A Circularity Mapping Framework for Urban Policymaking

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Abstract

In the context of urban policies, the circular economy can represent a virtuous model of sustainable and efficient management of resources and services for citizens, generating value for the community. Local policymakers play a central role in accelerating the circular economy transition, given that they organize and manage services that can significantly contribute to urban resilience. For policies to be properly designed, tools aimed at supporting territorial planning are needed to direct local policy towards choices that favor the circular economy and the resilience of cities. Among these urban planning tools, it is particularly important to have dashboards of comparative data on the degree of implementation of the circular economy. This paper provides a circularity mapping framework to map the degree of circularity and identify cities' strengths and weaknesses to design policies accordingly using a data-driven approach. Using a circular economy model based on 5 circular economy pillars, we identified 28 variables and assigned them to each of the pillars according to the variable's scope: sustainable inputs, social sharing, Product as a service, environmental policies, and resource efficiency. Both partial scores based on the five circular economy pillars, and a circularity index are provided for benchmarking and positioning analysis. Since urban life's environmental, economic, and social aspects are intertwined, only an integrated strategy can result in successful urban sustainable development. The paper supports policymakers in creating the conditions for efficient production and consumption markets and resource management systems while designing incentives and communications to citizens to support bottom-up initiatives and encourage virtuous behavior.

Keywords: local policy, circular economy, urban economy, SDG, local administrators, sustainability strategy

1. Introduction

Cities play a key role in the global economy, with more than half of the global population living in urban areas and accounting for approximately 85% of the world's GDP output. They are the heart of innovation and growth, although resource consumption and environmental impacts are increasing exponentially compared to population growth (Yang Zi, 2017). Due to the long-term unsustainability of resource exploitation, there has been a shift toward developing more circular cities based on effective environmental policymaking (Castán Broto & Bulkeley, 2013).

Given that cities are the centers of social and economic life, research on urban resilience has gained momentum. It is one of the most thought-provoking topics in urban research (Guo et al., 2022), and resilience variables have been gradually developed (Suárez et al., 2016). Resilience also cuts across the UN Agenda 2030 (Croese et al., 2020). Countries worldwide have placed the UN 2030 Agenda and, in particular, the Sustainable Development Goals (SDGs) at the center of the sustainable policies needed to achieve sustainability targets, mitigate climate change, and improve city resilience (Niemets et al., 2021; Taajamaa et al., 2022; Tarsitano et al., 2019).

Indeed, environmental issues associated with the rapid urbanization process have prompted policymakers to develop new policies to enhance the sustainability and resilience of cities (Dabaieh et al., 2022). No wonder interest in drivers shaping local innovation policies has increased (Okamuro & Nishimura, 2020). For example, the European circular economy package aims to promote a system of design, production, and consumption of goods and services, as well as waste management and the reuse of materials within the economic system, in which resource efficiency is the cornerstone of sustainable development (Beccarello & Di Foggia, 2022a).

The transition toward more circular and resilient cities requires citizens to actively engage in the transition process. In fact, the increasing complexity of socio-economic problems and budget constraints has inspired governments to innovate public service design and delivery by incentivizing citizens to engage in the public service production process (Cho & Melisa, 2021).

In this regard, it is essential, on the one hand, to create the conditions for efficient production and consumption markets and resource management systems and, on the other hand, to create a system of incentives and communication to citizens to support bottom-up initiatives and encourage virtuous behavior to promote a circular economy (Coskun et al., 2022; Sugandha et al., 2022). This concept is at the heart of the circular economy that, in this paper, is meant as a holistic approach aimed at promoting environmental sustainability and improving cooperation between all social players.

Provided that previous literature has provided insights into different aspects of urban sustainability, for example, in the field of city logistics (Paché & Morel, 2021), in energy efficiency (Yoon et al., 2017), in assessing water circularity (Arora et al., 2022), in the adaptive reuse of unique culturally relevant buildings (Foster & Saleh, 2021), in industrial and urban symbiosis (Fan et al., 2021), and in transport and food (Paiho et al., 2021), an interdisciplinary approach to understanding future trends is arguably one of the most thought-provoking topics (Bibri & Krogstie, 2017) together with the need to focus on barriers that may prevent the transition toward more circular cities (Campbell-Johnston et al., 2019). Additionally, previous literature has investigated factors related to smart cities (Esmaeilian et al., 2018; Farmanbar et al., 2019; Mendoza et al., 2015).

Since it is essential to consider the circular economy as a way of thinking (Sonnier & Grit, 2022), this article supports scholars and policymakers in growing cities sustainably by developing a data-driven tool to provide a benchmark to compare the performances of cities focusing on circularity.

Using a circularity mapping framework (CMF) containing five circular economy pillars (CEPs), namely, sustainable inputs, social sharing, products as service, environmental policies, and the efficient use of resources, 28 variables were collected and assigned to one of the CEPs according to the scope and field of each variable. After data normalization to rank cities according to their performance in each area, ranks were computed to benchmark cities according to the CEPs and to the circular index (CI). The CMF was tested on the 20 largest Italian cities by urban population and geographical coverage.

The variables considered in this paper can be used in impact analyses of new legislative proposals and are useful in ex-post assessments of the effectiveness of measures adopted. The social impact is also a key to evaluating the effects of many environmental policies at the urban level, which have thus far often failed to consider the risk of regressive economic impacts on the most disadvantaged members of urban society. We deem that social aspects have been underestimated, which shall be considered more (Castán Broto & Bulkeley, 2013; Sugandha et al., 2022).

That is why it is important to start by setting out proximity policies for residents and measuring the effectiveness of urban areas, which, as mentioned earlier, are currently the drivers of economic and social development (Di Foggia, 2016). The objective is, therefore, to develop a CI to facilitate regulatory impact analysis of environmental and sustainability policies. The aim is to provide a tool to support analysis and impact assessments to build circular economy policies as indicated by European and national legislation.

The paper is organized as follows: the second section includes a description of the methodological approach applied, the main variables taken into consideration, and the main critical issues addressed. The third section consists of a description of the results obtained by measuring the variables referring to the various aspects of the analysis. The fourth section discusses the different elements of the circular economy in an overall ranking of circularity. Conclusions follow.

2. Method

A framework based on five CEPs was identified to contextualize the research scope to the urban environment. Then, variables were identified, collected, and assigned to different CEPs to compute CEP scores and the CI. Given the recognized importance of frameworks and conceptualization patterns to understand circularity in an integrated way (Cohen & Muñoz, 2015; Paiho et al., 2020; Papageorgiou et al., 2021), the importance of variables and measures to assess the performance of cities concerning circularity and SDGs has recently gained momentum (Cetrulo et al., 2018; Haitsma Mulier et al., 2022; Kutty et al., 2022). No exception for policy implications (Batalhao et al., 2019; Ghiglione & Larbi, 2015; Sufiyan, 2013).

