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Measuring urban sustainability performance through composite indicators for Spanish cities

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ABSTRACT

The role that cities play in the transition to more sustainable growth is gaining increasing recognition. Measuring progress towards sustainable urban development requires quantifying this multi-dimensional phenomenon with the help of composite indicators. The purpose of this study is to propose an integrated approach to build a sustainable cities' interval of composite indicators that rely on the Sustainable Development Goals (SDGs) framework. In addition, we propose to overcome the problem of calculating a single number by constructing a strong-weak sustainability performance interval depending on the choice of the compensability level in the aggregation stage of individual indicators. One of the advantages of this interval is that it provides information on both the average performance and the worst value of the set of indicators considered for each SDG. Moreover, it also extends the analysis for the people, planet, prosperity, peace, and partnership dimensions defined by the 2030 Agenda. As an example of application, we constructed these intervals for 50 Spanish cities, which are provincial capitals. This application lets us get a more accurate vision that can serve as a valuable tool for better urban planning design.

1. Introduction

In recent decades there has been a mass migration from rural to urban areas. It is estimated that 68 per cent of the world's population will be urban by 2050 (United Nations, 2018). In the light of an increasing number of cities and city dwellers, urban growth is closely related to the need for sustainable development. In 2015, the United Nations adopted 17 Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development to address global challenges for the people, the planet, the peace, the prosperity and the partnership. Within the broader framework of the 2030 Agenda, SDG 11 "sustainable cities and communities" aims to make cities inclusive, safe, resilient and sustainable. Still, it is recognized that all other SDGs will also need to be met in the remaining cities. The UN Sustainable Development Solutions Network (SDSN) has been promoting integrated approaches to implement SDGs at different levels, including cities. There is, therefore, growing interest in measuring urban sustainability, for example, the SDSN network in the US has developed the US cities report, whose aim is to calibrate 105 US cities' progress towards the SDGs. Also, in Italy, the SDSN Italy's built their own SDGs City Index, which has been developed to rank 101 municipalities. In 2016 Spain undertook the commitment with the EU Urban Agenda and the UN Urban Agenda. As such, the SDSN in Spain provided a report to measure the achievement of the SDGs in 100 cities in Spain (Sánchez de Madariaga et al., 2018).

Sustainability assessment methods of urban development including projects, indices, frameworks and tools, have become an active research field. Furthermore, the majority of these methods have focused on environmental aspects such as energy efficiency, renewable resources and the reduction of carbon emissions (Ameen et al., 2015). The Index of Sustainable Economic Welfare (ISEW) (Daly et al., 1994), and the Genuine Progress Indicator (GPI) (Progress, 1995) are two pioneering examples of economic indicators that extend traditional growth measures by adding costs associated with pollution and other unsustainable costs. They have been applied to many territories, mainly countries or regions (see for example, O'Mahony et al. (2018), Lawn (2005), Castañeda (1999), Sánchez et al. (2020) and Cook and Davídsódttir

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(2021)). Composite indicator-based approaches to assess urban performance, including sustainability issues, have attracted much attention since 2015. Some examples are: the UN Prosperity Index (Moreno et al., 2015), The Sustainable Cities Index (Batten and Edwards, 2016), The IESE Cities in Motion Index (CIMI) (Berrone et al., 2016), The Global Power City Index (GPCI) (Ichikawa et al., 2017), the Mercer's Quality of Living (Mercer, 2016), The Spatially Adjusted Liveability Index (SALI) Unit, the Cities of Opportunity (CoO) index (PWC, 2016), and the Sustainable Assessment by Fuzzy Evaluation (SAFE) index (Phillis et al., 2017). A recent review of urban sustainability assessment tools is provided in Kaur and Garg (2019), which concludes that the main shortcomings of the existing, conventional approaches for monitoring urban sustainability is that these tools cover only limited or few specific aspects of sustainability. In monitoring sustainable development, composite indicators have gained remarkable popularity because of the multi-dimensional nature of sustainability. A composite indicator involves the combination of single indicators that represent different dimensions of a concept whose description is the objective of the analysis (Saisana and Tarantola, 2002; Nardo et al., 2005, 2008). As main advantages, composite indicators are easy to interpret, and they can provide key findings to make performance comparisons at different territorial scales from countries to cities. In the field of ecological economics, a significant number of contributions have supported the benefits of using composite indicators to measure and compare the welfare or socio-economic performance of regions or states by incorporating sustainability concerns.

Despite the increasing use of composite indicators to summarize complex multi-dimensional issues, they have also been subject to criticism as they may send misleading, non-robust policy messages if they are poorly constructed or misinterpreted. Nevertheless, scholars agree that the measurement of sustainability city performance is helpful to define goals and strategies that imply several advantages for public decision-makers, and especially to understand the success of policy measures in facilitating sustainable growth at the local level (Giffinger et al., 2010; Yang et al., 2016; Munda, 2016). Moreover, as underlined by Niemann et al. (2017), the sustainability performance of cities is subject to an ever-growing number of monitoring tools. As an example of application to the Spanish municipalities, González-García et al. (2019) developed a methodology based on the application of an adapted Leopold Matrix for indicators selection, a re-scaling approach for normalization, an Analytic Hierarchy Process (AHP) for weighting and an additive method for aggregation. These authors, applied this methodology to assess urban sustainability of 64 municipalities located in Northwest Spain. Later, Rama et al. (2020) applied the previous approach for the analysis of the three main areas of sustainability (economy, society and environment) considering a set of Spanish cities as a case study. A ranking of these cities was made using several indicators based on available information on the internet to build a composite indicator for each of the three areas.

However, as pointed out by Saez et al. (2020), who compares 21 of these monitoring tools, there is a lack of knowledge about methodological issues. Thus, the validity of the selected indicators, the normalization approach, and finally, the weighting and aggregation of the underlying indicators are the topics of greater concern. Besides, another outstanding issue lies in the fact that sustainability city performance is provided to end-users focusing only on a final score with scarce information on the methodological aspects (Meijering et al., 2014).

A high percentage of Spain's population is living in urban areas (79.9%). The first report carried out by the SDSN network in Spain highlighted that the Spanish cities are making progress in meeting the 17 SDGs (Sánchez de Madariaga et al., 2018). This pioneering analysis was carried out following the methodology developed globally by the SDSN and concluded that in Spain 82% of the SDGs are halfway there, and that it is therefore necessary to make progress in sustainability at the urban level. As stated in this report, the study provided a non-comparative overview of the status of the SDGs, without making comparisons. However, despite the effort involved in defining indicators to evaluate each of the SDGs at the municipal level, no synthetic indicator is presented that would allow a global assessment to be made and therefore allow comparability between cities.

With these questions in mind, this paper aims to contribute to the empirical literature on urban sustainability measurement by considering Spain as a case study. First, we propose an integrated approach to build a sustainable cities' interval of composite indicators which relies on the Sustainable Development Goal framework provided by the SDSN network in Spain. We then consider the five dimensions (people, planet, peace, prosperity and partnership) of 16 SDGs and 81 indicators for the 50 Spanish capitals of the province in the year 2018. Unlike the SDSN Spanish report, we do not consider the SDG 14 "Life below water" as not all the cities (only cities on the coast or with a river beach) can provide data on this goal. Secondly, our methodological strategy is to use a weak-strong performance interval to overcome one of the major criticism of composite indices, which provide a single number and thus only show a single "big picture". The proposed performance interval is constructed depending on the level of compensability of individual dimensions or indicators. It provides a range of values that do not depend on a single aggregation function and allows cities to be ranked by considering the fact that they score high and that there is a balance at each stage of the aggregation. In addition, the possible influences of other factors, such as population and Gross Domestic Product (GDP) are also analysed.

