



Research article

Development and application of a composite circularity index

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ABSTRACT

Resource depletion and environmental pollution are increasingly a matter of concern for their adverse effects on ecosystems, human health, and the economy. Circular Economy (CE) practices can help us address these challenges. This paper proposes a composite circularity index (CI) to assess the level of implementation of CE practices. The main advantage of the proposed index is its ability to combine multiple indicators of circularity for different units operating in a given sector (given as inputs), using a 'Benefit of the Doubt' model. This new model is innovative in the manner it deals with ordinal scales and also by considering both relative and absolute performance indices. These indices are computed using mathematical programming tools, building on ideas from Data Envelopment Analysis models.

Although the model can be applied to any sector, this work addresses the hotel industry in particular. The selection of indicators for this CI was based on seven blocks of the Circular Economy Action Plan and a literature review of circular practices. An application of the proposed index is performed by using data from Portuguese and Spanish hotels. The proposed CI allows the identification of the organizations with the best and worst performance in implementing the CE practices and clarifying the benchmarks they could follow to improve their level of circularity. Moreover, the index analysis also provides specific targets for improvement, indicating which circular practices should be improved for the lower performers to reach the implementation levels of the best performers.

1. Introduction

Resource depletion and environmental pollution are increasingly a matter of concern for their adverse effects on ecosystems, human health, and the economy. This reveals the evident capacity constraints of the environment to serve as a supplier of resources and as a repository of waste, to assimilate waste and turn it back into useful products. The excessive exploitation of resources and the generation of enormous amounts of waste impair the interactions of the environment with the economy, as "everything is an input into everything else" (Pearce & Turner, 1989, p. 37). This justifies the importance of the Circular Economy (CE) as a more natural economic system. A CE following the Triple Bottom Line dimensions benefits the economy, society, and the ecosystem (Homrich et al., 2018). This represents a transition from a linear "take-make-waste" economy towards a CE, in which materials are kept in useful circulation to yield environmental, social, and economic benefits (Walzberg et al., 2021). As the economic and environmental outcomes result largely from the decisions of producers and consumers,

their behaviour needs to be adjusted to become more circular (Li et al., 2022). It is also necessary to observe and sustain the stocks of exhaustible resources and preserve the environment as a direct provider of utility for the other vital functions of the environment (Kurz and Salvadori, 1997). Consequently, Pearce and Turner (1989) highlight the importance of establishing conditions "for the compatibility of economies and their environments" for sustainable development.

CE aims to maximize the reduction and reuse of products and materials, thereby decoupling economic activities from resource depletion (Stahel, 2016; Linder et al., 2017). In this context, it is essential to create suitable tools for companies to assess the level of circularity of their practices and provide some insights on reducing their environmental footprint.

Multiple tools are available to assess circularity. One of the most widely used tools is the Life Cycle Assessment (LCA), which focuses mainly on the environmental impacts associated with the life cycle of a product or service (Sassanelli et al., 2019; Merli et al., 2018). Lonca et al. (2018) suggest using the natural resource depletion impact category in

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life cycle impact assessment through the IPAT equations (Impact = Population Affluence • Technology) and index decomposition analysis methods. Material flow analysis is another well-known method which tracks the physical flow of materials in space and time within a system (Rincón et al., 2013). A scoring system and circular economy principles have also been used to assess specific products' circularity levels, such as the existing eco-labels (Lanaras-Mamounis et al., 2022). Beyond these tools, some indices or indicators have been proposed for assessing the level of implementation of a CE but in different contexts. For example, EMF (2015) propose a Material Circularity Indicator (MCI) to measure the extent to which the linear flow has been minimized, and the restorative flow maximized, and how long and intensively it is used, relative to a similar industry-average product; Di Maio and Rem (2015) suggest a Circular Economy Index but focusing on the product and measuring Circularity as the fraction of recycled material from a product's end-of-life incorporated in new versions of the same product; Park and Chertow (2014) propose the Reuse Potential Indicator (RPI), which is focused specifically on the circularity of materials in a logic of LCA. As can be seen, most of the indices or indicators proposed to assess circularity are focused mainly on products and use the rationale associated with the LCA. Also, some tools have been suggested to assess the level of circularity of companies or other systems. However, these tools require a great deal of time, resources, and vast amounts of very detailed data, often uncertain in nature, hindering their use in assessing the CE practices of many units in a given sector. In addition to the indicators and tools found in the literature, Saidani et al. (2019) argue that new tools are required to support practitioners, decision-makers, and policy-makers towards more CE practices and to monitor the effects of CE adoption. This work considers a less demanding circularity assessment approach based on a qualitative evaluation of circularity practices. Consequently, it is more easily applicable as an index suitable to monitor the circularity of a large number of units.

In this study, a new composite circularity index (CI) is proposed to combine multiple indicators of CE practices in a given sector, using a novel 'Benefit of the Doubt' (BoD) model (Cherchye et al., 2007), modified to handle qualitative scales, to aggregate these indicators into a composite index, based on ideas from Data Envelopment Analysis (DEA). The BoD model is a popular framework for developing composite indices, for which many options are available (Greco et al., 2019). As a data-driven model, it does not require eliciting subjective weights for its components or assuming any predetermined trade-offs. Moreover, as BoD lets each entity under evaluation choose the most favourable weights, potential conflicts about weighting are dismissed.

The developed model ensures the BoD and DEA principles are used to respect the ordinal nature of the collected data, following solutions proposed in other DEA models for this purpose. As a further methodological innovation, the relative benchmarking perspective obtained using DEA is complemented with an absolute benchmarking perspective, considering an ideal benchmark characterized by full implementation of all CE practices.

