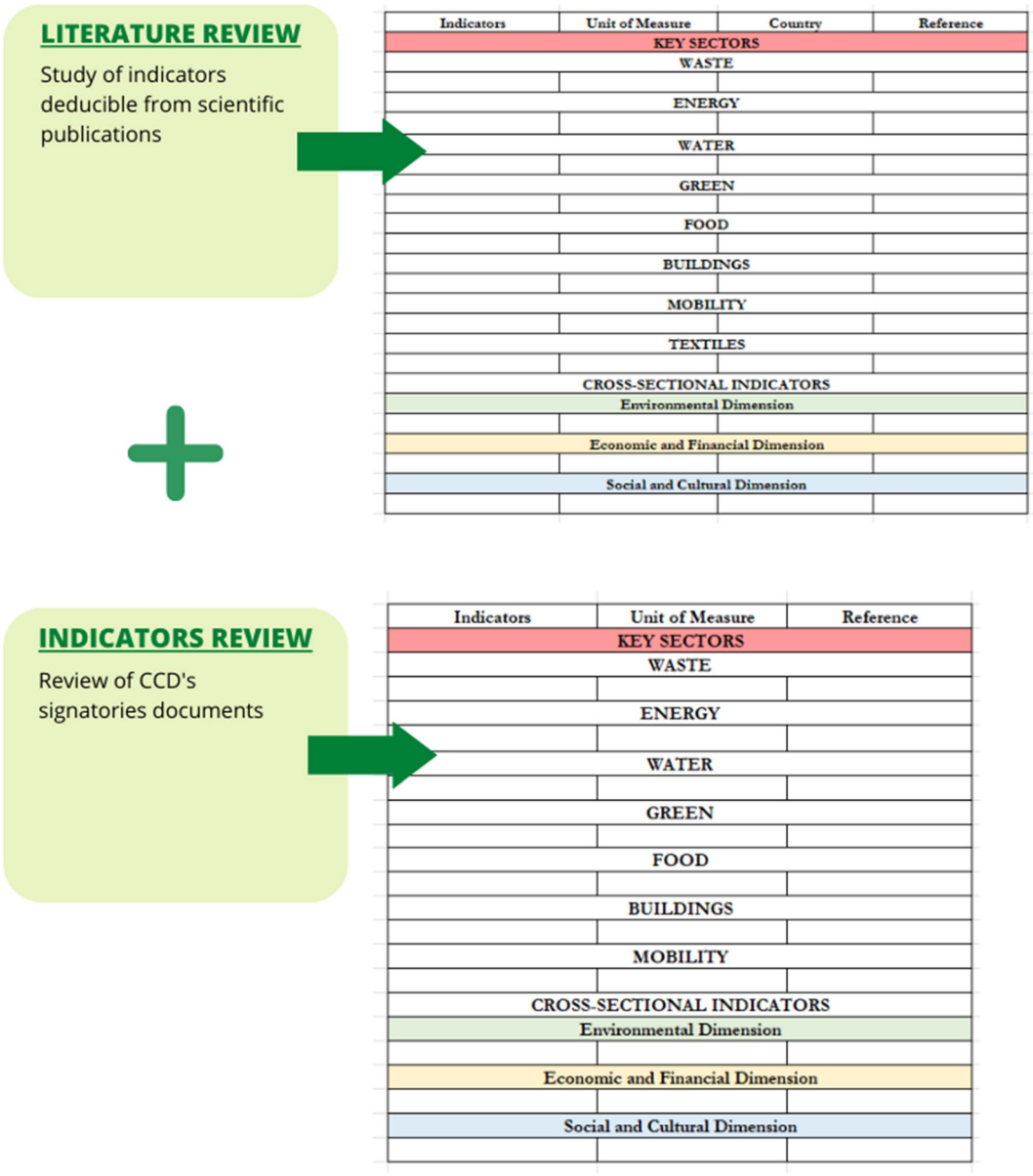

Figure 1. Proposed methodology.

Subsequently, the process continued by considering the indicators present in the international landscape, focusing on official documents issued by some of the signatory cities of the Circular City Declaration. This choice was made as it was deemed important to focus on the analysis of those cities that have already declared their commitment to circularity. The Declaration of European Circular Cities is a crucial tool in the changeover to the circular city, and was relaunched on 1 October 2020 at the European Sustainable Cities and Towns Conference in Mannheim. It was created to ensure that the transition from a linear to a circular economy can be accelerated, by having signatory cities commit to and, importantly, pioneer this new vision. This declaration stems from the idea that the methodical passage to a regenerative economic model is crucial if climate neutrality is to be achieved, a sustainable society promoted, and resource consumption contained within planetary limits. Among the difficulties encountered during the literature search was that indicators capable of capturing relevant aspects of the circular city have often been often used with extremely specific applications related to individual projects, and have not been applied to the urban context as a whole. Moreover, in some cases these indicators appear similar but are not identical, and different units of measurement make

their comparison and identification more difficult, while for others the unit of measurement is obscure. When it came to the analysis of official documents, the difficulty encountered was different. In cases where such documents exist, they do not always provide a clear view of the studies behind them, often they contain no reference to the indicators used, if indeed they were used. In the end, the two lists that were produced contained some 295 indicators for analysis.

However, despite difficulties related to the non-homogeneity of the material present, through the analysis of the indicators we are able in this paper to propose a possible selection of indicators that takes into account the aspects mentioned above, and is directly applicable to different urban realities. As already mentioned, the need to focus analysis on the key sectors of the city makes it necessary to break down the indicators in the different sectors under consideration. In this perspective it is therefore also necessary to have a tool that can assess the multidimensional impacts created in the different sectors for all the actors involved [6]. The indicators that are proposed have therefore been selected based primarily on the number of sources found for these indicators, therefore including those that are already most widely used in the literature and official documents. Secondly, we avoided selecting indicators whose unit of measurement was unclear or even unknown. Finally, indicators were chosen with their applicability in the urban context in mind while maintaining their division into the key priority areas (waste, mobility, energy, etc.), for application at the neighborhood or urban area scale. Again, a table is presented within which are listed indicators, the key sectors they belong to, and their units of measurement. In addition, these indicators were chosen by reasoning about the impacts of the key sectors, cross referencing waste versus energy, water, mobility, etc., thus allowing database users to search for indicators by themes of interest. This database was also designed to be accessible in Office or Excel, for easily updating and implementation.

3. Results

Based on the creation of existing indicator databases and their in-depth analysis, despite the various difficulties encountered and mentioned above, 33 indicators were selected that can be applied to urban realities with different conditions. Criteria for the selection of these indicators first included the number of sources found that propose the use of the specific indicator; those that were already most widely used in the literature and official documents were adopted. Second, indicators were chosen whose unit of measurement was clear and easily measurable (and thus monitorable). Finally, it was essential to consider their applicability in the urban context by their breakdown into key areas (this necessity emerged because of specific analysis).

3.1. Databases Existing Indicators

In terms of the presentation of the research results, as illustrated at approach level, the studies of existing indicators were divided into two different databases, the first created from scientific publications, and the second from official documents produced by various cities. All the implementations made are reported in the Appendix A, dedicated to this purpose to allow greater readability of the text. Seven different tables are provided; the first table is related to the circular cities indicator database deduced from the scientific publications mentioned above.