The paper is structured as follows. Section 2 describes the methodology proposed to select the indicators, re-scale and normalize the data, as well as the weighting and aggregation procedure to construct the interval of composite indicators. In Section 3, the results of the proposed performance interval applied to 50 Spanish capitals of province are discussed for the five dimensions of sustainable development and for each SDG through tables and visualization tools. Finally, we conclude the paper with remarks in Section 4.

2. Methodology

The procedure to construct the proposed interval of composite indicators to assess urban sustainability in Spain is described in the following subsections.

2.1. Indicator selection and criteria

This study is applied to Spanish cities following the theoretical framework and data provided by the report "*Los objetivos del Desarrollo Sostenible en 100 ciudades españolas*" (Sánchez de Madariaga et al., 2018) developed by the Sustainable Development Solutions Network (SDSN) in Spain. The 2019 report covers 100 Spanish cities with more than 80 000 inhabitants. Representing all the regions of Spain, the 50 provincial capitals have been chosen for this study, including 15 million inhabitants and constituting 32% of the Spanish population (see Fig. 1).

Therefore, we regard the system of indicators that have been previously selected and validated to construct a decision matrix including the data set $X = x_{ij}$ $(i = 1, \ldots, n;\ j = 1, \ldots, m)$ where n denotes the number of cities and m the number of scoreboard indicators. The report contains 85 indicators for the 17 SDG, although for one of them, the 14 (underwater life), there are no data for a good number of cities only cities on the coast or with a river beach can provide data on this goal. Thus, we decided to remove this SDG and their corresponding indicators, then the number of criteria is $m = \sum m_k = 81$, where m_k is the number of criteria included in the kth SDG. In a broad sense sustainability has been viewed through the prism of three fundamental elements, economic growth, environmental protection and society. However, with the adoption of the 2030 Agenda, the concept of sustainable development has taken on a deeper meaning by adding two fundamental components: partnership and peace. In complying with

Fig. 1. Location on the map of the Spanish cities considered in the research with population *P* and *GDP* per capita.

the framework of the 2030 Agenda, the 16 SDGs are grouped into five dimensions, which have been expressed through the "5 Ps", or five pillars of sustainable development: people, planet, prosperity, as well as peace and partnerships, see Fig. 2. Readers can find more detailed information about this framework, the description of indicators and their corresponding data source in the above mentioned report (Sánchez de Madariaga et al., 2018).

It is also important to highlight that the indicators are selected according to their relevance at the local level in this framework. As at the municipal level it is not always possible for all indicators to obtain the data, we have adopted a logic to integrate the missing ones based on a proxy-approach which allowed us to overcome the problem. Thus, we use a single imputation method where the missing data for an indicator included in a specific SDG is filled by the corresponding percentile mean in the nearest indicators. For example, if there are three indicators in the SDG, and we only have two values for one city, the missing data for that indicator is replaced with the value corresponding to the mean of percentiles in the remaining two indicators with available data.

2.2. Re-scaling and normalizing the data

The data has been processed using the Sustainable Development Solutions Network's (SDSN) own methodology described in Sánchez de Madariaga et al. (2018), and similar to that already used in its other reports for US cities (http://unsdsn.org/resources/publications/us-cities-sdg-index) and for the Global SDG Index (http://sdgindex.org). As explained in the report the normalized value is transformed into a value ranging from 0–1 to 0–100 to be directly assessable with the rest of the indicators. This standardization transforms all indicators into a scale from "worst" (score 0) to "best" (score 100) to be compatible with all available sources. In addition, lower and upper limits have been set to eliminate outliers at both ends of the distribution . For this purpose, we compute the $(n \times m)$ normalized decision matrix $N = v_{ij}$, in which the normalized value v_{ij} is obtained by:

$$v_{ij} = \frac{x_{ij} - x_{j*}}{x_j^* - x_{j*}} \times 100; \quad i = 1, 2, \dots, n; \quad j = 1, 2, \dots, m \tag{1}$$

where x_j^* corresponds to the mean of the five cities with the best performance, whereas the 2.5% percentile is considered for the x_{j*}. However, in some indicators, these values are given by absolute quantitative thresholds detailed in the SDGs targets, while in other cases, these values are provided by experts (the complete information about lower and upper limits can be obtained from the report (Sánchez de Madariaga et al., 2018), Figure 8). Moreover, all v_{ij} values exceeding x_j^* are scored 100, and values below x_{j*} are scored 0. As a result, we obtain a normalized score pointing out the progress made towards achieving the SDGs, with 100% meaning that the goal has been achieved.

2.3. Weights and aggregation

To arrive at a sustainable cities' composite index, indicators, goals and dimensions need to be weighted and aggregated. This is a fundamental step in the construction of a composite index as the use of different methodologies has profound implications on the ranking (Nardo et al., 2005). In the literature, weighting techniques can be categorized into three groups: equal weighting, data-driven methods and participatory methods (El Gibari et al., 2018). In line with the

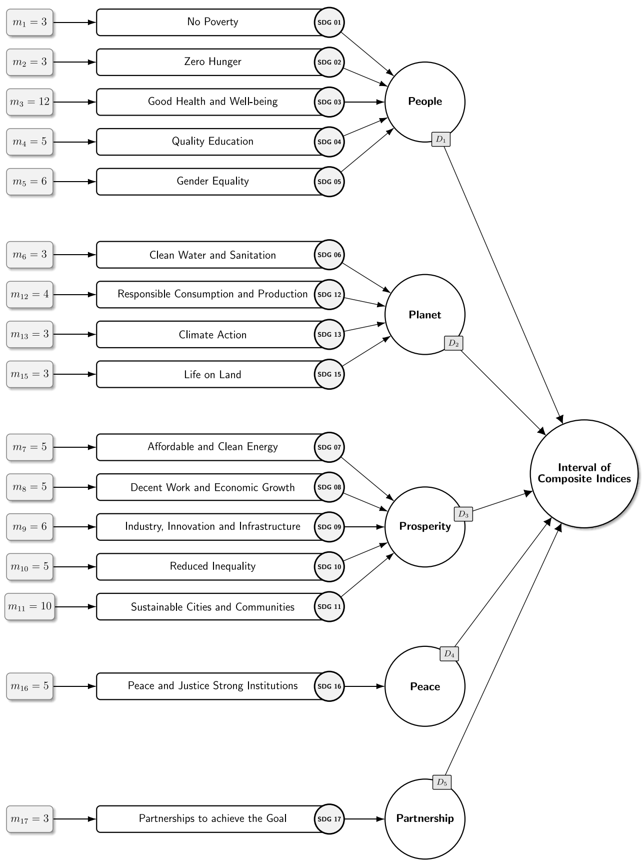

Fig. 2. Composite indicator hierarchy.
Source: Adapted from the SDSN framework in Spain Sánchez de Madariaga et al. (2018).

SDSN methodology, equal weights are used at the dimension, goal and indicator level. As a result, the relative weight of each indicator/goal/dimension is inversely proportional to the corresponding number of indicators to be aggregated.

There exists an ongoing debate on the choice of the aggregation technique as it determines the level of compensability or substitutability of the individual indicators (Greco et al., 2017). In the literature, an aggregation methodology can be classified into compensatory and non-compensatory depending on whether it permits compensability or not among individual indicators. A compensatory approach involves the use of linear functions, and by far the arithmetic mean is the method mostly used in practice. This approach aligns with a weak sustainability scenario since a bad performance in one indicator can be compensated by a good performance in another. In contrast, under a non-compensatory approach, the components of a composite indicator are non-substitutable. The most widespread non-compensatory method uses the minimum value of the indicator allowing for the maximum penalization for unbalanced values. This is the assumption underlying the choice of a strong sustainability scenario.