Although the model can be applied to any sector, this work addresses the hotel industry in particular. The tourism sector was chosen because: i) it has been insufficiently studied as a possible context for CE initiatives and analyses (Panchal et al., 2021; Costa et al., 2020); ii) hotels are increasingly concerned with CE practices due to a new profile of tourists willing to pay a premium to promote environmental sustainability during their stay (Julião et al., 2020), which encourages hotels to incorporate more environmentally-friendly products and services (Dief and Font, 2010); and iii) hotels are conscious of the need to adopt practices to become more competitive (Al-Aomar and Hussain, 2017).

In the hotel industry, the CE is already a concern reflected in the adoption of several practices: the use of towels and bed sheets for more than one day, using shower gel dispensers in place of small, individual (usually plastic) bottles, using greywater systems (Manniche et al., 2019); reusing and recycling products at later stages of the life cycle, cascading use of food, buying or leasing items that have been used or

remanufactured (Jurgilevich et al., 2016); using biological products in rooms and restaurants, producing raw materials, redirecting plant and animal parts that are not fit for human consumption to other sectors (Manniche et al., 2019); using renewable energy, the adoption of energy efficiency policies (Ball and Taleb, 2011); renting, leasing, or sharing as modalities to acquire equipment (Stahel, 2011); outsourcing the laundering of bed linen, offering local food products at their restaurants (Sloan et al., 2013); or using online platforms to trade or exchange products or services (Gligorijevic, 2016).

The proposed index was applied to a set of hotels in two European countries where tourism represents an important contribution to their economy: Portugal and Spain (total contribution of 17.1% and 14.0%, respectively, to the Gross Domestic Product in 2019, per the Annual Research Report of the World Travel and Tourism Council). The selection of the indicators for this index is based on the seven interconnected building blocks of the Circular Economy Action Plan, updated in 2021. More specifically, the indicators assess a set of circular practices related to the blocks suggested in this plan and in the tourism sector literature.

After this introduction, a brief literature review on circularity frameworks is presented, focusing on the Circular Economy Action Plan. Section 3 presents the methodology developed to propose the CI. Section 4 presents a customization of the CI to hotels, its application, and the results obtained. Section 5 compares the results with other studies, and the study's main contributions are discussed. Finally, this research's main conclusions are drawn, highlighting the main managerial contributions and limitations.

2. Literature review

The concept of CE was introduced by Boulding (1966) and Pearce and Turner (1990), with contributions from diverse theoretical backgrounds, including industrial ecology, environmental and ecological economics (Homrich et al., 2018) and 'cradle-to-cradle' thinking (Braungart et al., 2007). CE is aimed at reducing environmental impact while promoting economic growth through business development (Kalmykova et al., 2018).

Different CE perspectives appear in the literature. For instance, Ünal and Shao (2019) define CE as "a sustainable development initiative with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows". Murray et al. (2017) consider CE as "new concepts of system, economy, value, production and consumption, leading to the sustainable development of the economy, environment and society". The CE concept is frequently considered an important driver of sustainable development (Panchal et al., 2021; Rodríguez-Antón and Alonso-Almeida, 2020; Hansen and Schaltegger, 2018; Zeng et al., 2017). It is also associated with the 3Rs principles (Reduce, Reuse and Recycle) (Anderson, 2007) and, more recently, the 9Rs principles (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle) (Kirchherr et al., 2017; Mangers et al., 2021).

The circularity of an organization depends on restorative or regenerative usage of industrially symbiotic systems by intention and design, using and reusing natural materials to a greater extent in product manufacturing, and finding value throughput across the product life cycle (Vimal et al., 2021). The literature points out that the formulation and application of the CE concept lack methodological cohesion, namely in the criteria used for measuring its impacts (Bjørn and Hauschild, 2013).

As mentioned in the introduction section, several metrics (methods, tools, indices) have been developed for measuring circularity at different spatial levels, ranging between micro (company, product), mezzo (city, industrial park, and supply chain) and macro (national, regional) levels (Panchal et al., 2021; Corona et al., 2019; Banaité, 2016).

The publication in 2015 of the Circular Economy Action Plan, updated in 2021, marks the beginning of the EU's transition to the and

Saidani et al. (2019) highlight the importance of the Action Plan for the CE, recognising the need for CI to be aligned with the seven building blocks to assess CE growth. Based on this Action Plan, Taranic et al. (2016) developed a framework to support decision-makers and policy-makers in implementing CE business models. It comprises eight interconnected building blocks, consisting of “both well-established EU policies, such as resource and energy efficiency, and emerging economic concepts, such as the sharing and platform economy” (Taranic et al., 2016). A brief characterization of seven building blocks, all impacting use of resources, is presented next (the industrial symbiosis block is not included because it is targeted at industrial sectors, which makes it less relevant to this study addressing the service sector).