Additional indicators cross cutting those previously mentioned were then identified as encapsulating the whole selection, i.e., environmental, economic and financial, and social and cultural dimensions. Table A2 of Appendix A shows the indicators found in the literature, separated for these three cross-cutting indicators.

To identify the priority indicators in order to focus on measuring circularity at the urban level, the criteria identified by the proposed approach (see Section 3) were applied. To do this, the indicators shown in Tables A1 and A2 in the Appendix A were analyzed and a series of statistical analyses were conducted, described below.

First, analysis was conducted to assess the key sectors concerned (Figure 2). The most frequently used were related to energy (23.9%), waste (21.1%), and water (12.7%). Continuing to investigate the cross-cutting sectors, in first place with as much as 50% were those concerning the social and cultural dimension (Figure 3). This may be significant in that it underscores how research is not currently focused on technical or economic aspects compared with the social side, thus paying special attention to the wellbeing of the population and the quality of services offered by the city.

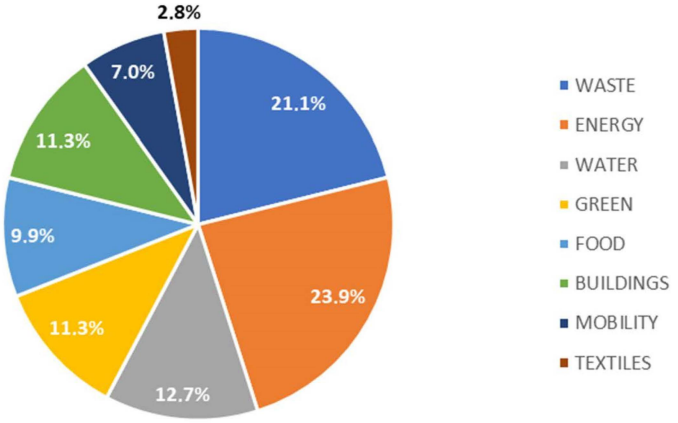

Figure 2. Analysis of indicators and key sectors.

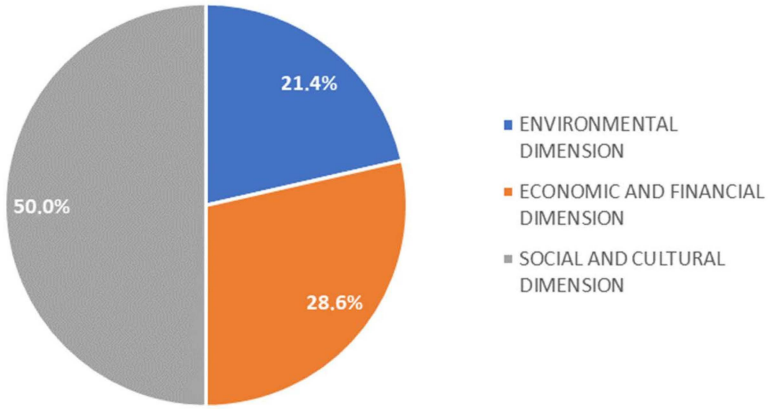

Figure 3. Analysis of indicators and cross-sectional sectors.

For the creation of the second database, indicators found in official documents published by 10 signatory cities to the Circular City Declaration were studied in depth. Currently, 60 cities have already signed the Declaration of European Circular Cities, thus demonstrating their leadership in picking an asset-efficient, low-carbon, and socially capable method of improvement, but for only 10 of these could relevant official documents be found online, shown in Table 1.

The main difficulty encountered during the analysis of official documents, after first finding them, was that those that do exist do not always provide a clear view of their objectives and the indicators they intend to use to achieve them. Tables A3 and A4 of the Appendix A provide the data showing the indicators that were found, separated into key sectors (see Appendix A, Table A3) and cross-cutting sectors (see Appendix A, Table A4).

For the indicators presented in Tables A2 and A3, analysis was again conducted by separating them according to key sectors (Figure 4) and cross-cutting key sectors (Figure 5). As can be seen in the first pie chart (Figure 4), the breakdown obtained was found to be comparable to that shown in Figure 2, including the percentages of each sector. In general, among the indicators deduced from scientific articles and those from official documents, in the first five positions were the categories of energy, waste, mobility, water, and buildings.

On the other hand, regarding the comparison of cross-sectoral sectors, shown in the graphs in Figures 3 and 5, the greater attention given to the indicators deduced from scientific articles for the economic-financial sector could be a further indication that, as already mentioned, these indicators were very often found in publications specifically related to individual projects in the business field, and not generally those related to the urban context as a whole.

Table 1. Circular City Declaration: city and official documents on circularity analyzed.

City (Country)	Document Name
Glasgow (United Kingdom)	Circular Glasgow [22]
Ljubljana (Slovenia)	Roadmap towards the circular economy in Slovenia [23]
Maribor (Slovenia)	Roadmap towards the circular economy in Slovenia [23]
Oulu (Finland)	Making City [24]
Paris (France)	Circular Paris [25]
Prague (Czech Republic)	Circular Prague [26]
Rotterdam (Netherlands)	Circular Rotterdam [27]
Tampere (Finland)	Carbon Neutral Tampere 2030 Roadmap [28]
Tirana (Albania)	Green City Action Plan of Tirana [29]
Umeå (Sweden)	The Circular Economy in Umeå, Sweden [30]

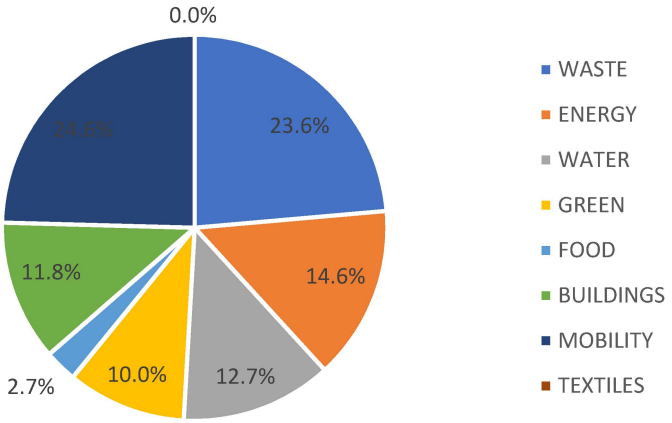

Figure 4. Breakdown by key sectors of indicators deduced from official documents.

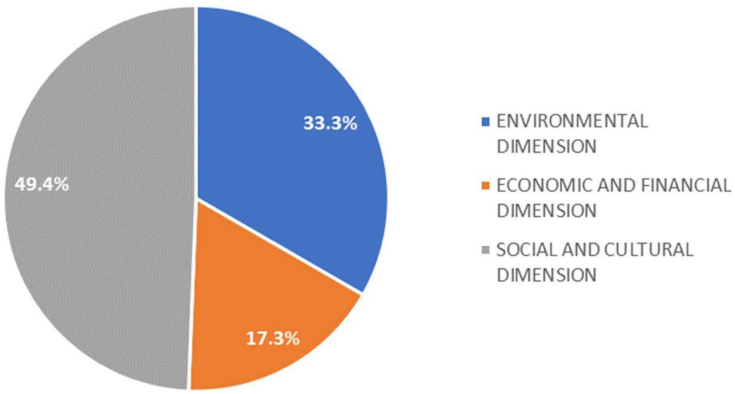

Figure 5. Breakdown by cross-cutting sectors of indicators deduced from official documents.