We developed an index to measure the circular economy and tested it in twenty Italian cities: in alphabetical order, Aosta, Bari, Bergamo, Bologna, Brescia, Cagliari, Catania, Florence, Genoa, Milan, Naples, Palermo, Perugia, Pescara, Reggio Calabria, Rome, Turin, Trento, Venice, and Verona.

By starting with a widely used framework to model the circular economy in cities, it is possible, by adapting it, to represent the concept of urban circularity through CEPs. Sustainable inputs: use of inputs from renewable sources or reuse and recycling. Social sharing: volunteering/platforms for asset sharing to reduce waste, products as a service: innovative business models to offer products in the form of services, environmental policies: solutions aimed at preserving the end-of-life value of an asset and reusing it. Resource efficiency: actions to increase the useful life of goods and services.

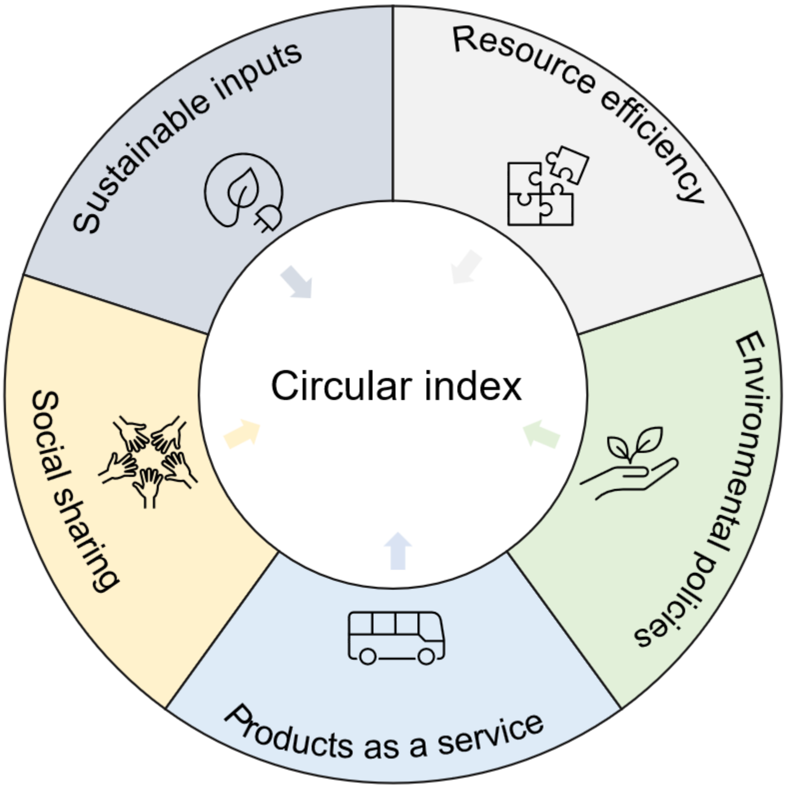

Figure 1. Framework

Source: own elaboration

Using the fundamental characteristics of each abovementioned principle of the circular economy, it is possible to obtain some variables that measure the performance of the urban areas considered.

2.2 Measures and Variables

According to the field and the aim, the variables collected to run the analyses were continuous, categorical, and discrete. For this reason, variables were normalized to an ordinal scale as described in equation 1. Based on the value of each variable described in Table 1, the normalized score that ranged from 0 to 1 were multiplied by 10 and the value 0 was mutated in 0.5 so to create 20 levels: one for each city. Thus, a score from 0.5 to 10 was assigned to each city to rank them according to the performance in each variable. Specifically, the scale ranged from 0.5, i.e., the minimum value, which reflected the lower relative performance, to 10, which reflected the best performance. Table 1 summarizes the variables and their positions within the identified CEPs.

Table 1. Pillars and variables

Pillar	Label	Variable	Label	Unit
SI	Sustainable input	SI1	Photovoltaic energy in the public sector	Percentage
		SI2	Private electric cars	Percentage
		SI3	Zero emission mobility	Percentage
		SI4	Urban green spaces	Square meters per capita
		SI5	Trees in city	Per 100 inhabitants
SS	Social Share	SS1	Annual expenditure for the disabled	Euro
		SS2	Annual expenditure for the elderly	Euro
		SS3	Residential facilities for migrants	Number
		SS4	Third sector organizations	Per 10,000 inhabitants
		SS5	Citizen satisfaction	Rank
PS	Products as service	PS1	Passengers public transport	Journeys per capitat
		PS2	Shared cars	Per 1,000 inhabitants
		PS3	km of bike lanes	Per 100 inhabitants
		PS4	km traveled by public transport	Km-vehicle/inhabitants

Pillar	Label	Variable	Label	Unit
		PS5	Cars in circulation	Per 100 inhabitants
		PS6	Level of traffic congestion	Percentage
PO	environmental policies	PO1	Municipal waste	Kg per capita
		PO2	Separated municipal solid waste	Percentage
		PO3	Door-to-door waste collection	Percentage
		PO4	Water purification	Percentage
		PO5	Water consumption	Daily liters per capita
		PO6	PM10 concentration	Micrograms/cubic meter
RE	Resource efficiency	RE1	Water network efficiency	Percentage
		RE2	Land use efficiency	Euro
		RE3	Sustainability patens	Number
		RE4	Workers employed in green jobs	Percentage
		RE5	Companies that invest in the green sector	Number
		RE6	Green businesses	Percentage

Starting from the CEPs and variables listed in Table 1 CEP were computed following equation 2 procedure. The CEP scores were subsequently linked to a general ranking according to equation 3. To rank cities' performances in different fields, the data were normalized using the min-max method according to equation 1

$$Z_i = \frac{X_i - \min{(X)}}{max(X) - min(X)} \tag{1}$$

Following this procedure, the values of each variable measured in absolute units were converted into values ranging between 0 and 1. The lowest value corresponded to 0, and the highest value was set to 1. Finally, the value was multiplied by 10 for comparison purposes. We identified five CEPs in the CMF. Once the variables were scaled according to equation 1, five CEP variables were created as an arithmetic mean of the variables' rank assigned to each CEP, as shown in Table 1, and formalized in equation 2.

$$C_i \frac{\sum(Xi)}{n}; X = (X1 \ldots Xn) \tag{2}$$

where C_i is the i_{th} CEP and n is the number of variables contained in the CEP, which ranges from five to six.