- 1 - Material resource efficiency – Material resource efficiency is determined by the amount of resources used to produce one unit of a product or service and, consequently, its environmental impact (UNEP, 2010). Excessive material consumption leads to accelerated resource degradation and increased ecological footprints (Global Footprint Network, 2016). Circular practices of hotels related to this block include: using towels for more than one day (vs. changed daily); using bed sheets for more than one day; using shower gel dispensers, and investing in greywater systems (Manniche et al., 2019).
- 2 - Product life-cycle extension – Designing products with an extended service life facilitates their repair or upgrade, reuse and recycling (Taranic et al., 2016). In the hotel industry, this block can be identified in the following practices: reusing and recycling products at later stages of the life cycle; cascading use of food (e.g., excess food can be distributed to feed people in need); buying or leasing items (e.g., furniture, equipment) that have been used or have been remanufactured (Jurgilevich et al., 2016).
- 3 - Biological products – To cope with the demands of population growth, modern agriculture has relied on the excessive use of pesticides and synthetic fertilisers. This has resulted in the deterioration of soil productivity (FAO, 2016), with environmental and economic impacts. Hotel practices related to this block are being developed, such as: using biological products in rooms and restaurants (e.g. natural soaps, biological produce); producing raw materials or redirecting to other sectors the plant and animal parts that are not fit for human consumption (Manniche et al., 2019).
- 4 - Energy efficiency and renewable energy – Energy efficiency and renewable energy contribute to the CE by decreasing the consumption of fossil fuels (Taranic et al., 2016). A considerable amount of energy is wasted in hotels, which justifies the necessity of improving energy efficiency and resource conservation in this sector (Bohdanowicz and Martinac, 2007). Current practices in hotels include using renewable energy (e.g. solar) and adopting energy efficiency policies (e.g. lights savings, central control cooling/heating) (Ball and Taleb, 2011).
- 5 - The performance economy – The performance economy consists of selling goods through services. Instead of owning the product, the customer uses it through renting, leasing or sharing business models (Stahel, 2011). The new “products as services” paradigm is already present in Business-to-Business (B2B) models, but its adoption in Business-to-Consumer (B2C) models is also required. Hotels seek to improve their economic performance, for instance, by using renting, leasing, or sharing modalities to acquire some equipment, and they are highly concerned with economic performance indicators such as the average occupancy rate in low season and in high season (Stahel, 2011).
- 6 - The sharing economy – The sharing economy is built on sharing resources or services among peers. This can be coordinated at different scales, from a more local network to a larger scale focused on community-based service provision (Hamari et al., 2015). Expanding the sharing economy can play an important role in regulating the excessive use of resources in the tourism sector,

stimulating the conservation of the environment, rationalizing consumption, and making the economic activity more sustainable (Rodríguez-Antón, 2016). Within this block, a set of practices can be identified in hotels, such as outsourcing the laundering of bed linen and offering local food products (grown or processed locally) at their restaurants (Sloan et al., 2013).

- 7 - The platform economy – Web-based platforms, by operating globally, enable greater information exchange and interaction between buyers and sellers. The platform economy also impacts other building blocks of the CE and enables a paradigm shift from B2B or B2C to trade and exchange products or services. Therefore, the platform economy contributes to the CE, by helping performance and sharing economies to expand. This block can be identified in hotels by using online platforms to trade or exchange products or services (Gligoric, 2016).

3. Methods

3.1. Framework of the CE

Attending to Lützkendorf and Balouktsi (2017), to deal with a significant number of indicators, it can be useful to define a taxonomy of indicators to facilitate their selection. Accordingly, in this study, the typology suggested by the Action Plan for the CE, composed of seven

Table 1

Blocks and indicators used in the construction of the proposed CI.

Blocks	Indicators assessing circular practices of hotels
1 - Material resource efficiency	1.1 - In the case of the same customer staying more than one night, towels are only changed when requested by the customer 1.2 - In the case of the same customer staying more than one night, bed sheets are changed only when requested by the customer 1.3 - Use of shower gel dispensers 1.4 - Investment in greywater systems
2. Product life-cycle extension	2.1 - Re-using and recycling of products at later stages of the life cycle, such as recycling fixtures, furniture, equipment, or carpets 1. 2.2 - Cascading use of food (e.g., excess food can be distributed to feed people in need) 2. 2.3 - Buying or leasing items (e.g., furniture, equipment) that have been used or have been remanufactured
3. Biological products	3.1 - Use of biological products in rooms and restaurant(s) of the hotel (e.g. natural soaps, biological vegetables) 3.
4. Energy efficiency and renewable energy	3.2 - Production of raw materials and sending plant and animal parts not fit for human consumption to other sectors, such as bioenergy and animal feeding 4.1 - Use of renewable energies in the hotel (e.g. solar energy) 4.
5. Performance economy	4.2 - Adoption of energy efficiency policies in the hotel (e.g. lights savings, central control cooling/heating) 5.1 - Acquisition of equipment/vehicles through renting, leasing or sharing modalities 5. 5.2.1 - Average occupancy rate in the low season 6. 5.2.2 - Average occupancy rate in the high season
6. Sharing economy	6.1 - Outsourcing of the laundering of hotels' linen 7. 6.2 - The restaurants in the hotel offer tourists local food products (grown or processed locally), showcasing the terroir's characteristics
7. Platform economy	7.1 - Use of online platforms to trade or exchange products or services

blocks (section 2), was followed and a framework comprising 17 indicators that reflect CE practices is suggested (Table 1). Indeed, the European Commission considers these blocks as a strategic necessity for a faster and better transition to the Circular Economy. Using them in our index is also an opportunity to get insight into how far we are reaching a CE by using indicators aligned with them and consequently with more global concerns. Other works, such as Saidani et al. (2019), also highlight the importance of the Action Plan for the CE, recognising the need for CI aligned with these blocks to assess its growth.

3.2. Data collection

The methodology used to collect data to apply the proposed index was a survey based on a questionnaire. This questionnaire, translated into Portuguese and Spanish, was sent to a sample of 402 hotel managers in Portugal (247) and Spain (155) in 2020. It was an internet-based survey, a common data collection strategy (e.g., Han et al., 2009). The survey included a self-assessment of CE practices and an assessment of the importance of these practices, using qualitative scales. A pilot questionnaire was tested to assess whether all questions were understood, validate the questionnaire, and decide the best way to collect data. The LinkedIn social network platform was used to identify the sample hotels' CEO or Senior managers and send them the questionnaire, following a procedure that has been used successfully in other works (e.g. Lops et al., 2011). A total of 51 completed questionnaires were received (a response rate of 13%).