For these indicators, moreover, it was decided to assess whether any relationship existed between their number and the sizes of the cities from which they were taken, in terms of number of inhabitants (Figure 6). From this analysis it can be seen, for example, that the number of indicators was the lowest for the largest city examined, i.e., Paris, and reached its maximum for the medium-sized city of Tirana. This supports the idea of proposing a minimum set of indicators applicable to all cities regardless of their characteristics, which can thus allow comparison of their progress and planned actions.

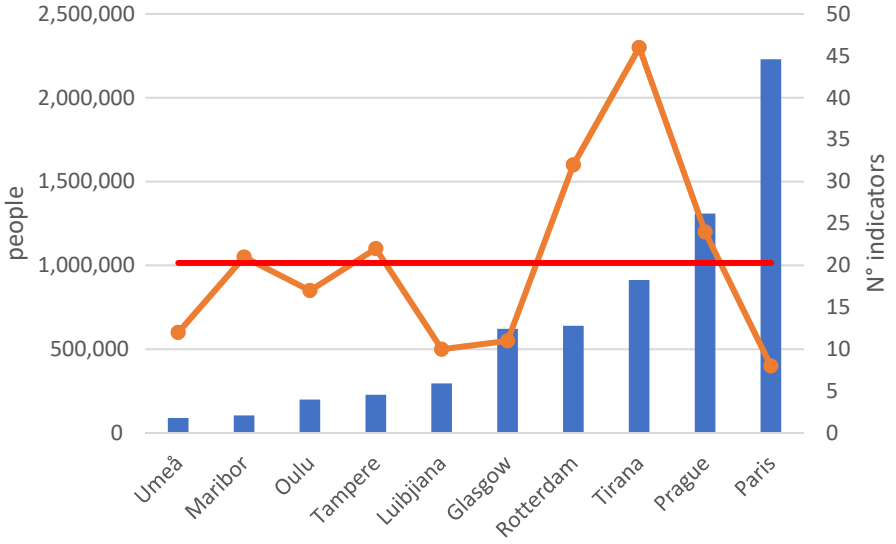

Figure 6. City size and number of indicators deduced from official documents.

3.2. Proposed Indicators

Following the obvious need for indicators quantifying the circularity of a city, it was decided to propose a selection of indicators (see Appendix A, Tables A5 and A6). Aiming to enable in-depth analysis on a neighborhood/urban area scale, the database of indicators that was designed was divided into the key priority areas identified in the urban sphere (waste, mobility, energy, etc.), in order to assess their impacts on each priority issue, and to arrive in conclusion at a unified vision of the different issues in the urban sphere. As mentioned above, it is indeed particularly important to consider the interaction of the various sectors with each other, so that we can respond to an organic issue with tools that are designed for organic use. It was also decided to select some of the transversal indicators (environmental, economic and financial, and social and cultural dimensions) while maintaining their characteristics of transversality, with a view to being applied at lower thematic or project levels. This route was taken because, as mentioned earlier, the circular economy also incorporates effects that refer to the social and environmental dimension, in addition to the economic dimension. Therefore, research in the urban context cannot be exempt from monitoring these sectors since they represent additional concerns and influence various aspects of the decisional procedures.

Through the analysis of the indicators examined, it was possible to propose a selection of indicators useful for assessing the circularity of actions planned and subsequently implemented in a city. From the analyses reported in Section 3.1, specific key areas emerged to be considered for assessing the circularity of urban areas, i.e., waste, energy, water, built environment, and mobility. These indicators were identified also for consideration of their applicability to different urban realities.

In addition, to make it easier to use the database and thus to improve the analysis and collection of data for measuring indicators, it was decided to group the data according to these five areas. The data can thus also be analyzed cross-sectionally, to evaluate the impact of, for example, waste compared with energy or mobility. In addition, indicators were considered for the so-called cross sectors (environmental, economic–financial and

social–environmental) and a sector was added representing the crossover of those mentioned above, for further analysis of results from the territory under consideration. This choice was motivated by the fact that, in this researcher's opinion, to promote sustainable innovation it is necessary to ensure that each city incentivizes and fosters the development of patents for advanced and sustainable technical innovations. In this sense, therefore, these areas represent very important sectors for evaluation when analyzing the circularity of an urban area.

All indicators were selected keeping in mind the definition of circular city described above. Based on the discussion in the literature and in case studies, these 33 indicators (20 for the identified key sectors, 13 for cross-cutting key sectors, and a single indicator for certifications) thus attempt to describe some of the different aspects by which circularity in a city is defined and their interactions with one another. Moreover, these indicators are designed to be quantified initially at the smallest scale (neighborhood) and then later to be re-proposed at larger scales (urban, municipal).

The motivation for this work and the creation of the dataset was to identify indicators as generic as possible, so that through the systematic use of this tool the circularity of any urban reality can be determined. Moreover, the design provides adequate differentiation between the areas under consideration that involve various problems and particular needs. The differentiated and simultaneously general character of these indicators have makes it possible for them to be compared among different case studies. Precisely with this in mind, this tool has been designed to be applied on a national or, even better, a European scale, where it can create a common basis that allows the evaluation of how an urban reality is positioned in the international panorama in relation to the other realities present. As far as specific cases are concerned, we refer instead to the possibility of using, in parallel with those proposed, indicators that are instead more pertinent to the context under consideration and therefore designed specifically for it. Moreover, it would be useful in general to be able to identify a circularity index from these indicators, to qualitatively assess the trends of urban transition in different cities examined. A particular problem that has not been addressed in the course of this work, but which must be kept in mind during implementation, is that of the necessary data collection. Data should be collected from the different sectors, requiring contact with the various bodies involved in their collection, and finally arriving at the creation of a common database for public access. This vision is, unfortunately, still far from being achieved, since the bodies responsible for these measurements at the sub-national level differ in their natures, leading to confusion caused by different definitions of indicators, lack of shared protocols in the construction of "elementary indicators", and consequent loss of relationship with the local context [31].

Precisely for this reason, indicators at the local level must remain as close as possible to those designed at the national and European levels, and should only later be specified at the detailed urban scale.

4. Discussion

This report shows that the changeover to the circular city is ongoing in its development, and that several key issues are still being researched, for example, the question of indicators. In this regard, as mentioned earlier, the assessment of circularity in urban areas is a multidimensional task that must necessarily consider all the dimensions and sectors involved. There is a need for an integrated assessment tool that can represent all the sectors involved, incorporate the relational aspects between the sectors, and capture their multidimensional impacts.

As seen in the previous chapters, effective tools to monitor and evaluate circularity in the urban context have been lacking. Within the scientific and international literature, examples can often be found relating to very narrow contexts (business applications, individual projects, etc.) but rarely has the topic been addressed by suggesting robust and integrated indicators.

In addition, aiming to comparatively assess propensities toward these issues, analysis was carried out into the geographical distribution of the examined papers, from which it emerged that the countries where the debate seems to be most heated are Italy (22.2%) and the United Kingdom (12.7%), as can be seen in Figure 7. In addition, European countries in general have shown strong sensitivity to the topic, providing 77.8% of the papers (Figure 8).