To define different levels of compensability we use the same methodology as the SDGs global index (Lafortune et al., 2018), which departs from the standard constant elasticity of substitution function (Arrow et al., 1961; Blackorby et al., 1982) to derive the composite index θ_{ik}:

$$\theta_{ik}(m_k, v_{ij}, \rho) = \left(\frac{1}{m_k} \sum_{j \in G_k} {v_{ij}}^{-\rho} \right)^{-\frac{1}{\rho}} \tag{2}$$

where v_{ij} denotes the normalized value of indicator j for the alternative i; G_k denotes the set of indicators associated with the kth SDG; m_k denotes the number of indicators included in this set, and ρ describes the substitutability across criteria which is ranged $-1 \leq \rho \leq \infty$.

The elasticity of substitution σ across SDGs criteria is defined as:

$$\sigma = \frac{1}{1+\rho} \tag{3}$$

with $0 \leq \sigma \leq \infty$. Then, parameter ρ, which is used in (2) can be straightforwardly derived as:

$$\rho = \frac{1-\sigma}{\sigma} \tag{4}$$

Following the recent theoretical discussion about when to use weak or strong sustainability indices (Gan et al., 2017), we propose to use both strong and weak aggregation methodologies to construct a strong-weak performance interval rather than a single composite index. Using a performance interval to construct a composite index depending on the level of compensability generates a lower and upper bound of the composite index (Mazziotta and Pareto, 2020; Garcia-Bernabeu et al., 2020b,a). The lower bound corresponds to the hypothesis of individual indicators' non-compensability (strong sustainability index), whereas the upper bound assumes full compensability (weak sustainability index). To derive the lower and upper bounds of the performance interval, we consider two special cases of the constant elasticity of substitution function θ_{ik}, which take the following form:

- Lower bound corresponding to the strong sustainability indicator. Consider the non-compensability variant of the aggregation methodology used when $\sigma = 0$ and $\rho = \infty$. In this case, the aggregation function for the criteria turns into a Leontief production function, and the minimum value determines the composite index:

$$\theta^s_{ik} = \min_{j \in G_k} v_{ij} \tag{5}$$

  where G_k is the set of indicators associated with the kth SDG.
- Upper bound corresponding to the weak sustainability indicator. Under a weak sustainability perspective, the criteria are considered perfect substitutes. This implies that $\sigma = \infty$ and $\rho = -1$. Hence, the composite index assumes the form of the arithmetic mean as follows:

$$\theta^w_{ik} = \frac{1}{m_k} \sum_{j \in G_k} v_{ij} \tag{6}$$

  where m_k is the number of criteria for the kth SDG.

As is often the case in most composite indicators, the SDNS framework is based on a system of indicators structured on a hierarchy of several levels. In our case, the normalized data matrix is structured in three levels, (see Fig. 3), where the 81 indicators are grouped into 16 SDGs, which are then grouped into the five dimensions of people, planet, prosperity, peace and partnership.

Therefore, we need to carry out a three-stages aggregation procedure as follows:

1. First aggregation (from indicators to goals). For each goal, we obtain the goal performance interval Θ_{ik}. On the left-hand side, we consider the minimum value of the single normalized indicators v_{ij}, which focuses on the criterion for the kth goal where a city performs worst. In contrast, on the right-hand side, we compute the arithmetic mean of the single normalized indicators v_{ij} included in each goal showing perfect substitutability.

$$\Theta_{ik} = \left[\theta^s_{ik}, \theta^w_{ik}\right] = \left[\min_{j \in G_k} v_{ij}\, ,\ \frac{1}{m_k} \sum_{j \in G_k} v_{ij} \right] \tag{7}$$

   where G_k is defined as the criteria set for the kth goal, and m_k is the number of criteria for the kth goal.

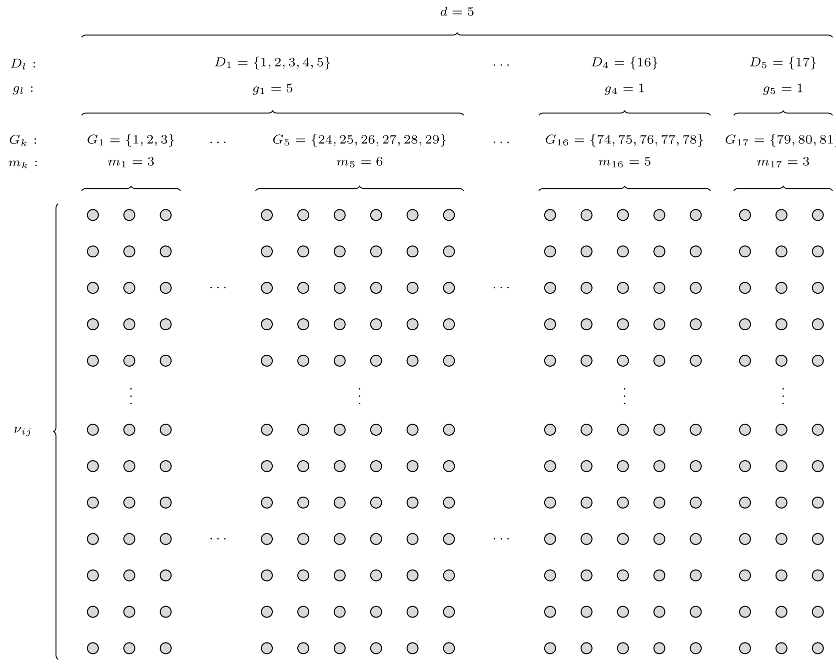

Fig. 3. Normalized data matrix structure and the hierarchy of criteria, goals and dimensions.

2. Second aggregation (from goals to dimensions). For each dimension, we derive the dimension performance interval Δ_{il} as follows:

$$\Delta_{il} = \left[\delta^s_{il}, \delta^w_{il}\right] = \left[\min_{k \in D_l} \theta^s_{ik}\,,\ \frac{1}{g_l} \sum_{k \in D_l} \theta^w_{ik}\right] \tag{8}$$

where D_l is defined as the set of goals associated with the lth dimension, and g_l corresponds to the number of goals for the lth dimension.

3. Third aggregation (from dimensions to index). We obtain the interval of composite indices Γ_i for each city. Note that at this level of the aggregation, we decide to consider as the lower bound the arithmetic mean of the strong scores for each dimension, while the upper bound is the arithmetic mean of the weak dimension indicator:

$$\Gamma_i = \left[\gamma^s_i, \gamma^w_i\right] = \left[\frac{1}{d} \sum_{l=1}^{d} \delta^s_{il}\,,\ \frac{1}{d} \sum_{l=1}^{d} \delta^w_{il}\right] \tag{9}$$

where d is the number of dimensions.

It seems particularly interesting to analyse the balance of the sustainability performance for a city taking into account the length of the Γ_i performance interval. To this end we propose a ratio, denoted as β_i to measure the link between the sustainability performance measured by the γ^w_i interval and its length given by the difference between the γ^w_i and the γ^s_i index. Thus, the value of β_i ratio is obtained as follows:

$$\beta_i = \frac{\gamma^w_i}{\gamma^w_i - \gamma^s_i} \tag{10}$$

The higher the length of the Γ_i performance interval, the lower the β_i will be, and thus it could be said that there is a great compensability among indicators. On the contrary, the lower the length of the Γ_i performance interval, the higher the β_i will be, and as result it is right to conclude that there is a balance between indicators.

To conclude this section, we shall briefly summarize by means of the flow chart in Fig. 4, the main steps of the methodology that has been described above.