3.3. Model development

The multiple dimensions encompassed in the CI are aggregated following a 'Benefit of the Doubt' (BoD) approach (Cherchye et al., 2007), initially developed by Lovell et al. (1995), and thus designated as it evaluates each unit under the best possible light. The BoD model is a particular case of Data Envelopment Analysis (DEA), a non-parametric method to assess performance, measuring the relative efficiency of homogeneous Decision-Making Units (DMUs) (for a discussion of different DEA models, please see Cooper et al., 2007 and Zhu and Cook, 2010, and for an application of DEA to the context of the circular economy, please see Mavi and Mavi, 2019). BoD models assess only outputs rather than productivity (i.e. outputs/inputs ratio). BoD models are often used to develop composite indicators, as is the case in this work. Recent examples include Santos et al. (2020) and Van Puyenbroeck et al. (2021). Indeed, the BoD model is ideal for comparing hotels in terms of circularity practices because it allows the construction of a performance index without specifying exact weights for the indicators.

Usually, BoD models aggregate quantities (cardinal scales). For the purposes of this study, which uses ordinal scales, we develop a new BoD model, allowing to incorporate multiple ordinal indicators of CE as well as the managers' perspectives regarding the importance of each indicator. Since only output slacks (deviations from the maximum level observed) are of concern, we adapt a slack-based DEA model to respect the qualitative nature of the scale used in the assessment of the outputs.

To understand how DEA calculates the relative performance of a DMU, let us consider a set of n DMUs to be compared, based on s outputs they produce. Consider that y_{rj} is the observed level of the r th output of DMU _{j} , that s_r^+ is the slack of the observed level of output r when compared with the level observed in the best practice frontier and that λ_j are the coefficients used to produce a virtual DMU, resulting from the linear convex combination of observed DMUs. The Linear Programming problem that allows the calculation of the relative performance score of DMU _{j} , based on Charnes et al. (1985) and adapted to the situation where only outputs are relevant, is presented below:

$$\text{Max} \sum_{r=1}^s s_r^+ \quad (1)$$

subject to:

$$\sum_{j=1}^n y_{rj} \lambda_j - s_r^+ = y_{r0}; r = 1, \dots, s$$

$$\sum_{j=1}^n \lambda_j = 1$$

$$\lambda_j \geq 0; j = 1, \dots, n$$

$$s_r^+ \geq 0; r = 1, \dots, s.$$

As a measure of relative performance, the present work uses a modification of the 'Russell measure' discussed in Färe and Lovell (1978), adapted for the BoD version of DEA:

$R(\text{DMU}_0) = \sum_{r=1}^s \frac{1}{1 + \frac{s_r^+}{y_{r0}}}$, calculated with the optimum solution to model (1).

This measure of relative performance varies from 0 to 1. $R(\text{DMU}_0) = 1$ when the DMU₀ is on the best practice frontier (it cannot improve in one of the indicators without worsening other indicator(s)). $R(\text{DMU}_0) < 1$ when DMU₀ is not on the best practice frontier and could improve in at least one of the indicators without worsening the other indicators. DMUs on the best practice frontier act as benchmarks to the remaining units. The identification of the respective benchmarks is a useful piece of information for the latter, showing what examples they could follow.

The dual linear program of Model (1) shows each DMU in the best possible light because it allows full flexibility in the choice of the positive weights used to form a weighted sum of outputs. However, one can limit this flexibility through the incorporation of weight restrictions. In particular, we consider constraints in the form $D(r_1) \geq D(r_2)$, stating that output r_1 is at least as important as another output r_2 . Such weight restrictions can be derived from plausible production trade-offs, as suggested by Podinovski (2004), or can be derived from judgements regarding the importance level of the outputs, as perceived by the stakeholders. In this work, we follow the latter approach, considering the perspective of hotel managers.

Let $N(r, h)$ denote the number of managers who assign importance level h to output r . Furthermore, let us consider that the level of perceived importance of each output is measured using a Likert scale with five levels of importance (1 – very low importance; 5 – very high importance). Then, for some positive metaweights $\omega_5 \geq \dots \omega_2 \geq \omega_1$, the importance degree of output r , can be defined as:

$$D(r) = \omega_1 N(r, 1) + \omega_2 N(r, 2) + \dots + \omega_5 N(r, 5), r = 1, \dots, s \quad (2)$$

Then,

$$\sum_{n=k}^5 N(r_1, n) \geq \sum_{n=k}^5 N(r_2, n), k = 1, \dots, 5 \Rightarrow D(r_1) \geq D(r_2), \forall (\omega_1, \dots, \omega_5 : \omega_5 \geq \dots \omega_1 \geq 0). \quad (3)$$

Multiple comparisons of this type will define a set of B homogeneous weight restrictions in the form of $\sum_{t=1}^s u_t Q_t \leq 0, t = 1, 2, \dots, B$. This set of weight restrictions originates a dual term $\sum_{t=1}^B \pi_t Q_t$ to be added to the left hand side of the first set of restrictions of model (1).

Model (1) assumes that outputs are *quantitative* and can be scaled continuously, but many situations also relevant for the evaluation of DMUs involve *qualitative* factors. Namely, this work considers that the level of implementation of each circularity measure is assessed using an ordinal Likert scale. Therefore, continuous scaling of the outputs is not appropriate because only discrete values are meaningful. Furthermore, this type of data cannot be interpreted as cardinal numbers; for example, level 4 cannot be interpreted as meaning twice the performance of the 2.

To compare DMUs in the presence of ordinal factors, model (1) needs to be modified. Cook and Zhu (2006) present several possibilities for dealing with ordinal data in DEA. In this study, we use an additive model

that guarantees a discrete projection for Likert scale data, i.e., modifying the model developed by Cook and Zhu (2006: 1035) to the BoD version and incorporating weight restrictions in the form of (3).

DEA is a relative assessment tool, as each DMU is compared with its peers. Hence, obtaining a relative score of one might not mean a hotel performs well if all the peers are performing poorly. To complement the information provided by the DEA index, we have also developed an absolute evaluation index by adding an ideal DMU that would have the maximum qualitative score (level 5) on all outputs. The latter model keeps the relative assessment model's structure, including the weight constraints.