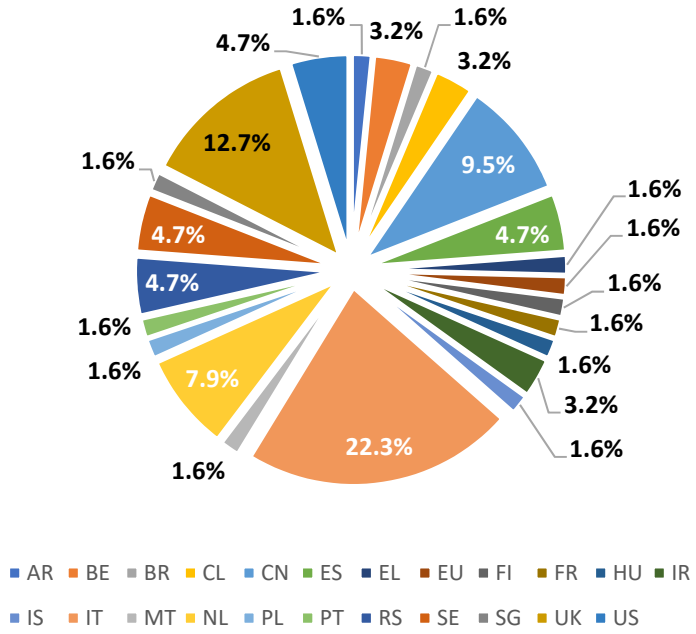

Figure 7. Distinct papers based on their country of origin.

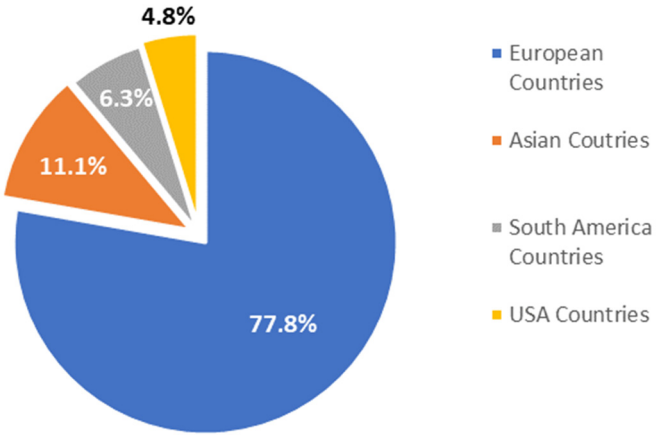

Figure 8. Distinct indicators based on their continent of origin.

Even when considering some of the more promising existing cases, the situation hardly changes. In this context we are often faced with the total nonexistence of documents that address the issue of urban circularity, or the published studies that do exist are too often lacking in detail and/or have been subject to censorship of data and topics that should be in the public domain, where they can foster the knowledge and interest of citizens and businesses.

The aim of this work, to identify indicators that are as generic as possible and therefore applicable to any urban reality, is thus confirmed as a possible solution to the problem highlighted, in that the general character of these indicators makes it possible for them to be compared between different case studies, with the intention that they be applied on a national or, even better, European scale. From these indicators it would be necessary to

create a circularity index to allow the qualitative and comparative evaluation of strategies applied in different cities.

Aiming finally to assess an initial analysis of the applicability of the proposed tool, taking advantage of the integrated assessment document on the quality of the urban environment "Cities in transition: Italian capitals towards environmental sustainability" produced by the National System for Environmental Protection [32], we undertook an assessment of how many of the proposed indicators would be immediately usable and implementable through existing numerical data. The result obtained showed that by using the database provided, 45.5% of the proposed indicators would already be implementable.

5. Conclusions

In conclusion, this study aims to bring to attention the highlighted problem and to suggest, if not a solution, at least a contribution to consider and a basis on which to build active and participatory discussion. The creation of a minimum set of indicators representative of the main sectors within the urban sphere is, in the authors' opinion, useful for comparing cities with each other, regardless of their particular characteristics, and avoiding the risk of circular cities becoming self-referential through the creation of their own indicators designed ad hoc for actions implemented by the administration. In addition, another point to keep in mind when approaching these issues is that of participation. It is difficult to imagine how these strategies can be implemented, or even discussed, without placing the citizen at their center. However, too often we are confronted with a lack of data and difficulty in accessing relevant information. Development of user-friendly tools for all would greatly shorten the time needed to reach completion of the urban ecological transition, as it would enabledirect interaction of the three pillars on which the circular city is based, i.e., public, private, and social. Within this framework, monitoring tools should also necessarily be designed to be as inclusive as possible, both with regard to the various issues under consideration and to the dissemination of information. The tool proposed here, due to its features of implementability and updatability, could be a first step in the right direction. The dissemination and use of such tools could help by providing continuous and diverse feedback, thus creating insights for new implementable and beneficial solutions with multiple scales of application.

In general, the current institutional system is often an obstacle, and even if some cities are trying to move toward the circular model, it remains a concept surrounded by some ambiguity. It is necessary to develop a strategy that can put these guidelines into practice, creating a plan at the regulatory level that brings together and communicates the various circular themes, which must integrate and coordinate with each other. Indeed, regarding sustainability, one cannot act only on individual sectors, but must develop a plan that represents common action. This plan of action must set out a forward-looking agenda co-created with economic and research personnel, citizens, and public administrators. It must present a series of interconnected initiatives aimed at establishing a strategic and coherent framework in which sustainable products, services, and business models will be the new normal, and transform old consumption patterns to make sure that we succeed in avoiding generation of waste.

Consequently, for all the reasons mentioned above, the discussion and exploration of circular city realization, and specifically means for its implementation and subsequent monitoring, is a fertile area of activity. The growing number of circular cities and increased attention to the topic will fuel further research and enable implementation and improvement of the indicators presented in this study.

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Appendix A

In this section, the six implemented tables analyzed in Sections 3.1 and 3.2 are shown.

Table A1. Circular cities indicator database deduced from scientific publications (for the years 2015–2022).

Indicator	Unit of Measure	Country	Reference
Key Sectors			
Waste			
Waste Quality Index	-	BR, AR	[33]
Waste generation	tons	BR, AR, CL, RS, IR, IT, UK	[33–37]
Recycling rate of municipal waste	%/year	US, CL, IR, SE, RS, NL, IT, FR, IS, CN, ES	[3,20,34,35,38–41]
Recycling rate of packaging waste	%/year	US, IT	[3,42]
Amount of landfilled waste	%/year or tons/year	US, SE, CL, RS, IR, NL, IT, FR, IS, CN, UK, EU, HU, EL	[3,20,34,38–40,43–49]
Percentage of material solid waste landfilled			
Percentage of household waste landfilled			
Percentage of material solid waste incinerated	%/year	UK, IT, SE	[43,47]
Percentage of material solid waste composted	%/year	CL, RS, IR, UK, EU, CN	[34,43,44,46]
Use of recycled goods in municipal administration	%/year	EU	[44]
Use of recycled goods in industrial production	%/year	EU	[44]
Percentage of material solid waste reused or recycled	%/year	EU, CN, IT, SE	[44,46,47]
Percentage of household waste reused or recycled	%/year	EU, SE, IR	[44,50]
Amount of recycled goods sold	N°/month (or year)	EU	[44]
Separated waste (recovery and treatment of waste generated in city)	kg/year	SE, US, IT, CN, NL	[20,36,46,48,51,52]
Energy			
Energy saved due to the use of recycled goods in industrial production	%/year or kWh/year	CL, RS, IR, EU, EL, IT, NL	[34,38,44,49,52]
Energy consumption	kWh inhabitant^{-1} year^{-1}	BR, AR, CN	[33,53]
Non-renewable energy use	%/year or kWh/year	UK	[43]
Renewable energy use	%/year or kWh/year	NL, IT, ES	[38,41,48,52,54]
Input (energy, materials) in production processes using renewable sources	-	SE, IR, IT	[50,51]