3. Results and discussion

3.1. Specific composite indicator interval outcomes

Measuring progress on the SDGs is a very important tool for cities, as it allows each municipality to benchmark its progress against the SDGs and against other similar cities, both in the same country and globally. This paper proposes a new approach that consists of computing a composite performance interval based on different aggregation rules to assess the overall SDG performance at the urban level. It should be noted that the proposed interval of composite indicator has been calculated within the five dimensions (people, planet, peace, prosperity and partnership) and for the overall performance.

In the most comprehensive approach to assessing SDG overall cities performance, we distinguish two main results depending on the choice of the aggregation rule. The lower bound corresponds to a non-compensability aggregation rule (strong sustainability perspective) and provides the worst performance of the group of indicators or dimensions that has been aggregated. It is proven that the consideration of a strong sustainability perspective successfully identifies the potential areas of improvement of each city. The upper bound is constructed allowing for full compensation using a linear rule-based of weighted or additive aggregation. From this point of view, poor performance in some indicators/goals is compensated by sufficiently high values in other indicators.

Furthermore, by looking at the five dimensions separately, the composite performance indicator at this level can indeed reveal patterns that do not directly emerge by looking at the overall composite index. Thus, the suggested approach provides an additional layer of information as it provides much richer information than a single composite index allowing the modeller to interpret the meaning of the composite measures and carry out corrective measures where necessary. Besides providing a global comparison at city level, the proposed methodology provides warning signals to policymakers on the areas where the dimensions need further improvements. In this sense, the results of this proposal are addressed to municipal policy makers as a useful tool for prioritizing action.

Step 1: Define the hierarchy of criteria, goals and dimensions according to the theoretical framework.

Step 2: Data preparation. a) Create the input data table with the values of selected indicators for each city; b) estimate missing values; c) discuss the presence of outliers; d) provide the ideal and anti-ideal values x_j^* and x_{j*}.

Step 3: Construct the normalized decision matrix $N = \nu_{ij}$, in which the normalized value ν_{ij} is obtained by:

$$\nu_{ij} = \frac{x_{ij} - x_{j*}}{x_j^* - x_{j*}} \times 100; \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots m.$$

Step 4: First aggregation. Compute the goal performance interval.

$$\Theta_{ik} = [\theta_{ik}^s, \theta_{ik}^w] = \left[\min_{j \in G_k} \nu_{ij}\,,\ \frac{1}{m_k} \sum_{j \in G_k} \nu_{ij}\right]$$

where G_k is defined as the criteria set for the k–th goal, and m_k is the number of criteria for the k–th goal.

Step 5: Second aggregation. Calculate the dimension performance interval Δ_{il} as follows:

$$\Delta_{il} = [\delta_{il}^s, \delta_{il}^w] = \left[\min_{k \in D_l} \theta_{ik}^s\,,\ \frac{1}{g_l} \sum_{k \in D_l} \theta_{ik}^w\right]$$

where D_l is defined as the set of goals associated with the l–th dimension, and g_l corresponds to the number of goals for the l–th dimension.

Step 6: Third aggregation. Calculate the interval of composite indices Γ_i for each city:

$$\Gamma_i = [\gamma_i^s, \gamma_i^w] = \left[\frac{1}{d} \sum_{l=1}^{d} \delta_{il}^s\,,\ \frac{1}{d} \sum_{l=1}^{d} \delta_{il}^w\right]$$

where d is the number of dimensions.

Step 7: Determine the β_i ratio:

$$\beta_i = \frac{\gamma_i^w}{\gamma_i^w - \gamma_i^s}$$

Step 8: Rank the cities with highest β_i ratio.

Fig. 4. Stepwise procedure for performing the interval of composite indicators.

3.2. Ranking of cities

After compiling the data of the selected cities, the mathematical methodology detailed in Section 2 has been applied to derive the strong and weak interval Γ of composite indicators. The analysis of the strong-weak interval of composite indicators highlights the worst and the best sustainability urban performance of the cities being studied by considering the SDGs framework.

Table 1 displays the overall interval Γ with the values of γ^s and γ^w, as well as the β ratio for each city. Moreover, the ranking position according to the β ratio as well as the strong and weak composite indicators are listed as r^β, r^s and r^w, respectively. Finally, the last column shows the positions gained (>0) or lost (<0) climbing or dropping in the ranking when the cities are sorted by the β ratio instead of the weak composite indicator. The ranking is headed by cities with a high value of γ^w but with a lower length of Γ performance interval indicating a balance among dimensions of sustainable development. Following this sorting procedure, the ranking is now headed by the cities of Zaragoza, Oviedo and Córdoba. On the other hand, the cities at the bottom of the ranking are Valencia, Palma de Mallorca and Almería.

For example, Zaragoza lies in the first position of the ranking according to the β ratio, and when the strong aggregation rule is applied ($r^s = 1$), thus obtaining the highest value for the lower bound of the composite indicator ($\gamma^s = 28.2\%$). However, within a weak sustainability perspective ($\gamma^w = 58.5\%$) falla this city to the 8th position compared to the others ($r^s = 8$). Therefore, Zaragoza climbs seven places in the ranking when priority is given to balance. Meanwhile, Vitoria-Gasteiz, which is ranked in the sixth place according to the β ratio, reaches the first position ($r^w = 1$) with the highest score ($\gamma^w =$

Table 1
Overall interval of composite indicators and ranking of cities sorted by β ratio.

City	$\Gamma = [\gamma^s, \gamma^w]$	β	r^β	r^s	r^w	$(r^w - r^\beta)$
Zaragoza	[28.2, 58.5]	1.93	1	1	8	7
Oviedo	[23.7, 57.4]	1.70	2	2	10	8
Córdoba	[21.8, 54.0]	1.68	3	5	23	20
Soria	[22.1, 58.7]	1.61	4	4	6	2
Palencia	[21.5, 57.5]	1.60	5	6	9	4
Vitoria-Gasteiz	[23.3, 62.6]	1.59	6	3	1	−5
Tarragona	[20.0, 55.4]	1.56	7	7	16	9
Valladolid	[19.4, 55.1]	1.54	8	8	19	11
Albacete	[19.2, 55.9]	1.52	9	9	14	5
Ciudad Real	[18.2, 54.0]	1.51	10	11	22	12
Lleida	[18.3, 54.6]	1.50	11	10	20	9
Badajoz	[15.5, 47.3]	1.49	12	17	44	32
Guadalajara	[17.9, 57.2]	1.46	13	12	12	−1
Huesca	[17.2, 55.2]	1.45	14	14	18	4
Murcia	[14.9, 49.8]	1.43	15	18	35	20
Segovia	[16.5, 55.9]	1.42	16	15	15	−1
Logroño	[17.3, 61.4]	1.39	17	13	2	−15
Barcelona	[14.2, 52.2]	1.37	18	20	27	9
Málaga	[12.9, 48.0]	1.37	19	22	40	21
Granada	[13.4, 50.5]	1.36	20	21	33	13
Burgos	[15.5, 59.6]	1.35	21	16	3	−18
Santander	[14.7, 58.5]	1.33	22	19	7	−15
Sevilla	[11.7, 47.6]	1.33	23	29	43	20
Pontevedra	[12.0, 49.2]	1.32	24	27	36	12
La Coruña	[11.6, 47.8]	1.32	25	30	42	17
Orense	[11.4, 48.1]	1.31	26	31	39	13
León	[12.1, 52.1]	1.30	27	25	28	1
Teruel	[11.3, 48.7]	1.30	28	33	37	9
Cádiz	[11.0, 48.1]	1.30	29	35	38	9
Girona	[12.1, 54.0]	1.29	30	26	24	−6
Cuenca	[11.3, 50.8]	1.29	31	32	32	1
Ávila	[12.6, 57.2]	1.28	32	24	11	−21
Donostia	[12.9, 59.2]	1.28	33	23	4	−29
Castellón de la Plana	[11.8, 55.2]	1.27	34	28	17	−17
Lugo	[10.5, 51.8]	1.25	35	36	29	−6
Pamplona/Iruña	[11.1, 56.5]	1.25	36	34	13	−23
Bilbao	[10.2, 53.8]	1.23	37	37	25	−12
Alicante	[8.9, 51.2]	1.21	38	40	31	−7
Cáceres	[9.3, 54.0]	1.21	39	39	21	−18
Madrid	[9.9, 58.8]	1.20	40	38	5	−35
Zamora	[7.8, 47.9]	1.19	41	41	41	0
S.C. de Tenerife	[6.7, 46.0]	1.17	42	42	48	6
Toledo	[6.6, 52.5]	1.14	43	43	26	−17
Las Palmas de G.C.	[5.6, 47.0]	1.14	44	45	46	2
Huelva	[5.4, 46.7]	1.13	45	46	47	2
Salamanca	[5.7, 50.0]	1.13	46	44	34	−12
Jaén	[5.1, 45.7]	1.13	47	47	49	2
Valencia	[5.0, 47.2]	1.12	48	48	45	−3
Palma de Mallorca	[3.3, 51.5]	1.07	49	49	30	−19
Almería	[2.0, 41.2]	1.05	50	50	50	0