By the same token, the CI was computed as the mean of CEPs, as shown in equation 3.

$$INDEX = \frac{\sum(Ci)}{N}; C = (C1 \ldots X5) \tag{3}$$

2.2 CEPs Definition

Sustainable inputs. This CEP reflects the new circular model where each resource, once used and exhausted, re-enters the production process as a new secondary raw material. The performance of Italian cities in dealing with sustainable inputs was analyzed using variables related to renewable raw materials, mobility, or the urban environment. SI1 targeted renewable solar thermal energy in the public sector measured in kW; this represents the distribution of energy from renewable sources, particularly solar thermal systems in public buildings. SI2 refers to electric cars as a percentage of the total number of privately owned vehicles. To analyze the level of sustainable mobility, we calculated the number of private electric vehicles owned as a percentage of the total number of cars registered in each city. SI3 is the percentage of zero-emission mobility that expresses the ratio of zero-emission car journeys out of the total number of car journeys in urban areas; it includes all trips made using transport other than fossil-fueled cars. Electric and public transport, as well as walking and cycling, are considered sustainable. SI4 maps the quantity of urban green areas measured in sqm/inhabitant, whereas SI5 maps the number of trees in an urban area measured in terms of the number of trees per 100 inhabitants.

Social sharing. The social sharing CEP highlights the collaboration and participation of all players within Italian cities, which is key to achieving full circularity and closure of the so-called economic circle. The variables examined are as follows: SS1 refers to the annual municipal expenditure for the disabled, and SS2 captures the yearly spending for elderly individuals. The first two variables analyzed reflect the services the State makes available to cities. SS3 embeds the residential facilities for migrants; in this case, the survey, which was carried out based on the Ministry of the Interior's annual census on the number of reception and residential centers for migrants, focuses on the location of these facilities within the country. SS4 is the number of nonprofit organizations per 10,000 inhabitants. Volunteering is the most important and symbolic variable for the evaluation of social sharing. The nonprofit sector continues to expand and records even higher average annual growth rates than companies operating in the same market. In addition to the number of volunteers, the number of institutions and organizations that provide nonprofit aid continues to grow. Finally, SS5 captures citizen satisfaction and expresses citizens' satisfaction rate.

Products as a service. The variables examined are as follows. PS1, named public transport passengers, indicates the number of journeys each inhabitant makes in a calendar year. Public transport service use is rising in small, medium, and large cities. Public transport use is also growing in medium-sized towns, albeit slower.

Similarly, PS2 summarizes the number of shared cars in the city. Note that this service has yet to be offered in many Italian cities and is mostly limited to large cities. PS3 measures the total km and the equivalent meters of cycle paths per 100 inhabitants. To obtain an effective variable to measure cycle path facilities, the following have been considered: km of cycle routes, km of reserved lane cycle paths, on-pavement cycle paths, mixed bike/pedestrian paths, and cycle paths in urban green areas. By the same token, PS4, on public transport offer, represents all the various modes of local public transport within a given city, whereas PS5 stands for cars per 100 inhabitants. PS6 refers to traffic congestion and represents the average percentage increase in the duration of a car journey due to traffic.

Environmental policies. One of the main objectives of the circular economy model is to treat today's waste as tomorrow's resources. Waste should not be the final stage of a product but can and must be reintroduced into the production chain as input for a new and different cycle. This CEP focuses on waste and municipal waste produced annually in major Italian cities. The variables used are shown below. In this cluster, municipal solid waste management plays an important role. PO1 refers to municipal waste production, and PO2 represents the percentage of separate collection. The uptake of separate collection practices in urban areas has grown in recent years and now stands at a national average of 56.3%. In recent years, several policies and services have been adopted and introduced by cities to help and encourage citizens to recycle waste correctly (Di Foggia & Beccarello, 2022), including the door-to-door collection of municipal waste. PO3 indicates the percentage of citizens with a door-to-door waste collection service. PO4 is the percentage of water purification. This variable shows how efficiently each city purifies wastewater before it ends up in the sewerage system. PO5 is the daily water consumption. Finally, PO6 is the air's concentration of fine particles (PM10).

Resource efficiency. Regarding the last CEP examined, cities must make the best use of the resources available to them to close the economic cycle completely by preventing unnecessary waste. RE1, i.e., the efficiency rate of public water networks, is the percentage difference between the amount of water distributed and the amount consumed by users. RE2 is the percentage of land use efficiency, defined as the percentage of land devoted to the use and construction of infrastructure. RE3 resumes the number of sustainable eco-patent fields. The data analyzed indicate the number of economic patents in the sustainability field. This is an important variable of how far along the linear-circular transition Italian cities are, as it shows the level of interest and engagement of cities and citizens in sustainable research and innovation. Each city needs to foster and encourage the development of patents for advanced and sustainable technical innovations to include them in new production and consumption systems as soon as possible. In the same field, RE4 represents the number of workers employed in green jobs, RE5 reflects the number of companies investing in the green sector, and RE6 represents green businesses as a percentage of the total number of companies in the province. Table 2 contains key information regarding the CEPs.

Table 2. Descriptive statistics of CEPs

CEP	Mean	Std. dev.	Min	Max
SI	5.605	1.815	2.200	8.400
SS	5.250	1.785	2.700	8.100
PS	5.375	1.874	3.000	8.500
PO	6.100	1.248	4.100	9.200
RE	5.575	2.255	2.500	9.300

Source: own elaboration. Annex a contains additional information on the variables

3. Results

The results were analyzed based on the identified variables by drawing up a symbolical ranking of the most circular Italian cities. For each variable, a partial ranking of the cities was drawn up, and according to the position reached on each ranking, each city was assigned a score (rank) between 0.5 and 10 to compare the results achieved. The objective was to develop an urban CI (UCI). Figure 2 presents the mean of each cluster, which is valuable information for policymakers regarding ranking priorities in policy design.