3.4. DEA model specification: outputs and weight restrictions

The outputs included in the model correspond to the 17 indicators (Table 2) used to evaluate the level of implementation of circular practices in the hotels. All indicators were measured using a 0–5 Likert scale (0 - 'Do not know or do not answer'; 1 - 'No implementation'; 2 - 'Poor implementation'; 3 - 'Moderate implementation'; 4 - 'Good implementation'; 5 - 'Full implementation'). Regarding the occupancy rate, the following correspondence was made: 0% - Level 0; [0%–20%] - Level 1; [20%–40%] - Level 2; [40%–60%] - Level 3; [60%–80%] - Level 4; [80%–100%] - Level 5. This correspondence is based upon the argument that, from a CE perspective, higher occupancy rates are preferred (Koenig and Bischoff, 2004). In this scale, level 5 is the best and level 0 is the worst. The option to consider that level 'Do not know or do not answer' is worth less than level 'No implementation' aims to create an incentive for data collection and reporting regarding the implementation of circularity measures. This is consistent with the suggestion by Kuosmanen (2009) for handling missing data.

Respondents also assessed the importance of each indicator using a Likert scale from 1 (very low importance) to 5 (very high importance). Weight restrictions were defined as described in §3.3, based on the number of survey respondents who indicated different importance levels to each circularity indicator (Table A1 in Appendix A). This originated 35 important relations (Fig. A1 in Appendix A). These relations, replicated for each one of the Likert scale levels, originated homogeneous restrictions of the form of (3) and were introduced in the DEA model.

4. Results

Our sample is composed of 51 hotels: 26 in Portugal, 25 in Spain. Table 2 presents the location, the number of employees and star rating of each of these hotels. The sample is diversified in terms of size and star rating. Three of the respondents are managers of hotel chains comprising hotels with a different star ratings, who answered the survey considering the circularity practices in their chains.

In order to evaluate the relative performance of each hotel in terms of the level of implementation of circularity practices, we have applied the model discussed in section 3 with weight constraints. The results are displayed in Table 2.

Nineteen out of the 51 hotels present a relative performance score of 100%. This means that, based on a comparison with the other hotels, there is no evidence that these 19 hotels could improve the implementation of the circularity practices included in the proposed framework. The remaining 32 hotels score below 100%, which presents evidence (the respective benchmark) that each of these hotels could improve in, at least one of the indicators. For instance, hotel 1 scores 78.82% and, compared with its benchmark (hotel 38), could improve the implementation level of the circularity measures related to six of the indicators. The hotel with the lowest score is hotel 31, a 4-star medium-sized hotel located in Portugal, showing a good implementation in terms of two circular practices, a moderate implementation in one practice and a low level of implementation in the remaining practices.

Hotel 38 is the most frequent benchmark (it is a benchmark to 25 other hotels). This medium size hotel has 4 stars and is located in

Table 2

Results of a relative evaluation versus an absolute evaluation.

	Hotel (or chain)	Number of employees	Number of stars	Relative performance [benchmark in brackets]	Absolute performance
Spanish Hotel units	H1	30–100	4	78.82% [H38]	69.61%
	H2	30–100	4	76.47% [H38]	67.65%
	H3	<30	3	100% [H3]	79.41%
	H4	<30	4	100% [H4]	82.35%
	H5	>100	5	75.1% [H38]	65.69%
	H6	<30	4	67.65% [H38]	57.84%
	H7	<30	4	71.76% [H42]	62.75%
	H8	>100	4	100% [H8]	71.57%
	H9	>100	5	71.96% [H38]	62.75%
	H10	>100	5	77.84% [H38]	68.63%
	H11	>100	4	81.18% [H38]	70.59%
	H12	>100	4	71.27% [H38]	62.75%
	H13 (chain)	>100	3, 4, 5	88.63% [H47]	74.51%
	H14	<30	No stars	70.78% [H38]	60.78%
	H15	<30	4	100% [H15]	73.53%
	H16	<30	4	80.2% [H47]	68.63%
	H17	30–100	4	79.51% [H47]	65.69%
	H18	30–100	4	89.8% [H38]	79.41%
	H19	30–100	4	85.49% [H38]	75.49%
	H20	>100	5	64.71% [H38]	54.9%
	H21	30–100	5	100% [H21]	79.41%
	H22	<30	4	78.24% [H47]	65.69%
Portuguese Hotel units	H23	30–100	4	100% [H23]	76.47%
	H24	>100	4	80.2% [H38]	69.61%
	H25 (chain)	>100	3, 4, 5	73.73% [H47]	63.73%
	H26	30–100	3	100% [H26]	84.31%
	H27	30–100	4	83.33% [H38]	74.51%
	H28	30–100	4	87.06% [H38]	78.43%
	H29	30–100	4	68.24% [H38]	57.84%
	H30	30–100	3	79.61% [H38]	69.61%
	H31	30–100	4	58.82% [H38]	49.02%
	H32	30–100	4	100% [H32]	86.27%
	H33	30–100	4	100% [H33]	76.47%
	H34	<30	4	87.94% [H38]	78.43%
	H35	<30	3	87.94% [H38]	78.43%
	H36	30–100	4	100% [H36]	80.39%
	H37	>100	5	100% [H37]	80.39%
	H38	30–100	4	100% [H38]	89.22%
	H39	<30	4	66.67% [H38]	56.86%
	H40	30–100	5	100% [H40]	79.41%
	H41	30–100	4	88.73% [H47]	75.49%
	H42	<30	3	100% [H42]	87.25%
	H43	30–100	4	68.24% [H38]	57.84%
	H44 (chain)	>100	3, 4, 5	72.35% [H38]	61.76%
	H45	>100	4	100% [H45]	77.45%