62.6%) if the weak perspective is applied, but has the third position ($r^s = 3$) from the strong perspective. As shown in the last column, the city drops five places in the ranking if the SDGs balance prevails over the option of compensability among criteria.

The relationship between γ^w and γ^s provides valuable information on the city's management of its sustainability. Furthermore, two structural factors are considered to expand the analysis of the weak-strong performance index for each city: population and GDP. This information has been obtained from the Spanish National Institute of Statistics (INE) for 2019 (most recent data available when performing this study). To better analyse it, Fig. 5 is presented where the bubble size represents the GDP per capita, and the intensity of the bubble colour represents population.

Fig. 5 defines four quadrants based on the median of each indicator. Those cities, with high values in both weak and strong indicators, appear in Quadrant I (top-right); this is the case of Zaragoza and Vitoria-Gasteiz. Quadrant II (top-left) gathers cities with a good performance, on average given by γ^w score, although several SDGs achieve low scores as shown by the γ^s score. This is the case of Madrid. Then, Quadrant III (bottom-left) presents the cities which are bad-scored in both indicators. Finally, Quadrant IV (bottom-right) gathers cities with low γ^w but γ^s over the median.

It should be pointed out that more than 70% of the cities lie in Quadrant I (top-right) and Quadrant III (bottom-left). In both quadrants, the interval is small as both indicators have similar scores. A more detailed analysis of the urban cities performance at the level of goals and dimensions is provided below.

3.3. Monitoring city performance by SDGs and dimensions

Bearing in mind that we consider 16 SDGs and their corresponding five dimensions, it is necessary to extend the information provided by the overall interval of composite indicators. The analysis by dimensions is provided in Table 2 through the Δ interval of composite indicators with the values of δ^s and δ^w for each city. Therefore, we employ charts to illustrate the urban sustainability profiles of each city (see Fig. 6). In profiling a city, we highlight in the chart the strong performance given by the δ^s value of a goal with dark petals, while the weak performance given by δ^w score appears with light petals. Moreover, each of the five dimensions of the planet, people, prosperity, peace and partnership, is given a different colour. In addition, the corresponding overall interval of composite indicators and the β ratio are also indicated on a label to the right of the chart.

This analysis provides additional insights to investigate the level of compliance with SGDs at the urban level. In this sense, this way of visualization is a valuable tool to guide the planning of city resources towards those SDGs with the worst performance and to highlight those areas in which the city achieves a good position. In what follows, we will explain in more detail some of the above-mentioned city charts. The complete results at SDGs level for the 50 capitals of province (sorted alphabetically), as well as all the cities' profiles can be downloaded by clicking on the following link: Supplementary material.

Notice that 36% of the cities in Fig. 5 scored high in both indicators of Quadrant I. Zaragoza (Fig. 6(a)) and Vitoria-Gasteiz (Fig. 6(b)) are the best scored cities with high values in both indicators. Zaragoza is the capital of province of Aragón and it is the fifth most populated in Spain. GDP per capita was above the national average. The scores of SDG 6, SDG 16 and SDG 17 for Zaragoza, yield γ^s over 50% and γ^w over the 70%. Within these three SDGs, three of the five dimensions (planet, peace and partnership) are represented. Vitoria-Gasteiz is the capital city of the Basque Country and of Alava territory. With a population of around 250 000 inhabitants, it has the highest per capita income in the whole of Spain. It presents values above 60% in most SDGs but stands out above all in the dimension of prosperity and the planet, where SDG 6 exceeds 80%. However, there are some goals in the people and prosperity dimension where there is underperformance, as indicated by γ^s (dark petals).

As stated above, in Quadrant II, we highlight the case of Madrid. Fig. 6(c) plots in detail the performance of Madrid for each SDG and for the five dimensions. It can be seen that SDG 2, SDG 10, or SDG 15 have a γ^w (light petals) under the 40% and a γ^s (dark petals) under the 10%. On the other hand, SDG 6 and SDG 8 are more equilibrated as γ^w is higher than 70% and γ^s higher than 50%. Similar results can be seen in Pamplona and the other cities of the second quadrant of Fig. 5.

As an extreme case, in Quadrant III Almería is worth pointing out, as shown in Fig. 6(d). All strong indicators are under the 40%. Peace and partnership have strong null indicators. Just two weak indicators are over the 60%, SDG 3 and SDG 6. Thus, the homogeneity of results is high, but they are significantly upgradable, indicating that Almería has significant challenges to address in all dimensions of sustainable development.

On the other hand, Quadrant IV (bottom-right) includes cities with low γ^w but γ^s over the median. This is the case of Barcelona (Fig. 6(e)). There are just seven weak indicators above 60% (SDG 1, SDG 3, SDG 4, SDG 7, SDG 8, SDG 13 and SDG 16), but more than half

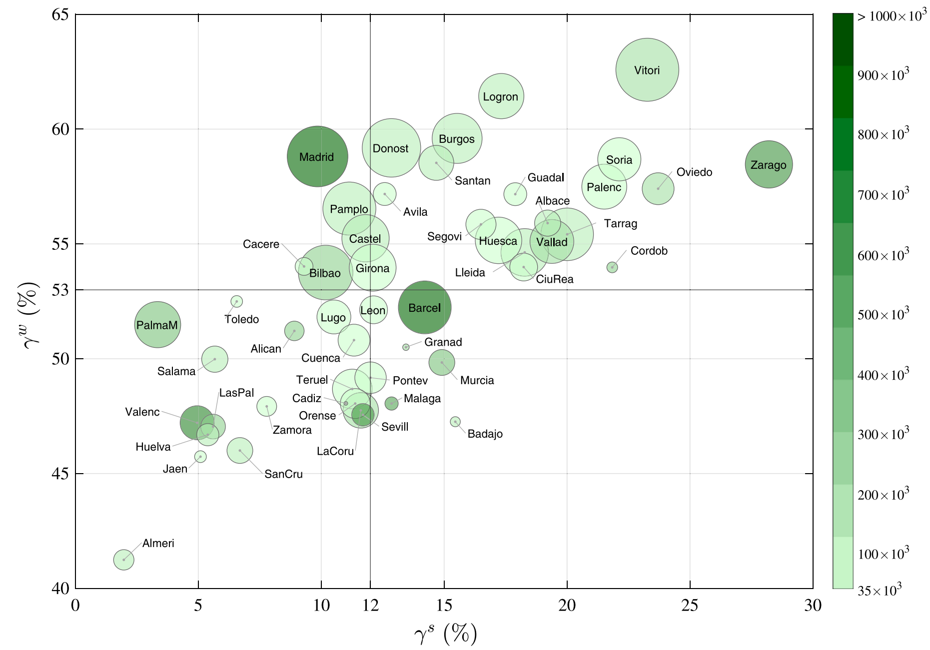

Fig. 5. Weak and Strong indicators relationship considering population and GDP per capita.

of the strong indicators are over the 20%, which is a relevant score considering that the mean is at 12% and the highest is 28.2%. Cities with significant issues to improve can also be found in this quadrant since both indicators are low. For example, Valencia (Fig. 6(f)) is being penalized due to extremely bad results of some of the SDGs, such as the SDG 11, SDG 15, SDG 16 or SDG 17, all in different dimensions. Remarkably, some of them can change in a short period of time as SDG 16 linked to justice. Once the corruption cases are closed, the indicator might improve.