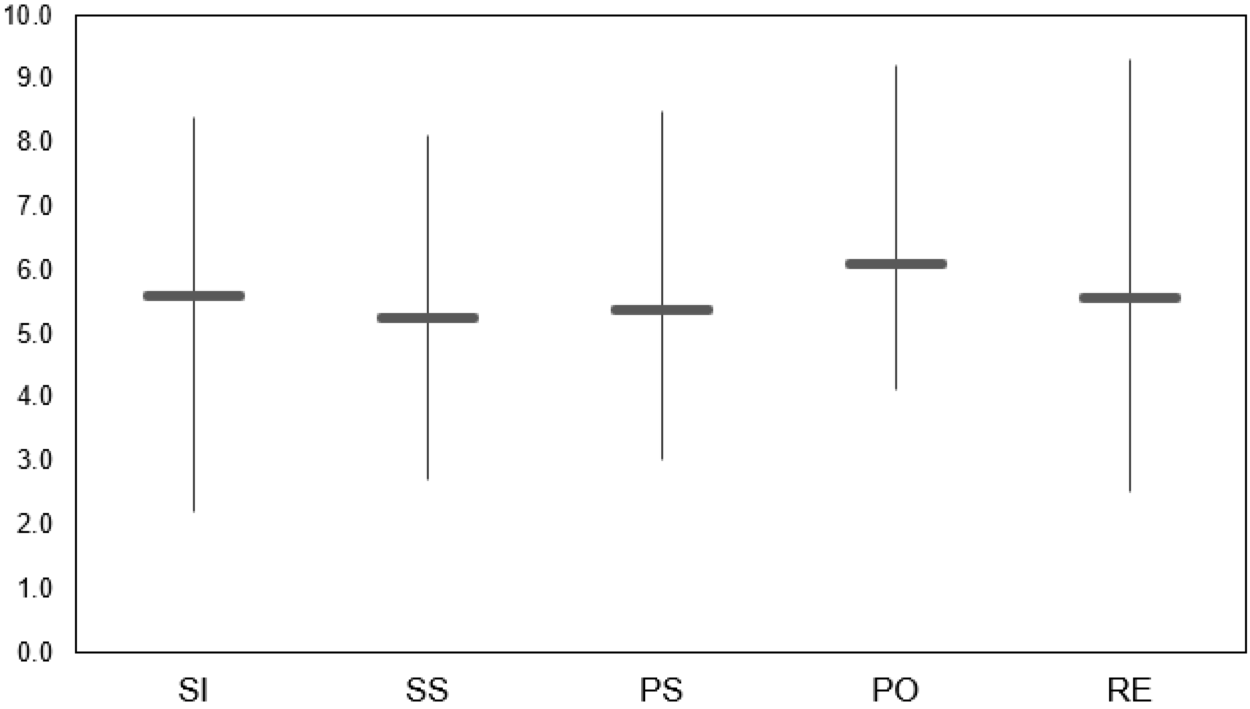

Figure 2. CEPs score

Source: own elaboration.

Starting from Figure 2, Figure 3 contains partial ranks for all the cities and towns used to test the circular economy framework according to the five CEPs.

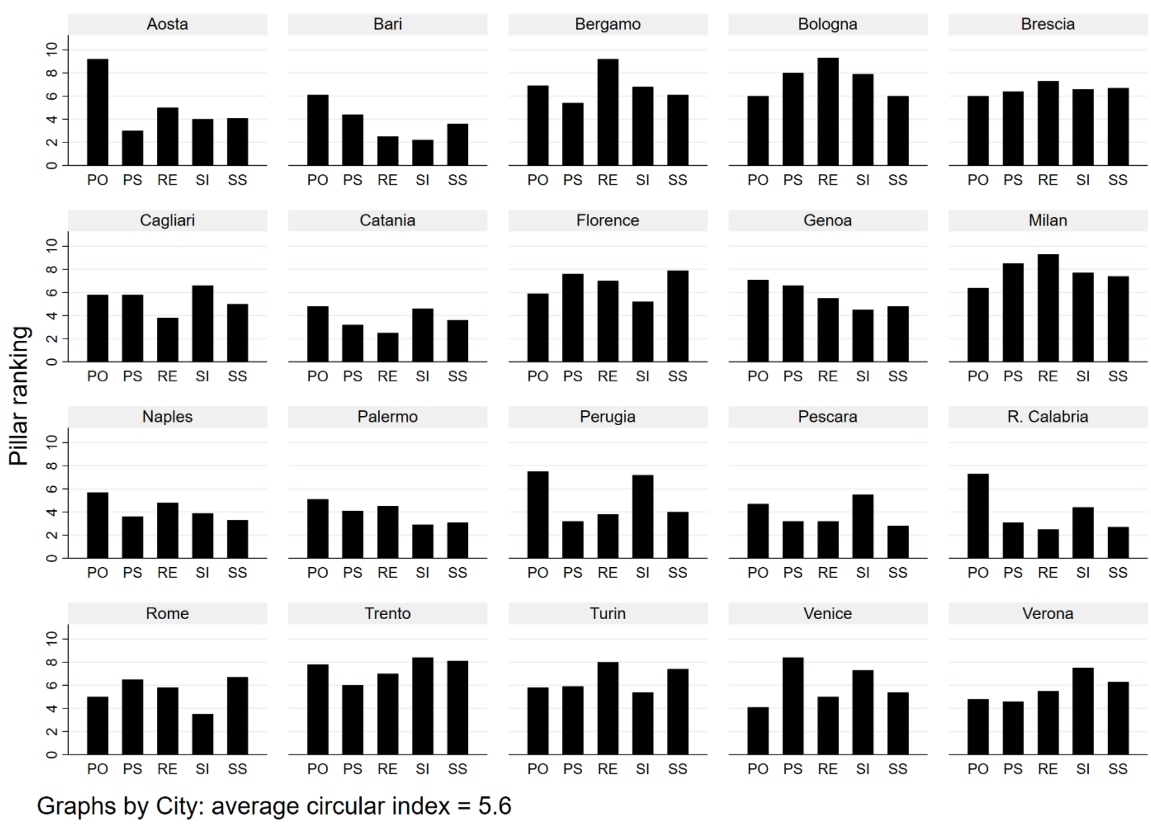

Figure 3. City-level partial ranking

Source: own elaboration.

Figure 3 shows the results achieved by the various cities and the associated indexes. On average, the CEP related to environmental policies ranks first, providing insights into local administrators' commitment to challenging challenges.

Figure 3 is useful for policymakers who can use it as an evaluation parameter referring to the comparative analysis of cities located in different contexts with similar objectives in terms of sustainable development. Figure 3 also aims to reduce information asymmetries concerning specific CEPs. Consequently, it can be a viable tool for policymakers to prioritize alternative investments according to their city's positioning. Figure 4 presents the CI. As seen in Figure 4, the most circular city of those analyzed is Milan, with a score of 7.7 out of 10, followed by Trento and Bologna.