Table A1. *Cont.*

Indicator	Unit of Measure	Country	Reference
Input in production processes involving reused materials	-	IT	[55]
Input in production processes using recycled materials	-	IT	[55]
Output from production processes using renewable sources	-	IT	[55]
Output from production processes involving reused materials	-	IT	[55]
Output from production processes using recycled materials	-	IT	[55]
Volume (amount) of resource flow	-	UK	[56]
Amount of recycled resources	-	UK	[56]
Amount of reused resources	-	UK	[56]
Amount of resources saved	-	BE	[57]
Amount of waste heat from industry used for heating the city and for horticulture	kWh/year	NL	[58]
Amount of groundwater warmed in the earth and used to heat homes and offices	m^3/year	NL	[58]
Number of homes receiving their energy (heat and electricity) from biogas (i.e., fermenting the manure of cows)	N°/total	NL	[58]
	Water		
Water use	Mm^3	UK, IT, SE	[37,47]
Dispersion from municipal water supply	-	IT, SE	[47,48]
Water consumption productivity	water consumption (m^3)/revenues (V)	ES	[41]
Water consumption for habitation (for example, reduction due to harvesting rainwater on the roofs)	%/year or l/year	UK, IT, NL, BE, CN, US, SG	[43,52,57,59,60]
Safe water accessibility (water issues regarding treatment and distribution)	-	SE, US, UK, SG	[20,60]
Water efficiency (water issues regarding treatment and distribution)	-	SE, US	[20]
Saving water due to the use of recycled goods in industrial production	%/year mc/year	NL, EU, UK, SG, US, CN	[38,44,60,61]
Amount of phosphate recovered from sewage water	kg/day	NL	[58]
Percentage of water consumption for habitation (for example, reduction due to harvesting rainwater on the roofs)	%/year	UK, BE	[43,57]
	Green		
Utilized agricultural area—SAU	km^2	IT, SE, UK,	[47,51,62]
Number of farms		IT, UK	[51,62]
Ecological and sustainable land-use regeneration	% (m^2 of regenerated land/m^2 of abandoned land)	IT	[63]

Table A1. *Cont.*

Indicator	Unit of Measure	Country	Reference
Mixed functionality	-	IT	[64]
Permeable surface area	m^2	IT	[64]
Green space area per capita	m^2/person	IT, SE, CN, PT	[47,48,51,59,65,66]
Density of the urban fabric (sqm of built environment on the total)	-	IT	[51]
Percentage of green roofs	%/total city surface	SE, US, PT	[20,66]
Food			
- Amount of food waste treated - Food waste treated in small and medium-sized enterprises (SMEs)	%/total food waste	SE, US, IR, FI, PL	[20,50,67]
Recycling surplus food/food waste		MT, UK	[68]
Unsold products recovered every day for redistribution through the market itself or nearby community facilities	kg/day	EU	[44]
Percentage of local nutrient recovery	%	NL	[54]
Food waste	-	BE	[69]
Circular markets	-	IT, FR, IS	[39]
Buildings			
Number of new buildings	N°	IT, SE	[47]
Buildings designed for complete disassembly	N°	NL	[54]
Reuse of building components at their end of life	%	NL	[54]
Design for flexibility by using modular systems	%	NL	[54]
Recycling rate of recyclable materials and constructions	%	NL	[54]
Percentage of retrofitting interventions on buildings	%/total building	SE, US, IT	[20,63]
Percentage of degraded buildings	%/total building	SE, US, IT	[20,51,64]
Percentage of reuse or recycling of recyclable demolition materials	%	IT, NL	[52,58]
Mobility			
Public transport usage	% of inhabitants using public transport	SE, US	[20]
Electrical energy consumed in the transport sector	% of transport sector using electrical energy	SE, US, IT	[20,47]
Integration of new transport systems	-	IT	[70]
Proximity to public transport	-	IT	[64]
Pedestrian connections	-	IT	[64]
Textiles			
Low-impact and non-toxic materials used in production processes	%	NL	[54]
Sustainable materials sourced from certified or eco-verified sources	%	NL	[54]

Table A2. Database of cross-sectional indicators for circular cities deduced from scientific publications (for the years 2015–2022).

Indicators	Unit of Measure	Country	Reference
Environmental Dimension			
Carbon footprint	$MtCO_{2eq}$	UK	[37]
- CO_2 emissions - CO_2 consumption footprint - GHG emission per capita	-	BR, AR, NL, SE, IR, CN, IT, ES,	[33,38,50,53,71–73]
- Annual amount of greenhouse gas emissions, annual amount of CO_2 emissions - Percentage reduction of greenhouse gas emissions	%/year or tons/year	IT, UK, EU, NL	[42–44,74]
Air quality	mg/Nm^3	IT, NL	[48,52,65]
Economic and Financial Dimension			
Disposable income of households (improvement through reduced costs of products and services)	€/year	IT	[42]
Revenue from recycled goods sold	€/month €/year	EU	[44]
Potential value of material after recovery and re-use	€	UK	[56]
Circular economy innovation budget (in relation to platforms and businesses leading to innovation in areas of the circular economy)	%/year	SE, US	[20]
Investment costs	m^2/€	IT	[64]
Payback period (PBP)	year	IT	[64]
Green investment	-	NL	[38]
Attractiveness	-	IT	[64]
Synergies among industries	N°	SE, US	[20]
Social and Cultural Dimension			
Livability (e.g., improvement through reduction of time lost from congestion, reduction of air pollution, improved waste, wastewater treatment)	-	IT, UK, SG, US	[42,60]
Walkability (length of pedestrian path)	km	IT	[65]
Percentage of CE patents	[CE patents/total patents] × 100	ES	[41]
Percentage of CE investment	CE investment in tangible goods (V)/total investment in tangible goods	ES	[41]
Percentage of CE jobs	%	ES	[41]
- Job creation - Employment opportunities	N° of jobs	IT, EU, BE, UK	[42,44,57,64,75]
Number of events and dissemination activities about circular economy	N° of events/year	EU, IT	[44,64]
Participants in events about circular economy (including public bodies, companies, universities, research centers, professional associations, etc.)	N° of participants/year	EU, IT, UK	[44,75]
Cultural and Recreational Services	N°	IT	[64]
Socio-cultural Associations	N°	IT	[64]
Potential for cultural initiatives	-	IT	[64]
Integration of compact adaptive space design in urban strategies	Qualitative (yes/no)	IT, UK	[75]
Adoption of nature-based solutions	N° of practices in the city	IT, NL, UK	[52,75]
Attractiveness	-	IT	[64]

Table A3. Circular city indicator database deduced from official documents.