4. Conclusions

Composite indicators are increasingly recognized as useful tools in policy analysis and public communication to assess the performance of units, such as countries, regions and even cities, with respect to a multidimensional phenomenon. The main advantage is that they can be used to illustrate complex and sometimes difficult to understand issues represented by a huge number of individual indicators. On the other hand, "the big picture" provided by the composite index may suggest to users (especially policy-makers) to come to simplistic analysis or policy conclusions. Being aware of the pros and cons of using composite indicators to monitor urban sustainability performance could imply, our proposal must be seen as a starting point for initiating discussion and attracting public interest. Besides, we propose to overcome the problem of calculating a single number by constructing a strong-weak sustainability performance interval depending on the choice of the compensability level in the aggregation stage of individual indicators. Furthermore, the composite indicator interval provides additional insights to investigate the level of compliance with SGDs at the urban level and could be a valuable tool to guide the planning of city resources towards those SDGs with the worst performance and highlight those areas in which the city achieves a good accomplishment.

The present work allows for a quantitative and objective evaluation of the sustainability of cities considering the construction of an interval of composite indicators that can be of great interest for decision making in an urban planning context. Our objective is to investigate compliance with the SDGs at the urban level by ranking cities. To this end, we have developed a methodology to build an interval of composite indicators based on the information generated by the SDSN network in Spain that evaluates the level of compliance Sustainable Development Goals (SDGs) defined by both the 2030 Agenda and the New Urban Agenda of the United Nations.

As a novelty of the methodological proposal, the interval of composite indicators is developed to overcome one of the most common criticisms in the construction of composite indicators related to the compensability of individual indicators in the aggregation stage. In this way, and starting from different values of the constant elasticity of substitution, the lower limit is calculated with a non-compensatory approach. In contrast, the upper limit of the interval allows for a total compensation. Since the SDGs start with indicators to measure each goal and are also grouped into five dimensions, the aggregation has been carried out to obtain the interval of composite indices at three levels. The first level involves aggregating the indicators for each goal. At the second level, the goals corresponding to each of the five pillars of sustainable development are aggregated, and finally, the global interval is presented. Moreover, we propose to rank the cities by considering the balance between the strong and weak perspectives given by the β ratio.

With a high percentage of Spain's population living in urban areas, new tools are needed to guide policies towards a new era of inclusive and sustainable prosperity. Our main intention is not to point out a better or worse performance of cities according to SDG targets but to provide municipal policy-makers with a helpful tool for prioritizing action. Furthermore, this approach aims to provide accessible and understandable information for all audiences: government officials, government technicians, the private sector, the media and the general public. This report is intended to assist the reflection already underway in the cities on their priorities and help them take early action. Although the methodology has been applied to Spanish cities as an example, it could be used to any other group of cities when monitoring their sustainability performance, as long as they share the same methodology in selecting individual indicators.

The methodology proposed in this paper has been applied to assess compliance with 16 of the 17 SDGs in a total of 50 Spanish provincial capitals. The results obtained for the global interval of composite

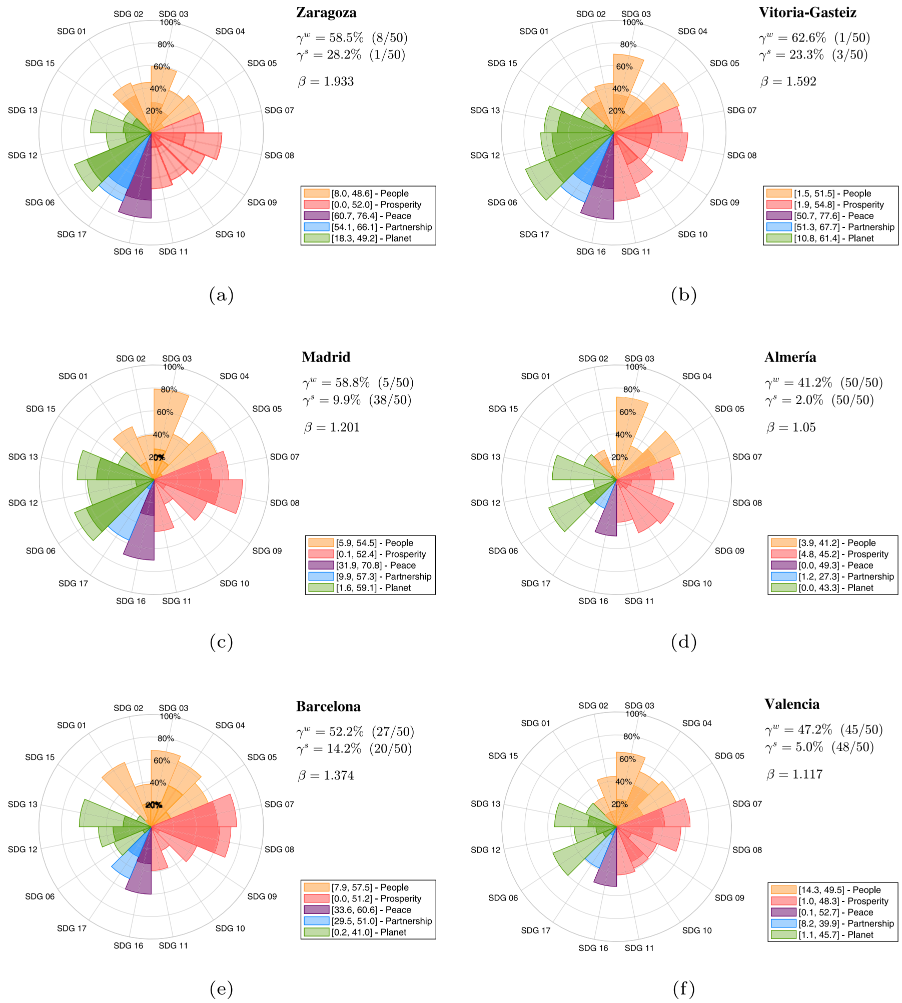

Fig. 6. Dimensions and SDGs analysis for several cities.

indicators at the urban scale show that the top positions in the ranking according to the β ratio are occupied by the cities of Zaragoza, Oviedo and Córdoba. However, if we were to take into account a fully compensated aggregation rule, the first three cities would be Vitoria-Gasteiz, Oviedo and Burgos. Most cities either have better results from both the strong and weak perspectives or approach all dimensions with interest and acceptable results, although there is always room for improvement. Just a few cities show heterogeneity, with a disparity between the weak and strong perspectives. These cities focus their results on a specific area, demonstrating an opportunity for improvement in the management of those SDGs with lower performance.