(continued on next page)

Table 2 (continued)

Hotel (or chain)	Number of employees	Number of stars	Relative performance [benchmark in brackets]	Absolute performance
H46	<30	4	64.71% [H38]	54.9%
H47	30–100	4	100% [H47]	84.31%
H48	30–100	5	100% [H48]	74.51%
H49	30–100	4	100% [H49]	86.27%
H50	>100	5	100% [H50]	76.47%
H51	30–100	4	71.18% [H38]	61.76%

Portugal. It presents full implementation in eight indicators, good implementation in seven, and moderate implementation in the remaining two. This hotel shows a high level of implementation in the practices considered most important by the respondents. Other hotels appear less frequently as benchmarks. Hotel 47 is the benchmark for six other hotels, and hotel 42 is the benchmark for another hotel. Hotels 42 and 47 also show a very high level of implementation in the indicators considered most relevant by the respondents but, contrasting with hotel 38, both have one indicator with no (or poor) implementation, inhibiting their choice as a benchmark to hotels that have at least a moderate level of implementation in those measures. The remaining 16 hotels in the best practice frontier score 100% but do not stand as a benchmark to any other hotel.

As discussed earlier, an evaluation with DEA is a relative comparison, considering that the DMUs are evaluated in relation to the best practice empirical frontier (derived from the observations included in the sample). The results depend, therefore, on the level of circularity implementation observed in the sample. To complement this relative evaluation, we have also undertaken an absolute evaluation of each hotel (last column of Table 2). The scores of the absolute evaluation vary from 49.02% (H31) to 89.22% (H38), revealing a reasonable level of implementation of circular practices.

Fig. 1 shows a high degree of association between relative and absolute scores. However, this does not occur for the hotels scoring 100% in the relative evaluation. Hotel 38 scores 100% in the relative evaluation and is the best in absolute terms. Hotel 8 scores 100% in relative terms but has relatively low performance in absolute terms. This hotel reports full implementation in nine indicators but does not provide information regarding the level of implementation in four indicators. In contrast, hotel 18 scores below 100% in the relative evaluation (hotel 38

is the benchmark) but shows relatively high performance in absolute terms. It performs poorly on only two indicators and presents at least moderate implementation in the remaining 15 indicators, but hotel 38 shows it is possible to do better.

The individual assessment of the hotels in terms of the implementation of circularity practices is useful for identifying hotels that exemplify best practices. To complement this individual assessment, we have also analysed the full sample, in aggregate terms. Firstly, we explored the effect of location on the performance scores. Table 3 presents the results of comparing the performance of hotels in Spain with those in Portugal. Based on the mean relative performance and mean absolute performance, the level of implementation of circular practices is slightly higher for hotels in Portugal than for hotels in Spain. However, this difference is not statistically significant at the 5% confidence level by using a Mann Whitney *U* test.

Secondly, we compared the performance of hotels based on their size (using the number of employees to create size categories). Table 4 groups the hotels using the usual categories of small, medium, and large companies based on the number of employees. The results indicate that performance (relative and absolute) is slightly higher in hotels of medium size than in the other two size categories. However, the Mann Whitney *U* test for ranks does not find these differences significant at the 5% level.

Thirdly, we investigated the effect of the star rating on the performance of the hotels. The hotels that belong to hotel chains were included in the group of hotels with three stars, as all these chains include mostly

Table 3

Comparison of the relative performance of hotels based on location.

	Number of hotels	N.º [%] of hotels with 100%	Mean relative performance	Mean absolute performance
Hotels in Spain and Portugal (*)	50	19 [38%]	85.67%	71.84%
Hotels located in Spain	24	6 [25%]	83.28%	69.77%
Hotels located in Portugal	26	13 [50%]	87.88%	73.75%
Mann – Whitney <i>U</i> test for ranks			$Z = -1.238$	$Z = -1.75$
H_0 : Performance Portugal = Performance Spain			$(P = 0.216)$	$(P = 0.08)$

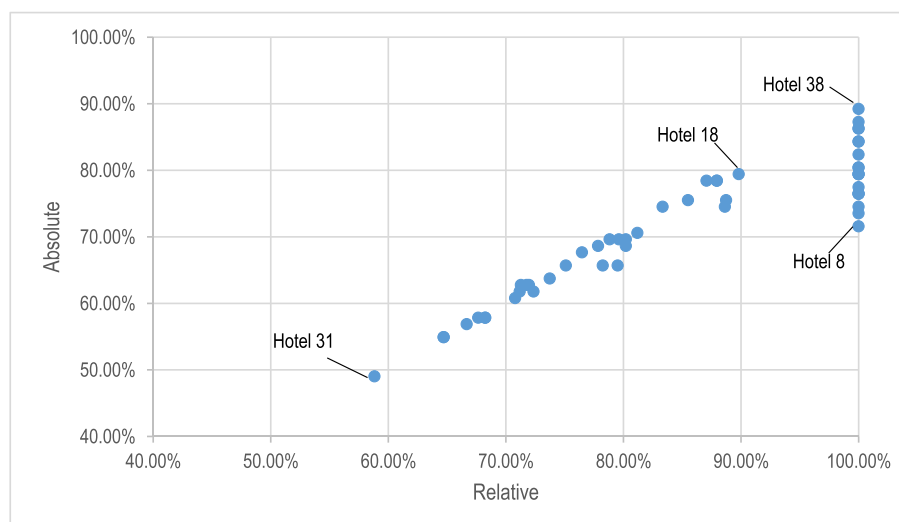


Fig. 1. Relative evaluation versus absolute evaluation scores.

Table 4
Comparison of the relative performance of hotels based on size.