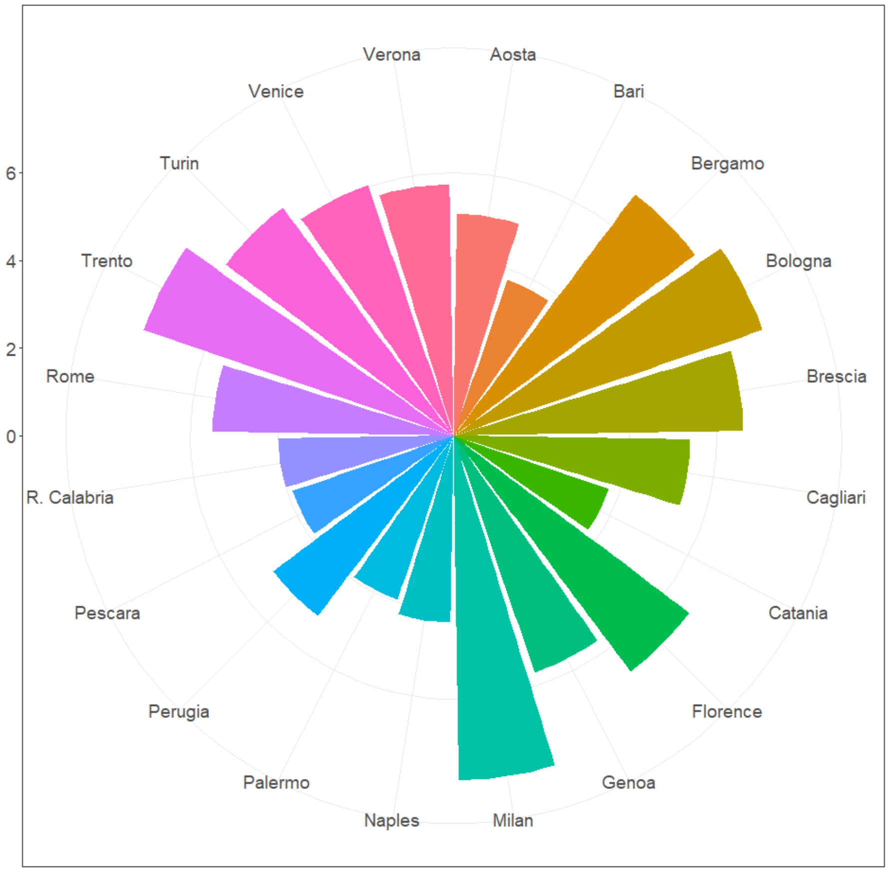

Figure 4. Circularity index

Source: Own elaboration.

The ranking results suggest that eight of twenty cities achieved a satisfactory score based on the circular variables analyzed. Moreover, the significant differences represent an obstacle to the transition toward a more circular economy. Finally, Figure 5 shows the CEP and the CI correlations.

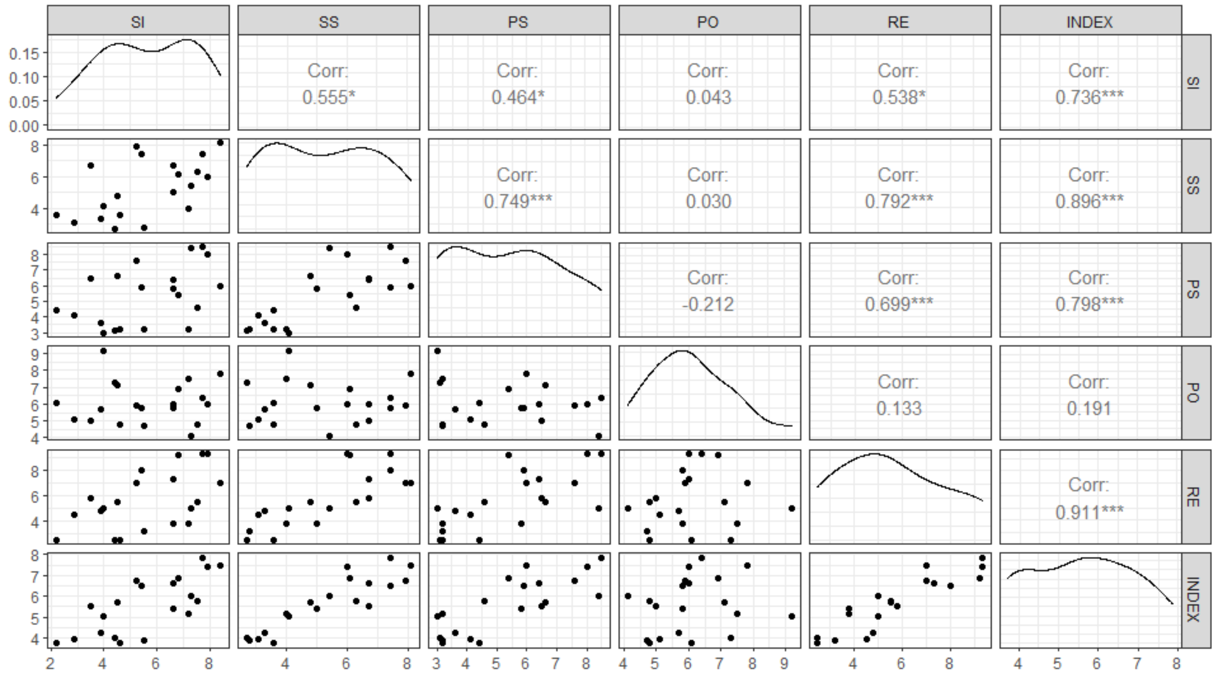

Figure 5. Correlation matrix: CEPs vs. CI

Source: Own elaboration

At first sight, Figure 5 shows that the correlation of the CEP related to environmental policies with CI is relatively low and non-statistically significant (0.191); the same happens with the others is always law, and the reason lies in the typology of variables contained in the PO CEP that being referred to utterly important environmental services such as waste and waste management are typically managed by environmental utilities or that depend of exogenous factors such as waste management capacity (Di Foggia & Beccarello, 2021) and waster networks efficiency; therefore policies aimed at such services require relatively long periods.

4. Discussion

The application of circular economy principles in cities can represent a virtuous model of sustainable and efficient management of resources and services for citizens, creating value and increasing urban attractivity. Local policymakers play a central role in accelerating the circular economy transition by creating the right conditions for favoring advancement in the file CEPs. To improve cities' sustainability in an integrated and participative way and promote knowledge sharing and capitalization for the benefit of stakeholders, the results of this paper support policymakers and practitioners in benchmarking cities using comparable data, i.e., one of the most precious resources nowadays. Reliable data may promote partnerships with the corporate sector, foster interagency cooperation, and increase public involvement. Cities are adopting various planning and strategic approaches as data play a more prominent role in local administration.