Indicators	Unit of Measure	Reference
Key Sectors		
Waste		
Amount or percentage of recycled material	Tons/year or %/year	Circular Rotterdam, Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana)
Amount or percentage of products reused	Tons/year or %/year	Circular Rotterdam, Roadmap towards the circular economy in Slovenia (Maribor)
Amount or percentage of products recovered	Tons/year, or %/year, or T/inhabitant/year, or %	Circular Prague, Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana), The Circular Economy in Umeå, Sweden
Waste diverted from landfill	Tons/inhabitant/year or %	The Circular Economy in Umeå, Sweden
Mixed waste composition	-	Carbon Neutral Tampere 2030 Roadmap
Percentage of incoming/outgoing flows	%/year	Circular Paris
Average amount of products going to landfill or incineration	Tons/year	Circular Prague
Percentage of MSW landfilled disposed of in EU-compliant sanitary landfills	%	Green City Action Plan of Tirana
Percentage of collected MSW composted	%	Green City Action Plan of Tirana
Waste reduction in production of goods–raw material efficiency	kg of waste per €1000 output	Circular Prague
Amount or percentage of waste separation	%/year or tons/year	Circular Rotterdam, Circular Prague
Increase in clean plastics and drink packaging streams from residual waste	%/year	Circular Rotterdam
- Percentage of recycling of solid waste generated in the city - Percentage of packaging waste recycled - Percentage of municipal waste recycled	%/year or %	Circular Rotterdam, Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana), Green City Action Plan of Tirana, Carbon Neutral Tampere 2030 Roadmap, Making City (Oulu)
Tonnage of waste diverted via repair, reuse, recovery, and upcycling activities (recycling centers, artisans, second-hand goods stores, fab labs, etc.)	tons/year	Circular Paris
Traceability of hazardous waste	-	Roadmap towards the circular economy in Slovenia (Maribor)
- Amount of waste produced in the city - Amount of waste generated per capita	Tons/year, or tons/per capita/year, or kg/year/capita	Circular Rotterdam, Green City Action Plan of Tirana
Amount of waste produced in the city and treated within the city itself	tons/year or %/year	Circular Prague
Amount of solid waste reused	Tons/year or %/year	Circular Prague; Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana), Circular Glasgow
- Amount or percentage of waste avoided - Amount of household waste reduced by preventing waste and encouraging reuse	Tons/year or %/year	Circular Prague; Maribor (Slovenia), Circular Glasgow, Circular Rotterdam, Circular Paris

Table A3. *Cont.*

Indicators	Unit of Measure	Reference
Amount of biowaste processed in biogas facilities	% or tons/year	Circular Prague
Share of the population with weekly municipal solid waste (MSW) collection	%	Green City Action Plan of Tirana
Difference between quantity of waste and quantity of products consumed	Tons of waste/tons of products consumed	Circular Rotterdam
	Energy	
Energy consumption of city properties	total consumption and consumption per m^2	Carbon Neutral Tampere 2030 Roadmap, Making City (Oulu)
Energy savings per year	%/year, or kg/inhabitant/year, or %	Circular Glasgow, Circular Paris, The Circular Economy in Umeå, Sweden, Making City (Oulu)
Energy requirement per capita	GJ/person/year	Circular Rotterdam
GDP per energy requirement	€/GJ	Circular Rotterdam
Supply of renewable energy	%	Circular Rotterdam, Carbon Neutral Tampere 2030 Roadmap
Embedded energy use	tons/capita	Circular Rotterdam
Percentage of renewable or recycled energy use	%/year	Green City Action Plan of Tirana
Percentage of renewable electricity and heat supply for all municipal operations	%	Carbon Neutral Tampere 2030 Roadmap
Electricity consumption per capita	MWh per Capita/year	Making City (Oulu)
Primary energy consumption per capita	MWh per Capita/year	Making City (Oulu)
Primary energy sources (share)	% or MWh/cap	Making City (Oulu)
Percentage of buildings heated mainly by natural gas	%	Circular Prague
Percentage of buildings heated mainly by energy from incineration	%	Circular Prague
Electricity consumption in industry, per unit of industrial GDP	kWh/2010 USD	Green City Action Plan of Tirana
Emissions from centralized energy production	t CO_{2e}	Carbon Neutral Tampere 2030 Roadmap
Emissions from oil heating	t CO_{2e}	Carbon Neutral Tampere 2030 Roadmap
	Water	
Water consumption per capita	l/day/capita	Green City Action Plan of Tirana
Water consumption per unit of city GDP	l/day/USD	Green City Action Plan of Tirana
Water savings	Ml/inhabitant/year or %	The Circular Economy in Umeå, Sweden
-Biochemical oxygen demand (BOD) in rivers and lakes -Ammonium (NH4) concentration in rivers and lakes	µg/l	Green City Action Plan of Tirana
Percentage of water samples in a year that comply with national potable water quality standards	%	Green City Action Plan of Tirana
Water Exploitation Index	%	Green City Action Plan of Tirana
Unit of water consumed in power plants, per unit of primary energy generated	l/MW/h	Green City Action Plan of Tirana

Table A3. *Cont.*

Indicators	Unit of Measure	Reference
Industrial water consumption as percent of total urban water consumption	%	Green City Action Plan of Tirana
Non-revenue water	%	Green City Action Plan of Tirana
Annual average of daily number of hours of continuous water supply per household	h/day	Green City Action Plan of Tirana
Percentage of residential and commercial wastewater that is treated according to applicable national standards	%	Green City Action Plan of Tirana
Percentage of buildings (non-industrial) equipped to reuse grey water	%	Green City Action Plan of Tirana
Percentage of wastewater from energy generation activities that is treated according to applicable national standards	%	Green City Action Plan of Tirana
Green		
Proportion of green and recreational areas per capita	%	Roadmap towards the circular economy in Slovenia (Maribor)
Number of contaminated sites	CSs/1000 inch (or km^2)	Green City Action Plan of Tirana
- Concentration of mercury in soil - Concentration of cadmium in soil - Concentration of zinc in soil - Concentration of mineral oil in soil (using infrared spectroscopy)	mg/kg	Green City Action Plan of Tirana
Open green space area ratio per 100,000 inhabitants	Hectares or m^2 per resident	Green City Action Plan of Tirana, Carbon Neutral Tampere 2030 Roadmap
Share of green space areas within urban limits	%	Green City Action Plan of Tirana
- Abundance of bird species (all species) - Abundance of other species	Annual % of change	Green City Action Plan of Tirana
Ecosystem services provided by green spaces	-	Carbon Neutral Tampere 2030 Roadmap
Food		
Percentage of sustainable food	%	Circular Rotterdam
Amount of food waste	%	Carbon Neutral Tampere 2030 Roadmap
Share of units offering vegetarian options	%	Carbon Neutral Tampere 2030 Roadmap
Buildings		
Construction materials from secondary sources	%	Circular Prague
Tons of residual materials not utilized (construction sector)	Tons/total	Circular Prague
Percentage of reduction of emissions due to smart and clean building logistics (construction sector)	%	Circular Rotterdam
Amount of construction waste saved by implementing interventions related to circular economy	tons/year	Circular Rotterdam
- Electricity consumption in residential buildings - Electricity consumption in non-residential buildings	kWh/m^2 or kWh per resident	Green City Action Plan of Tirana, Carbon Neutral Tampere 2030 Roadmap