	Number of hotels	N.º [%] of hotels with 100%	Mean relative performance	Mean absolute performance
All hotels	51	19 [37%]	85.26%	71.51%
Small companies Hotels with <50 employees	30	10 [33%]	84.58%	71.73%
Medium sized companies Hotels 50–250 employees	16	8 [50%]	89.25%	73.22%
Large companies Hotels units with >250 employees	5	1 [20%]	76.55%	64.71%
Mann Whitney U test for ranks			Z = −1.177 (P = 0.239)	Z = −0.231 (P = 0.817)
H ₀ : Performance Medium ≠ Performance Small				
Mann Whitney U test for ranks			Z = −1.892 P = 0.059	Z = −1.777 P = 0.076
H ₀ : Performance Medium ≠ Performance Large				

hotels with three stars. The performance (relative and absolute) does not vary significantly with the star rating since the small differences found are not statistically significant at the 5% level (Appendix B).

Fig. 2 shows the level of implementation of CE practices. Indeed, the number of hotels that indicate full implementation varies considerably across indicators (from 2 respondents for indicator 2.3 to 44 respondents for indicator 6.1). The highest level of implementation (more than 50% of the hotels in the sample at level 5) is found in indicators 6.1; 4.2; 5.2.2 and 1.3. In contrast, indicators 1.4; 2.3 and 3.2 (more than 50% of the respondents answered with level 2, 1 or 0) found a level of low implementation or no implementation. This information has important implications for policy and practice, as it points to areas that require more attention in the future.

5. Discussion

The CI proposed in this work allows evaluating the level of

circularity of hotels, giving insights not only on their absolute and relative individual performance but also on how they can learn from others. This allows for identifying the best and worst performers in terms of circularity and the practices that need improvement. In addition, the benchmarking analysis performed can act as an important driver to improve hotels' circular behaviour. Consequently, the proposal of this index provides a potentially important contribution to reaching the main objectives of the Paris Tourism Agreement (United Nations-UN, 2015) updated in 2021, regarding the mitigation of climate change and the adoption of more sustainable operations management within hotels (Girard et al., 2017).

Applying the proposed index allowed us to identify Hotel 38 as the best-performing hotel. This 4-star Portuguese hotel with 32 employees has a relative score of 100% and an absolute score of 89.22%, being a benchmark to 25 other hotels (Table 2). The worst performer is also a medium-sized Portuguese hotel (Hotel 31), with 4 stars, with a relative score of 58.82% and an absolute score of 49.02%.

This study also explored the influence of the location, size and star rating on the circularity performance of the hotels. Regarding location, although the level of implementation of circular practices is slightly higher for hotels in Portugal than for hotels in Spain, this difference is not statistically significant. Rodríguez-Antón and Alonso-Almeida (2019) also concluded that location has no influence on the level of CE practices in the hospitality industry across different European countries.

Regarding the influence of hotels' size on the implementation level of circular practices, our results indicate that medium-sized hotels have slightly higher performance, but this difference is not statistically significant. Although Dief and Font (2010) observe that large companies are more pressured by their stakeholders than smaller ones to adopt environmental strategies, our findings suggest that the size of hotels does not influence the level of implementation of circular practices.

Finally, the star rating also seems not to influence the level of circularity in hotels. The star rating was also identified by Stylos and Vassiliadis (2015) as not influencing hotels as regards environmental concerns.

Furthermore, our study identified the following circular practices as having a higher level of implementation among the hotels studied: outsourcing of the laundering of hotels' linen; adoption of energy efficiency policies in the hotel; achieving a high occupancy rate in the high season; and use of shower gel dispensers. The circular practices

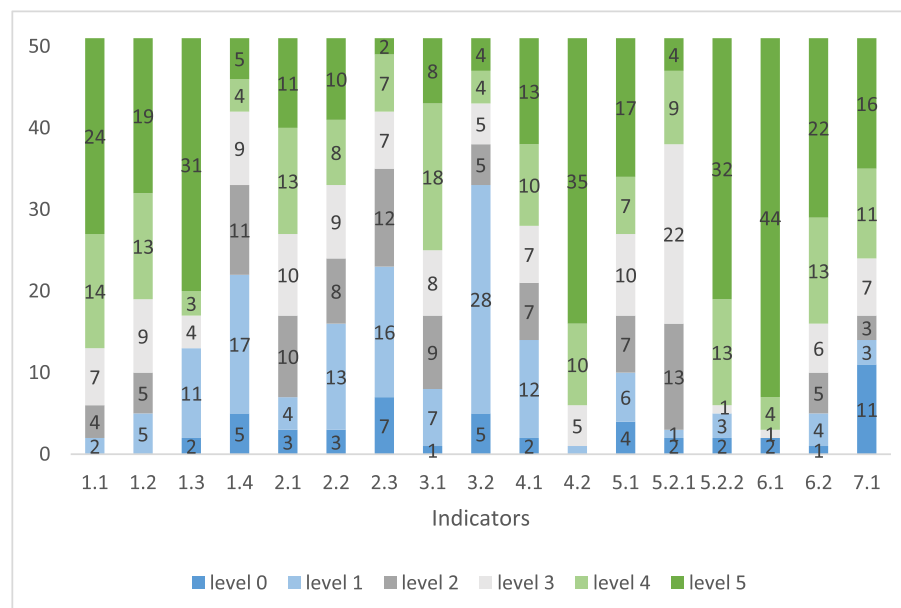


Fig. 2. Number of respondents who chose each level of implementation for each practice.

displaying a lower level of implementation were: investment in grey-water systems; buying or leasing items that have been used or have been remanufactured; production of raw materials, and sending plant and animal parts not fit for human consumption to other sectors. These findings corroborate the results of previous works (e.g. Rodríguez-Antón and Alonso-Almeida, 2019) and might be justified by the conclusions reached by Julião et al. (2020), who found evidence that consumers tend to value their personal experience (e.g. items that impact their comfort) more than they value environmental safety and sustainability (e.g., cleaning products less harmful to the environment).