Since urban life's environmental, economic, social, and cultural aspects are intertwined, only an integrated strategy can result in successful urban sustainable development (Bote Alonso et al., 2022; Prendeville et al., 2018). Local policies must be integrated with those that support environmental protection, social inclusion, economic development, and, in particular, SDGs (Beccarello & Di Foggia, 2022b).

Therefore, strong collaborations between civil society, businesses, and various levels of government are also required to put policies into practice. Given the serious challenges that cities are currently facing, including the impact of climate change, specific demographic shifts, economic uncertainty, variable job creation, and social advancement, such a strategy is particularly crucial at this time (Martos et al., 2016; Obia, 2016).

By focusing on comparable information, policymakers can benefit from this article to improve the quality of policies and, consequently, the well-being of city administrators. Tools such as the CMF presented in this article can support new working methods to ensure maximum utilization of the growth potential of cities and to tackle social challenges successfully while promoting solutions to meeting SDGs.

For example, as the results of our analysis show, there are prominent differences between cities that can be analyzed to understand better how to design policies to fill the gap toward more sustainable cities. Such insights guide both local and national policymakers. Indeed, local administrators could find it helpful to plan urban development policies based on a comparable information benchmark across the country. In contrast, national policymakers may benefit from our results to design cohesion policies to reduce the long-lasting differences across different regions.

It is also worth highlighting the role of the many institutional players involved in circular economy plans and policies that must be carefully considered. Different parties and policies are involved from a hierarchical standpoint which, although targets may converge, results may be alleviated due to potential overlapping. The central government sets national goals and incentives, local governments implement such policies in different territories, and environmental agencies set technical and economic rules. Finally, local policymakers design, organize and define local services.

The CMF was tested on twenty Italian cities using available open data; therefore, although the results can also have external validity, given that the CEPs can be applied to other cities, some adjustments may be required to contextualize the CMF to different territories.

Future research shall focus on integrating data-driven tools into the programming documents, together with the financing measures necessary for implementing policies developed considering the insights obtained from the tools, such as the CMF presented in this paper.

5. Conclusion

Focusing on how data-driven policymaking supporting tools may help increase cities' circularity and resilience has justified the development of a circular economy mapping framework tested in twenty Italian cities. Based on a circular economy model, we have selected twenty-eight openly accessible variables that were used to run the analyses after having been assigned to one of the five CEPs.

Cities are a strategic reference point in terms of policies for the population's sustainability and quality of life. From a methodological point of view, the measurement of city performance contributes to assessing the impact of environmental policy regulation on the resolution of important long-term problems in modern economies. Our measurement of circular economy practices in Italian cities has provided a numerical value to the five CEPs of the model used.

Some noticeable results have emerged from applying the circularity model to Italian cities. Among others, some correlations based on geographical location and socio-economic conditions with the degree of circularity and the fact that the CPE related to environmental policies has emerged to be slightly correlated with other CEPs. This is probably because some variables contained in the environmental policies CEP refer to some environmental services, such as waste and water management which organization is typically set for multiple years and depend on higher policy levels and exogenous structural factors. Also, we have underlined that for such tools to work properly, different levels of government must share the same goals using compatible approaches.

Provided that this study's objective was to establish the relationship between the circular economy model by analyzing the level of circularity achieved in urban areas, the CMF is intended as a tool to support environmental policies in urban areas in response to the climate and environmental crisis. Indeed, urban policymakers often need comparable data to benchmark the cities they administer. Consequently, this tool can support them in designing urban policies to improve circularity.

References

Arora, M., Yeow, L. W., Cheah, L., & Derrible, S. (2022). Assessing water circularity in cities: Methodological framework with a case study. *Resources, Conservation and Recycling*, *178*, 106042. https://doi.org/https://doi.org/10.1016/j.resconrec.2021.106042

Batalhao, A. C. S., Teixeira, D., Martins, M. de F., Bellen, H. M. van, & Caldana, A. C. F. (2019). Sustainability Indicators: Relevance, Public Policy Support and Challenges. *Journal of Management and Sustainability*, *9*(2), 173. https://doi.org/10.5539/jms.v9n2p173

Beccarello, M., & Di Foggia, G. (2022a). Introducing a system operator in the waste management industry by adapting lessons from the energy sector. *Frontiers in Sustainability*, *3*, 984721. https://doi.org/10.3389/frsus.2022.984721

Beccarello, M., & Di Foggia, G. (2022b). Sustainable Development Goals Data-Driven Local Policy : Focus on SDG 11 and SDG 12. *Administrative Sciences*, *12*(4), 167. https://doi.org/10.3390/admsci12040167

Bibri, S. E., & Krogstie, J. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society*, *31*, 183–212. https://doi.org/10.1016/j.scs.2017.02.016

Bote Alonso, I., Sánchez-Rivero, M. V., & Montalbán Pozas, B. (2022). Mapping sustainability and circular economy in cities: Methodological framework from europe to the Spanish case. *Journal of Cleaner Production*, *357*, 131870. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.131870

Campbell-Johnston, K., Cate, J. ten, Elfering-Petrovic, M., & Gupta, J. (2019). City level circular transitions: Barriers and limits in Amsterdam, Utrecht and The Hague. *Journal of Cleaner Production*, *235*, 1232–1239. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.06.106

Castán Broto, V., & Bulkeley, H. (2013). A survey of urban climate change experiments in 100 cities. *Global Environmental Change*, *23*(1), 92–102. https://doi.org/10.1016/j.gloenvcha.2012.07.005

Cetrulo, N. M., Cetrulo, T. B., Gonçalves-Dias, S. L. F., & Moreira, R. M. (2018). Waste Management and Sustainability: Indicators under Ecological Economy Perspective. *Journal of Management and Sustainability*, *8*(1), 20. https://doi.org/10.5539/jms.v8n1p20

Cho, W., & Melisa, W. D. (2021). Citizen Coproduction and Social Media Communication: Delivering a Municipal Government's Urban Services through Digital Participation. *Administrative Sciences*, *11*(2). https://doi.org/10.3390/admsci11020059

Cohen, B., & Muñoz, P. (2015). Sharing cities and sustainable consumption and production: Towards an integrated framework. *Journal of Cleaner Production*, 1–11. https://doi.org/10.1016/j.jclepro.2015.07.133