Table A3. *Cont.*

Indicators	Unit of Measure	Reference
- Heating and cooling consumption in buildings, fossil fuel use in residential buildings, fossil fuels - Heating and cooling consumption in residential buildings, fossil fuels - Heating and cooling consumption in non-residential buildings, fossil fuels	kWh/m^2	Green City Action Plan of Tirana
Share of energy class A in new residential buildings	%	Carbon Neutral Tampere 2030 Roadmap
Share of recovered materials in construction	%	Carbon Neutral Tampere 2030 Roadmap
Building connected to the DH network or renewable energy grid	%	Oulu
Low-emission new materials, verification with CO_2 calculations	%	Carbon Neutral Tampere 2030 Roadmap
Mobility		
Access to public transport	%	Making City (Oulu)
Energy consumption in transport sector	kWh/year or MWh/cap	Roadmap towards the circular economy in Slovenia (Maribor), Making City (Oulu)
Average age of car fleet (total and by type)	Year	Green City Action Plan of Tirana
Percentage of diesel cars in total vehicle fleet	%	Green City Action Plan of Tirana
Fuel standards for light passenger and commercial vehicles	€	Green City Action Plan of Tirana
Share of total passenger car fleet run by electric, hybrid fuel cell, liquefied petroleum gas (LPG) and compressed natural gas (CNG) energy	%	Green City Action Plan of Tirana, Carbon Neutral Tampere 2030 Roadmap
Percentage of low-emission buses in bus fleet	%	Green City Action Plan of Tirana
Transport modal share of commuting (cars, motorcycles, taxi, bus, metro, tram, bicycle, pedestrian)	Private transport %	Green City Action Plan of Tirana
Transport modal share of total trips	%	Green City Action Plan of Tirana
Motorization rate	Number of vehicles per capita	Green City Action Plan of Tirana
Average number of vehicles (cars and motorbikes) per household	Number of vehicles per household	Green City Action Plan of Tirana
- Kilometers of road dedicated exclusively to public transit per 100,000 population - Kilometers of bicycle path per 100,000 population	Km	Green City Action Plan of Tirana
Share of population having access to public transport within 15 min by foot	%	Green City Action Plan of Tirana
Frequency of bus service	Average number of passengers at station per hour in bus network	Green City Action Plan of Tirana
- Average travel speed on primary thoroughfares during peak hour - Travel speed of bus service on major thoroughfares (daily average)	km/h	Green City Action Plan of Tirana
Share of households within 300 m or 700 m of the main public services	%	Carbon Neutral Tampere 2030 Roadmap

Table A3. *Cont.*

Indicators	Unit of Measure	Reference
- Modal share of public transport on an autumn weekday - Modal share of walking on an autumn weekday - Modal share of cycling on an autumn weekday - Modal share of travel by car on an autumn weekday	%	Carbon Neutral Tampere 2030 Roadmap
Amount of outsourced transport services using low emission fuel sources	line km	Carbon Neutral Tampere 2030 Roadmap
Car travel output	km/person	Carbon Neutral Tampere 2030 Roadmap
Modal split	%	Making City (Oulu)
Fuel mix in mobility	%	Making City (Oulu)
Public infrastructure promoting low-carbon mobility	km/100,000 people	Making City (Oulu)

Table A4. Cross-sectional indicators database of circular cities deduced from official documents.

Indicators	Unit of Measure	Reference
Environmental Dimension		
- Amount of CO_2 emissions - Amount of greenhouses gases emissions - Annual CO_2 equivalent emissions per capita	kg of CO_2/year or tons/year/capita	Circular Glasgow, Circular Prague, Green City Action Plan of Tirana, Making City (Oulu)
Annual CO_2 emissions per unit of GDP	Tons/m. USD of GDP	Green City Action Plan of Tirana
- CO2 (or CO_2 equivalent) emissions saved (also through industrial and urban symbiosis) - GHG emissions saved (for example, by an increase in circularity)	Tons/year, or T CO_2 equivalent/year, or %/year, or tons CO_2/capita, or %	Circular Glasgow, Circular Prague, The Circular Economy in Umeå, Sweden, Making City (Oulu)
Amount of NOx emissions	Tons/year	Circular Prague
- Amount of fine dust emissions - Annual average air quality particulate matter	Tons/year or PM2.5 $\mu g/m^3$	Circular Prague Circular Rotterdam
CO_2 intensity	tons/capita	Circular Rotterdam
Embedded CO_2 emissions	tons/capita	Circular Rotterdam
- Average annual concentration of PM2.5 - Average annual concentration of PM10 - Average daily concentration of SO2 - Average daily concentration of NOx	$\mu g/m^3$	Green City Action Plan of Tirana
Climate change adaptation	-	Circular Prague
- Primary resources used - Raw material avoided - Virgin resources used - Amount of primary resource use avoided	Tons/year, or %/year, or T/inhabitant/year, or %	Circular Rotterdam, Circular Prague, Circular Glasgow, The Circular Economy in Umeå, Sweden
Use of renewable resources	%/year	Circular Rotterdam
Primary raw material demand per capita	ton/capita	Circular Rotterdam
Raw material consumption	%/year	Circular Prague
Raw materials with high risk for impact on biodiversity	%	Circular Rotterdam
Percentage of dwellings damaged by the most intense flooding in the last 10 years	%	Green City Action Plan of Tirana

Table A4. *Cont.*

Indicators	Unit of Measure	Reference
Awareness and preparedness for natural disasters	-	Green City Action Plan of Tirana
Annual number of storm water/sewerage overflows per 100 km of network length	Number of events per year	Green City Action Plan of Tirana
Economic and Financial Dimension		
Gross added value	€/year	Circular Prague
Total investments	-	Making City (Oulu)
Return on investment	€	Circular Prague, Making City (Oulu)
Sustainability of investments from the municipality	-	Green City Action Plan of Tirana
Value creation from growth of circular economy models	€/year	Circular Paris
Volume of sales from growth of circular economy models	Amount/year or €/year	Circular Glasgow
Sales of locally produced goods	Amount/year or €/year	Circular Glasgow
Revenues through sales from growth of circular economy models	€/year	Circular Glasgow
Change in GDP through circular activities	%	Circular Rotterdam
Resources productivity	-	Roadmap towards the circular economy in Slovenia (Maribor)
Creating added value and economic growth	€/year	Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana)
Turnover of organizations working in the circular economy (including all sectors and types)	€/year	Circular Paris
Existence of funding programs and economic incentives for circular economy projects with specific objectives, prioritized sectors, and a monitoring framework for the outcomes	qualitative	The Circular Economy in Umeå, Sweden
Estimated economic damage from natural disasters (floods, droughts, earthquakes etc.) as a share of GDP	%	Green City Action Plan of Tirana
Social and Cultural Dimension		
- Number of new jobs - Share of circular jobs (full- or part-time jobs related to one of the seven basic principles of circular employment) - Percentage of new jobs related to the circular economy - Number of new jobs from recycling of packaging - Number of new jobs from industrial ecology - Number of new green jobs	N°/year or %/year	Circular Rotterdam, Circular Paris, Circular Glasgow, Roadmap towards the circular economy in Slovenia (Maribor), Circular Prague, Roadmap towards the circular economy in Slovenia (Ljubljana)
- New business opportunities - New businesses that have integrated circularity into their development process	N°/year or %/year	Circular Rotterdam, Circular Paris, Circular Glasgow, Roadmap towards the circular economy in Slovenia (Maribor), Circular Prague, Roadmap towards the circular economy in Slovenia (Ljubljana)