6. Conclusion

This work contributes to the literature by proposing, for the first time, a CI based on qualitative assessments to combine multiple indicators of CE practices implementation. A modified slack-based DEA model, which implements the BoD principles to aggregate ordinal scales, was developed for a relative performance assessment. This model was customized to assess the circularity practices of hotels into a composite index, thereby synthesizing a multidimensional concept aimed at raising awareness about the necessary changes concerning the CE and at fostering the adoption of the best practices in this industry. An absolute performance assessment was also carried out.

To explore the applicability of the proposed CI in a real-life context, data was collected from a sample of Portuguese and Spanish hotels with different sizes and star ratings. Applying the framework proposed to assess the circularity of these hotels provided insightful information.

Firstly, it allowed the identification of the hotels with the best performance in implementing the CE practices. Overall, when a relative assessment is performed, an average performance of 85.26% is observed in terms of implementing the CE practices, with 19 hotels being in the frontier of best practices. However, when an absolute assessment is carried out, comparing each hotel with an ideal situation where all the CE practices are fully implemented, the average performance of the hotels decreases to 71.51%.

Secondly, for those hotels presenting the potential for improvement, the analysis identified the benchmarks they could follow to improve their level of circularity.

Thirdly, for each hotel, the analysis shows which circularity practices have higher and lower levels of implementation.

Although differences were observed in the performance of the hotels depending on their location, size and number of stars, these differences are not statistically significant.

7. Managerial implications

This research provides hotel managers with information on circular practices that hotels towards a more circular behaviour can implement. Moreover, the suggested index represents a helpful framework for monitoring the circularity performance of hotels, either for benchmarking or for informing policy makers about targets and priorities. Using this index, it is possible not only to obtain a score representing each hotel's implementation level, but also to benchmark their performance against the best circularity practices in the industry. On the one

hand, it allows identifying the best practice hotels which can be used as platforms for learning. On the other hand, it provides specific targets for improvement, signalling that the lower performers must improve circular practices to reach the implementation levels of the best performers. By studying these best practices, hotels can identify feasible improvement pathways.

7.1. Limitations

The construction of the proposed CI requires several judgments to be made. This concerns mainly the selection of indicators to include in the composite index and the need to value the indicators. Since different stakeholders might have different views regarding these aspects, a robustness analysis of the CI is recommended to assess the sensitivity of the results to changes to the model (Agarwal et al., 2014).

CRedit author statement

SUSANA GARRIDO – She is responsible for ensuring that the descriptions are accurate and agreed by all. Conceptualization Ideas; formulation or evolution of overarching research goals and aims, Writing - Original Draft Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation), **JOSÉ RODRÍGUEZ-ANTÓN** - - Investigation Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection, **CARLA A. F. AMADO** - Data Curation Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse. Formal analysis Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data, **SÉRGIO SANTOS** - Data Curation Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse. **LUÍS C. DIAS** - Data Curation Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse.

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.

Data availability

Data will be made available on request.

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Appendix A. Attribute importance constraints

Table A1

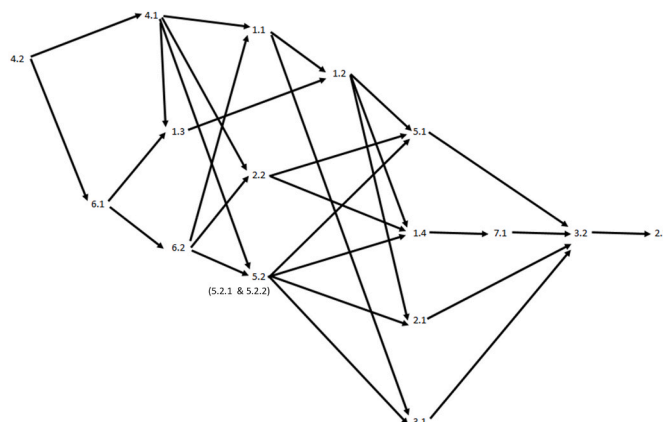
Number of respondents who indicated different importance levels to each indicator/circular practice

Importance level	Indicators/circular practices																
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	4.2	5.1	5.2.1	5.2.2	6.1	6.2	7.1
= 5	25	21	29	12	11	25	3	7	3	32	38	14	19	19	32	26	12
≥4	41	39	38	38	34	38	13	31	20	47	50	30	39	39	46	42	32

(continued on next page)

Table A1 (continued)

Importance level	Indicators/circular practices																
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	4.2	5.1	5.2.1	5.2.2	6.1	6.2	7.1
≥3	46	46	45	43	44	47	33	47	42	49	50	43	47	47	50	50	43
≥2	50	50	49	48	50	49	44	49	47	50	50	48	50	50	50	50	47

Fig. A1. Importance relations derived from Table 3. Arrows mean “is no less important than”, e.g., weight of indicator 4.2 \geq weight of indicator 4.1

Appendix B. Comparison of the relative performance of hotels based on number of stars

	Number of hotels	N.° [%] of hotels with 100%	Mean relative Performance	Mean absolute Performance
All hotels	51	19 [37%]	85.26%	71.51%
Group A	9	3 [33%]	85.89%	73.31%
Hotels with 3 stars or less				
Group B	33	11 [33%]	84.41%	71.06%
Hotels with 4 stars				
Group C	9	5 [56%]	87.73%	71.35%
Hotels with 5 stars				
Mann Whitney U test for ranks			Z = -0.328	Z = -0.568
H ₀ : Performance A \neq Performance B			(P = 0.743)	(P = 0.57)
Mann Whitney U test for ranks			Z = -0.599	Z = -0.138
H ₀ : Performance B \neq Performance C			(P = 0.549)	(P = 0.89)

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