Coskun, A., Metta, J., Bakırlıoğlu, Y., Çay, D., & Bachus, K. (2022). Make it a circular city: Experiences and challenges from European cities striving for sustainability through promoting circular making. *Resources, Conservation and Recycling*, *185*(June). https://doi.org/10.1016/j.resconrec.2022.106495

Croese, S., Green, C., & Morgan, G. (2020). Localizing the Sustainable Development Goals Through the Lens of Urban Resilience: Lessons and Learnings from 100 Resilient Cities and Cape Town. *Sustainability*, *12*(2). https://doi.org/10.3390/su12020550

Dabaieh, M., Maguid, D., & El-Mahdy, D. (2022). Circularity in the New Gravity–Re-Thinking Vernacular Architecture and Circularity. *Sustainability*, *14*(1). https://doi.org/10.3390/su14010328

Di Foggia, G. (2016). Steering the implementation of urban sustainability projects: Implications for policy. *Journal of Environmental Management and Tourism*, *7*(1), 5–20. https://doi.org/10.14505/jemt.v7.1(13).01

Di Foggia, G., & Beccarello, M. (2021). Market Structure of Urban Waste Treatment and Disposal: Empirical Evidence from the Italian Industry. *Sustainability*, *13*(7412). https://doi.org/10.3390/su13137412

Di Foggia, G., & Beccarello, M. (2022). An Overview of Packaging Waste Models in Some European Countries. *Recycling*, *7*(3), 38. https://doi.org/10.3390/recycling7030038

Esmaeilian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., & Behdad, S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Management*, *81*, 177–195. https://doi.org/https://doi.org/10.1016/j.wasman.2018.09.047

Fan, Y. Van, Varbanov, P. S., Klemeš, J. J., & Romanenko, S. V. (2021). Urban and industrial symbiosis for circular economy: Total EcoSite Integration. *Journal of Environmental Management*, *279*, 111829. https://doi.org/https://doi.org/10.1016/j.jenvman.2020.111829

Farmanbar, M., Parham, K., Arild, O., & Rong, C. (2019). A widespread review of smart grids towards smart cities. *Energies*, *12*(23). https://doi.org/10.3390/en12234484

Foster, G., & Saleh, R. (2021). The Circular City and Adaptive Reuse of Cultural Heritage Index: Measuring the investment opportunity in Europe. *Resources, Conservation and Recycling*, *175*, 105880. https://doi.org/https://doi.org/10.1016/j.resconrec.2021.105880

Ghiglione, S., & Larbi, M. (2015). Eco-Cities in China: Ecological Urban Reality or Political Nightmare? *Journal of Management and Sustainability*, *5*(1), 101–114. https://doi.org/10.5539/jms.v5n1p101

Guo, P., Li, Q., Guo, H., Li, H., & Yang, L. (2022). A Bibliometric and Visual Analysis of Global Urban Resilience Research in 2011–2020: Development and Hotspots. *Sustainability*, *14*(1). https://doi.org/10.3390/su14010229

Haitsma Mulier, M. C. G., van de Ven, F. H. M., & Kirshen, P. (2022). Circularity in the Urban Water-Energy-Nutrients-Food nexus. *Energy Nexus*, *7*, 100081. https://doi.org/https://doi.org/10.1016/j.nexus.2022.100081

Kutty, A. A., Kucukvar, M., Abdella, G. M., Bulak, M. E., & Onat, N. C. (2022). Sustainability Performance of European Smart Cities: A Novel DEA Approach with Double Frontiers. *Sustainable Cities and Society*, *81*, 103777. https://doi.org/https://doi.org/10.1016/j.scs.2022.103777

Martos, A., Pacheco-Torres, R., Ordóñez, J., & Jadraque-Gago, E. (2016). Towards successful environmental performance of sustainable cities: Intervening sectors. A review. *Renewable and Sustainable Energy Reviews*, *57*, 479–495. https://doi.org/10.1016/J.RSER.2015.12.095

Mendoza, J. M. F., Sanyé-Mengual, E., Angrill, S., García-Lozano, R., Feijoo, G., Josa, A., Gabarrell, X., & Rieradevall, J. (2015). Development of urban solar infrastructure to support low-carbon mobility. *Energy Policy*, *85*, 102–114. https://doi.org/10.1016/j.enpol.2015.05.022

Niemets, K., Kravchenko, K., Kandyba, Y., Kobylin, P., & Morar, C. (2021). World cities in terms of the sustainable development concept. *Geography and Sustainability*, *2*(4), 304–311. https://doi.org/https://doi.org/10.1016/j.geosus.2021.12.003

Obia, A. E. (2016). Emerging Nigerian Megacities and Sustainable Development: Case Study of Lagos and Abuja. *Journal of Sustainable Development*, *9*(2), 27. https://doi.org/10.5539/jsd.v9n2p27

Okamuro, H., & Nishimura, J. (2020). What Shapes Local Innovation Policies? Empirical Evidence from Japanese Cities. *Administrative Sciences*, *10*(1). https://doi.org/10.3390/admsci10010011

Paché, G., & Morel, C. (2021). Environmental Issues in City Logistics: The Case of Low Emission Zones in Europe. *Journal of Management and Sustainability*, *11*(1), 88. https://doi.org/10.5539/jms.v11n1p88

Paiho, S., Mäki, E., Wessberg, N., Paavola, M., Tuominen, P., Antikainen, M., Heikkilä, J., Rozado, C. A., & Jung, N. (2020). Towards circular cities—Conceptualizing core aspects. *Sustainable Cities and Society*, *59*, 102143. https://doi.org/https://doi.org/10.1016/j.scs.2020.102143

Paiho, S., Wessberg, N., Pippuri-Mäkeläinen, J., Mäki, E., Sokka, L., Parviainen, T., Nikinmaa, M., Siikavirta, H., Paavola, M., Antikainen, M., Heikkilä, J., Hajduk, P., & Laurikko, J. (2021). Creating a Circular City–An analysis of potential transportation, energy and food solutions in a case district. *Sustainable Cities and Society*, *64*, 102529. https://doi.org/https://doi.org/10.1016/j.scs.2020.102529

Papageorgiou, A., Henrysson, M., Nuur, C., Sinha, R., Sundberg, C., & Vanhuyse, F. (2021). Mapping and assessing indicator-based frameworks for monitoring circular economy development at the city-level. *Sustainable Cities and Society*, *75*, 103378. https://doi.org/https://doi.org/10.1016/j.scs.2021.103378