In addition, we have taken into account some structural variables such as population and per capita income to assess the cities, generating a visualization map that provides additional information to the global level of SDGs compliance measured through the interval of composite indicators. Also, to expand the information at the global level, an analysis is presented at the level of SDGs and dimensions using charts to illustrate the urban sustainability profile of the cities. In this way, it is possible to deepen the picture of the sustainability of cities measured through the SDGs, which can serve as a warning system to assist in policy decision making.

CRediT authorship contribution statement

Vanesa G. Lo-Iacono-Ferreira: Investigation, Resources, Validation, Writing – original draft. **Ana Garcia-Bernabeu:** Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Adolfo Hilario-Caballero:** Conceptualization, Data curation, Investigation, Software, Visualization, Writing – review & editing. **Juan Torregrosa-López:** Formal analysis, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.131982.

Table 2
Interval of composite indicators by dimension: Cities sorted alphabetically.

City	People	Prosperity	Peace	Partnership	Planet
Albacete	[4.3, 49.1]	[0.0, 52.6]	[58.3, 80.7]	[26.4, 48.0]	[7.1, 49.1]
Alicante	[4.1, 45.3]	[0.0, 47.3]	[33.9, 72.8]	[6.5, 44.3]	[0.0, 46.4]
Almería	[3.9, 41.2]	[4.8, 45.2]	[0.0, 49.3]	[1.2, 27.3]	[0.0, 43.3]
Ávila	[0.0, 48.9]	[0.0, 51.0]	[49.4, 80.2]	[3.8, 44.5]	[9.7, 61.2]
Badajoz	[13.6, 45.7]	[0.0, 50.3]	[48.9, 56.7]	[11.8, 32.6]	[3.0, 50.9]
Barcelona	[7.9, 57.5]	[0.0, 51.2]	[33.6, 60.6]	[29.5, 51.0]	[0.2, 41.0]
Bilbao	[0.9, 50.0]	[0.0, 51.2]	[50.0, 74.5]	[0.0, 51.1]	[0.0, 41.9]
Burgos	[0.0, 45.0]	[0.7, 56.9]	[0.0, 60.9]	[76.9, 81.3]	[0.0, 53.9]
Cáceres	[0.0, 47.6]	[2.5, 52.0]	[37.0, 66.8]	[1.8, 48.2]	[5.2, 55.6]
Cádiz	[0.0, 53.6]	[0.0, 42.1]	[45.3, 67.5]	[9.7, 24.9]	[0.0, 52.2]
Castellón de la Plana	[2.5, 46.0]	[1.0, 49.9]	[53.1, 70.5]	[2.4, 59.3]	[0.0, 50.6]
Ciudad Real	[16.1, 51.3]	[0.0, 48.9]	[54.3, 82.2]	[6.0, 41.0]	[14.8, 46.5]
Córdoba	[7.1, 45.5]	[1.2, 43.3]	[47.0, 65.1]	[48.0, 64.8]	[5.9, 51.3]
Cuenca	[0.0, 43.4]	[0.3, 53.3]	[56.4, 73.5]	[0.0, 44.1]	[0.0, 39.7]
Donostia	[0.7, 52.0]	[0.0, 52.3]	[52.5, 79.0]	[11.0, 54.1]	[0.0, 58.5]
Girona	[15.2, 55.6]	[0.0, 50.0]	[35.1, 75.0]	[10.2, 41.9]	[0.0, 47.4]
Granada	[7.1, 51.2]	[2.4, 43.3]	[48.2, 65.2]	[6.4, 43.4]	[3.2, 49.4]
Guadalajara	[0.0, 47.3]	[0.0, 46.5]	[39.1, 78.5]	[30.2, 60.0]	[20.2, 53.6]
Huelva	[0.0, 48.0]	[0.0, 44.3]	[26.9, 72.7]	[0.0, 30.3]	[0.0, 38.1]
Huesca	[0.7, 49.4]	[0.0, 51.9]	[63.9, 85.7]	[11.3, 34.2]	[10.1, 54.6]
Jaén	[0.0, 47.5]	[0.0, 47.4]	[17.9, 58.4]	[0.0, 22.4]	[7.6, 53.0]
La Coruña	[0.0, 43.6]	[0.0, 45.3]	[52.7, 67.7]	[5.3, 38.3]	[0.0, 43.9]
Las Palmas de G.C.	[0.7, 47.3]	[2.0, 44.0]	[21.6, 56.2]	[0.2, 33.0]	[3.5, 54.8]
León	[0.0, 44.6]	[0.0, 46.8]	[59.7, 79.2]	[1.0, 43.0]	[0.0, 47.0]
Lleida	[20.5, 45.4]	[0.0, 53.4]	[41.7, 68.0]	[26.3, 59.5]	[2.9, 46.9]
Logroño	[3.5, 51.2]	[2.0, 56.6]	[47.9, 86.7]	[33.2, 64.4]	[0.0, 48.4]
Lugo	[0.0, 38.9]	[0.0, 56.2]	[44.9, 75.2]	[0.4, 40.0]	[7.3, 48.8]
Madrid	[5.9, 54.5]	[0.1, 52.4]	[31.9, 70.8]	[9.9, 57.3]	[1.6, 59.1]
Málaga	[12.1, 48.8]	[1.0, 44.0]	[16.8, 54.4]	[25.4, 47.5]	[9.1, 45.5]
Murcia	[18.4, 45.7]	[0.0, 38.8]	[50.8, 77.2]	[5.4, 50.3]	[0.0, 37.2]
Orense	[0.0, 40.4]	[0.6, 48.5]	[44.9, 65.6]	[1.4, 36.9]	[10.0, 48.8]
Oviedo	[0.0, 46.9]	[3.0, 52.1]	[58.0, 78.1]	[47.6, 65.9]	[9.9, 44.0]
Palencia	[0.0, 44.3]	[0.3, 51.8]	[52.0, 81.6]	[45.4, 60.7]	[9.9, 49.1]
Palma de Mallorca	[6.3, 49.7]	[0.1, 48.6]	[8.2, 50.7]	[0.8, 53.2]	[1.4, 55.2]
Pamplona/Iruña	[0.0, 52.1]	[0.0, 54.6]	[37.2, 66.6]	[18.5, 55.2]	[0.0, 54.1]
Pontevedra	[0.0, 45.3]	[1.8, 49.8]	[57.1, 75.1]	[0.5, 34.9]	[0.6, 40.8]
Salamanca	[0.0, 41.9]	[0.0, 46.5]	[20.1, 62.4]	[6.4, 46.0]	[1.8, 53.1]
S.C. de Tenerife	[0.0, 46.2]	[0.0, 43.6]	[24.5, 50.3]	[0.0, 34.8]	[9.0, 55.1]
Santander	[1.8, 43.8]	[1.0, 53.3]	[61.8, 80.9]	[8.6, 56.4]	[0.2, 58.2]
Segovia	[0.4, 44.5]	[0.0, 49.7]	[79.1, 88.7]	[2.9, 52.3]	[0.0, 44.0]
Sevilla	[3.5, 47.5]	[0.0, 44.0]	[51.1, 71.8]	[3.8, 40.5]	[0.0, 34.0]
Soria	[0.0, 45.4]	[0.0, 54.1]	[51.1, 82.5]	[50.1, 55.1]	[9.4, 56.3]
Tarragona	[7.9, 49.0]	[2.0, 50.4]	[39.5, 62.9]	[50.6, 69.8]	[0.0, 44.9]
Teruel	[1.4, 46.4]	[0.4, 52.2]	[54.6, 78.2]	[0.0, 33.5]	[0.0, 33.2]
Toledo	[0.0, 51.9]	[0.0, 41.5]	[17.9, 70.1]	[2.7, 51.7]	[12.3, 47.1]
Valencia	[14.3, 49.5]	[1.0, 48.3]	[0.1, 52.7]	[8.2, 39.9]	[1.1, 45.7]
Valladolid	[3.8, 46.4]	[2.0, 52.2]	[60.5, 77.0]	[30.5, 54.7]	[0.0, 45.1]
Vitoria-Gasteiz	[1.5, 51.5]	[1.9, 54.8]	[50.7, 77.6]	[51.3, 67.7]	[10.8, 61.4]
Zamora	[0.0, 37.9]	[0.0, 49.8]	[38.4, 74.3]	[0.6, 32.4]	[0.0, 45.2]
Zaragoza	[8.0, 48.6]	[0.0, 52.0]	[60.7, 76.4]	[54.1, 66.1]	[18.3, 49.2]

References

Ameen, R.F.M., Mourshed, M., Li, H., 2015. A critical review of environmental assessment tools for sustainable urban design. Environ. Impact Assess. Rev. 55, 110–125.