Table A4. *Cont.*

Indicators	Unit of Measure	Reference
Unemployment rate	%/year	Circular Rotterdam, Roadmap towards the circular economy in Slovenia (Maribor), Malmö (Sweden), Roadmap towards the circular economy in Slovenia (Ljubljana)
Change in circular jobs	%	Circular Rotterdam
Percentage of population that shows an increase in circular behavior	%	Circular Rotterdam
Social cohesion (objective participation)	-	Circular Rotterdam
Percentage of population that describes their own health as good or very good	%/year	Circular Rotterdam
Percentage of population dying from diseases of the respiratory system (diseases of the respiratory system can be an air quality indicator, but also of habits such as smoking)	%/year	Circular Rotterdam
Number of new circular initiatives	%/year	Circular Rotterdam
Percentage of residents participated in dialogue and/or design related to circular economy	N°/year	Malmö (Sweden), Making City (Oulu)
Development of cooperative economy	-	Roadmap towards the circular economy in Slovenia (Maribor)
Number of new forms of enterprises (SMEs, start-ups, incubators, etc.)	N°/year	Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana)
Level of citizens' satisfaction with the administration services	qualitative	Roadmap towards the circular economy in Slovenia (Maribor)
Transformation of neighborhoods and local community	-	Roadmap towards the circular economy in Slovenia (Maribor)
Competitiveness of the economy	-	Roadmap towards the circular economy in Slovenia (Maribor)
Professional and managerial transformation of the city administration	-	Roadmap towards the circular economy in Slovenia (Maribor)
Attractiveness in terms of tourist visits	N° of visitors/year	Roadmap towards the circular economy in Slovenia (Maribor), Roadmap towards the circular economy in Slovenia (Ljubljana)
Annual number of visitors (with active engagement) to the reuse hubs	N°/year	Circular Prague
Number of public administrations/departments involved in the design of the circular economy imitative.	N°	The Circular Economy in Umeå, Sweden
- Number of actions identified to achieve the objectives. - Number of circular economy projects to implement the actions.	N°	The Circular Economy in Umeå, Sweden
- Number of staff employed for the circular economy initiative's design within the city, region, or administration. - Number of stakeholders involved to co-create the circular economy imitative.	N°	The Circular Economy in Umeå, Sweden
- Number of projects financed by the city or regional government/total number of projects. - Number of projects financed by the private sectors/total number of projects.	N°	The Circular Economy in Umeå, Sweden

Table A4. *Cont.*

Indicators	Unit of Measure	Reference
- Existence of a circular economy strategy with specific goals and priorities, actions, sectors, and a monitoring framework. - Co-ordination mechanisms across levels of governments to set and implement a circular economy strategy or initiative are well established and functioning. - Existence of overall policy coherence between circular economy initiatives and related policy areas (e.g., climate change, sustainable development, and air quality). - Regular capacity-building programs for activities associated with designing, setting, implementing, and monitoring the circular economy strategy. - Existence of a circular public procurement framework (e.g., waste diversion from procurement activities, raw materials avoided, and percentage of recycled content). - Existence of an information system on the circular economy. Data are publicly available and citizens and business informed of the opportunities related to circular business models and behaviors. - Existence of a monitoring and evaluation framework that includes environmental, economic and social aspects.	qualitative	The Circular Economy in Umeå, Sweden
Residents' satisfaction with the attractiveness and functionality of the urban environment in the continuous resident survey	-	Carbon Neutral Tampere 2030 Roadmap
Share of recreational areas in the total detailed planning area of the inner city	%	Carbon Neutral Tampere 2030 Roadmap

Table A5. Database of proposed circularity indicators.

<table>
<tr><th colspan="6">Indicators and [Unit of Measure] for Each Key Sectors</th></tr>
<tr><th>Thematics</th><th>Waste</th><th>Energy</th><th>Water</th><th>Built Environment</th><th>Mobility</th></tr>
<tr><td rowspan="2">Waste</td><td>- Waste generation per capita [tons/Ab *year]</td><td>- Saving energy due to the use of recycled goods [kWh/year]</td><td rowspan="2">- Water consumption per capita [l/year/capita]</td><td rowspan="2">- Percentage of reuse or recycling of recyclable demolition materials [%]</td><td rowspan="2">- Amount of waste produced in the city and treated within the city itself [tons/year or %/year]</td></tr>
<tr><td>- Recycling percentage (recycling, repair, reuse, recovery, and upcycling activities) [%]</td><td>- Renewable energy use [%/year or kWh/year]</td></tr>
<tr><td rowspan="3">Energy</td><td rowspan="3"></td><td>- Total energy consumption [kWh inhabitant^{-1} year^{-1}]</td><td rowspan="3"></td><td>- Electricity consumption in residential buildings [kWh/m^2 or kWh per resident]</td><td rowspan="3">- Share of total passenger car fleet run by electric, hybrid fuel cell, liquefied petroleum gas (LPG) and compressed natural gas (CNG) energy [%]</td></tr>
<tr><td rowspan="2">- Energy requirement per capita [GJ/person/year]</td><td>- Electricity consumption in non-residential buildings [kWh/m^2 or kWh per resident]</td></tr>
<tr><td>- Percentage of building heating mainly through renewable sources [%/total buildings]</td></tr>
<tr><td>Water</td><td></td><td></td><td>- Annual average of daily number of hours of continuous water supply per household [h/day]</td><td>- Dispersion from municipal water supply [%]</td><td></td></tr>
<tr><td rowspan="2">Built Environment</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>- Percentage of degraded buildings [%/total buildings]</td><td>- Public space density: Pedestrian areas, squares, and green spaces [% of municipal area/neighborhood]</td></tr>
<tr><td>- Percentage of retrofitting interventions on buildings [%/total buildings]</td><td>- Kilometers of road dedicated exclusively to public transit per 100,000 population [km]</td></tr>
<tr><td>Mobility</td><td></td><td></td><td></td><td></td><td>- Public transport usage [% of inhabitants using public transport]</td></tr>
</table>

Table A6. Database of proposed cross-cutting circularity indicators.

Environmental Dimension	Economic and Financial Dimension	Social and Cultural Dimension
Indicators	**Indicators**	**Indicators**
- Annual amount of greenhouse gas emissions [%/year or tons/year]	- Green investment	- Job creation [N°]
- Annual amount of CO_2 emissions [%/year or tons/year]	- Investment costs [m^2/€]	- Employment opportunities [N°]
- Percentage of reduction of greenhouse gas emissions [%/year or tons/year]	- Payback period (PBP) [year]	- Number of events and dissemination activities about circular economy [N° of events/year]
	- Return on investment [€]	- Participants in events about circular economy (including public bodies, companies, universities, research centers, professional associations, etc.) [N° of participants/year]
		- Nature-based solutions adoption [N°]
Certifications		
- Density of certifications produced in the territory [N°/Ab]		

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