Prendeville, S., Cherim, E., & Bocken, N. (2018). Circular Cities: Mapping Six Cities in Transition. *Environmental Innovation and Societal Transitions*, *26*, 171–194. https://doi.org/https://doi.org/10.1016/j.eist.2017.03.002

Sonnier, E., & Grit, A. (2022). A narrative for circular economy in Cities: Conditions for a Mission-Oriented innovative system. *City and Environment Interactions*, *16*, 100084. https://doi.org/https://doi.org/10.1016/j.cacint.2022.100084

Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). Towards an Urban Resilience Index: A Case Study in 50 Spanish Cities. *Sustainability*, *8*(8). https://doi.org/10.3390/su8080774

Sufiyan, A. M. (2013). Initiatives of Global Cities in Environmental Sustainability: A Case of London and New York City. *Journal of Sustainable Development*, *6*(3), 1–15. https://doi.org/10.5539/jsd.v6n3p1

Sugandha, Freestone, R., & Favaro, P. (2022). The social sustainability of smart cities: A conceptual framework. *City, Culture and Society*, *29*, 100460. https://doi.org/https://doi.org/10.1016/j.ccs.2022.100460

Taajamaa, V., Joensuu, M., Karanian, B., & Bettencourt, L. (2022). Seven Steps to Strategic SDG Sensemaking for Cities. *Administrative Sciences*, *12*(1). https://doi.org/10.3390/admsci12010033

Tarsitano, E., Calvano, G., & Cavalcanti, E. (2019). The Mediterranean Way a model to achieve the 2030 Agenda Sustainable Development Goals (SDGs). *Journal of Sustainable Development*, *12*(1), 108. https://doi.org/10.5539/jsd.v12n1p108

Yang Zi, L. (2017). Urbanization and Economic Growth in China—An Empirical Research Based on VAR Model. *International Journal of Economics and Finance*, *9*(3), 210. https://doi.org/10.5539/ijef.v9n3p210

Yoon, I., Lee, Y., & Yoon, S. K. (2017). An empirical analysis of energy efficiency measures applicable to cities, regions, and local governments, based on the case of South Korea's local energy saving program. *Mitigation and Adaptation Strategies for Global Change*, *22*(6), 863–878. https://doi.org/10.1007/s1102

Annex A

	Aosta	Bari	Bergamo	Bologna	Brescia	Cagliari	Catania	Florence	Genoa	Milan	Naples	Palermo	Perugia	Pescara	Reggio Calabria	Rome	Turin	Trento	Venice	Verona
SI1	2.89	0.01	10.53	6.08	1.04	4.88	4.41	1.15	2.24	2.28	0.24	0.28	6.78	1.65	0.72	0	0.36	14.5	1.2	26.5
SI2	0.02	0.02	0.11	0.07	0.12	0.01	0.02	0.06	0.03	0.13	0.01	0.02	0.06	0.02	0.01	0.02	0.05	0.61	0.05	0.06
SI3	3	12	19	48	21	27	30	17	39	52	50	14	15	20	16	20	40	39	44	27
SI4	18.8	8.6	23.4	26.1	23.1	54.9	16.3	21.5	6.4	17.9	12.6	11.6	62	38.6	104	15.9	22.2	415	55.5	28.2
SI5	11		19	21	64	17	5	19	10	34	6	11	29	14	6	11	13	17	24	19
SS 1	0	764	5172	4413	4514	8165	1582	3983	2526	5098	882	1272	1333	2290	1091	3194	4845	9826	5154	4958
SS 2	741	75	70	85	90	145	87	133	76	118	41	28	41	34	34	69	98	230	116	100
SS 3		33	21	23	22	2	28	57	2	2	38	48	14	10	31	82	229	11	8	40
SS 4	110	42.4		61.4		62.8		73.7	70	56.2	36	43.5	77.7	61.2	47.9	54.7	67.8	116	62.4	62
SS 5	7.46	6.64	7.15	7.16	7.17	6.7	6.37	7.27	7.23	7.49	6.47	6.43	6.97	6.9	6.53	7.13	6.83	7.59	6.77	6.67
PS 1	12	80	144	286	206	182	39		406	474	98	39	75	33	33	330	236	185	695	170

PS 1	0	0	0.01	0.57	0.03	0.57	0.35	1.7	0.19	2.43	0.02	0.23			0.12	0.8	1.2	0.08	0.11	
PS 3	8.7	26	36.7	153.2	97.5	21	11.3	60.1	11.5	174	19.2	33.8	14.1	26	5.8	129	147	41.8	112	76.1
PS 4	10	32	27	44	39	53	22	40	47	87	15	21	38	14	23	57	38	48	59	27
PS 5	64	56	60	53	61	65	72	52	47	50	57	59	74	61	63	62	66	64	43	65
PS 6		27	14	25	14	22	28	25	31	30	30	35		21	27	39	24			20
PO 1	471	613	523	597	584	582	733	641	486	504	527	572	580	585	396	605	512	465	640	527
PO 2	67.3	43.1	71.4	52.9	66.9	36	7.7	51.4	33.3	59.7	36	16.2	64.5	36.2	44.8	43.9	45.7	85.1	59.4	48
PO 3	91.2	15.6	99.4	10.7	100	100	16	1.4		100	50.4	29.6	100	0.1	95.1	33.9	54.5	0.1	0	0
PO 4	100	95	97	99	97	97	56	96	100	100	95	61	85	91	96	87	100	99	72	84
PO 5		136.5	183.4	152.8	224.4	162		137	122	274.7	150.3	140	139	176	240	165.2	197.6	150	164	177
PO 6	12	14	53	33	56	50	10	24	11	73	58	45	23	36	8	41	75	19	73	50
RE 1	32.8	48.8	24.1	28.8	29	54.9	45.5	31	38.8	15.2	40.2	34.6	41	49.7	41.2	38	29.3	15	30.9	32.7
RE 2	6.25	5.2	9.35	9.35	7.75	8.65	6.25	7.95	7.6	10	8.6	8.25	6.05	6.55	5.9	8.65	7.9	7.4	3.9	4.9
RE 3	51.2	15.22	116.2	199.6	75.72	7.58	5.61	73.9	73.5	96.53	9.48	4.83	38.9	24.1	6.36	28.89	116.4	54.5	59.2	77.3
RE 4		0.021	0.025	0.026	0.014			0.02	0.02	0.134	0.035					0.079	0.05		0.01	0.02
RE 5		12214	8095	8430	10201		5671	8068	6228	30902	17866					30406	15499		7709	8258
RE 6		0.324	0.307	0.336	0.306		0.29	0.28	0.33	0.351	0.304					0.315	0.332		0.34	0.34