Arrow, K.J., Chenery, H.B., Minhas, B.S., Solow, R.M., 1961. Capital-labor substitution and economic efficiency. Rev. Econ. Stat. 43 (3), 225–250. http://dx.doi.org/10.1007/s11573-018-0902-z.

Batten, J., Edwards, C., 2016. Sustainable cities index 2016. Arcadis Glob. 10, https://www.arcadis.com/en/knowledge-hub, accessed January 10, 2021.

Berrone, P., Ricart, J., Carraso, C., Ricart, R., 2016. IESE cities in motion index, 2016, 60.

Blackorby, C., Donaldson, D., Weymark, J.A., 1982. A normative approach to industrial-performance evaluation and concentration indices. Eur. Econ. Rev. 19 (1), 89–121.

Castañeda, B.E., 1999. An index of sustainable economic welfare (ISEW) for Chile. Ecol. Econom. 28, 231–244.

Cook, D., Davídsóttir, B., 2021. An estimate of the genuine progress indicator for iceland, 2000–2019. Ecol. Econom. 189, http://dx.doi.org/10.1016/j.ecolecon.2021.107154.

Daly, H.E., Cobb, Jr., J.B., Cobb, J.B., 1994. For the Common Good: Redirecting the Economy Toward Community, the Environment, and a Sustainable Future, Vol. 73. Beacon Press.

El Gibari, S., Gómez, T., Ruiz, F., 2018. Building composite indicators using multicriteria methods: a review. J. Bus. Econ. 1–24.

Gan, X., Fernandez, I.C., Guo, J., Wilson, M., Zhao, Y., Zhou, B., Wu, J., 2017. When to use what: Methods for weighting and aggregating sustainability indicators. Ecol. Indic. 81, 491–502.

Garcia-Bernabeu, A., Cabello, J.M., Ruiz, F., 2020a. A multi-criteria reference point based approach for assessing regional innovation performance in Spain. Mathematics 8 (5), 797.

Garcia-Bernabeu, A., Hilario-Caballero, A., Pla-Santamaria, D., Salas-Molina, F., 2020b. A process oriented MCDM approach to construct a circular economy composite index. Sustainability 12 (2), 618.

Giffinger, R., Haindlmaier, G., Kramar, H., 2010. The role of rankings in growing city competition. Urban Res. Pract. 3 (3), 299–312.

González-García, S., Rama, M., Cortés, A., García-Guaita, F., Núñez, A., Louro, L.G., Moreira, M.T., Feijoo, G., 2019. Embedding environmental, economic and social indicators in the evaluation of the sustainability of the municipalities of Galicia (northwest of Spain). J. Cleaner Prod. 234, 27–42.

Greco, S., Ishizaka, A., Tasiou, M., Torrisi, G., 2017. On the methodological framework of composite indices: A review of the issues of weighting, aggregation, and robustness. Soc. Indic. Res. 1–34.

Ichikawa, H., Yamato, N., Dustan, P., 2017. Competitiveness of global cities from the perspective of the global power city index. Procedia Eng. 198, 736–742.

Kaur, H., Garg, P., 2019. Urban sustainability assessment tools: A review. J. Cleaner Prod. 210, 146–158.

Lafortune, G., Fuller, G., Moreno, J., Schmidt-Traub, G., Kroll, C., 2018. SDG index and dashboards detailed methodological paper. Sustain. Dev. Solut. Netw..

Lawn, P.A., 2005. An assessment of the valuation methods used to calculate the index of sustainable economic welfare (ISEW), genuine progress indicator (GPI), and sustainable net benefit index (SNBI). Environ. Dev. Sustain. 7, 185–208. http://dx.doi.org/10.1007/S10668-005-7312-4.

Sánchez de Madariaga, I., García López, J., Sisto, R., 2018. Los objetivos de desarrollo sostenible en 100 ciudades españolas.

Mazziotta, M., Pareto, A., 2020. Composite indices construction: The performance interval approach. Soc. Indic. Res. 1–11.

Meijering, J.V., Kern, K., Tobi, H., 2014. Identifying the methodological characteristics of European green city rankings. Ecol. Indic. 43, 132–142.

Mercer, L., 2016. Quality of living rankings.

Moreno, E., Murguía, R., Lavagna, G., 2015. The city prosperity initiative: 2015 global city report.

Munda, G., 2016. Multiple criteria decision analysis and sustainable development. In: Multiple Criteria Decision Analysis. Springer, pp. 1235–1267.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., 2005. Tools for composite indicators building. Eur. Comm. ISPRA 15, 19–20.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., Giovannini, E., 2008. Handbook on constructing composite indicators.

Niemann, L., Hoppe, T., Coenen, F., 2017. On the benefits of using process indicators in local sustainability monitoring: Lessons from a dutch municipal ranking (1999–2014). Environ. Policy Govern. 27 (1), 28–44.

O'Mahony, T., Escardó-Serra, P., Dufour, J., 2018. Revisiting ISEW valuation approaches: The case of Spain including the costs of energy depletion and of climate change. Ecol. Econom. 144, 292–303. http://dx.doi.org/10.1016/J.ECOLECON.2017.07.024.

Phillis, Y.A., Kouikoglou, V.S., Verdugo, C., 2017. Urban sustainability assessment and ranking of cities. Comput. Environ. Urban Syst. 64, 254–265.

Progress, R., 1995. Gross production vs genuine progress. In: Excerpt from the Genuine Progress Indicator: Summary of Data and Methodology. Redefining Progress, San Francisco.

PWC, P., 2016. Cities of Opportunity. PwC, London, UK.

Rama, M., González-García, S., Andrade, E., Moreira, M.T., Feijoo, G., 2020. Assessing the sustainability dimension at local scale: Case study of spanish cities. Ecol. Indic. 117, 106687.

Saez, L., Heras-Saizarbitoria, I., Rodriguez-Nunez, E., 2020. Sustainable city rankings, benchmarking and indexes: Looking into the black box. Sustainable Cities Soc. 53, 101938.

Saisana, M., Tarantola, S., 2002. State-of-the-Art Report on Current Methodologies and Practices for Composite Indicator Development. Citeseer.

Sánchez, M., Ochoa M, W., Toledo, E., Ordóñez, J., 2020. The relevance of index of sustainable economic wellbeing. Case study of ecuador. Environ. Sustain. Indic. 6.

Unit, E.I., 2012. Best cities ranking and report: A special report from the economist intelligence unit.

United Nations, 2018. Revision of World Urbanization Prospects. United Nations: New York, NY, USA.

Yang, W.-C., Lee, Y.-M., Hu, J.-L., 2016. Urban sustainability assessment of Taiwan based on data envelopment analysis. Renew. Sustain. Energy Rev. 61, 341–353.