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University of Southern Denmark

Developing a green city assessment system using cognitive maps and the Choquet Integral

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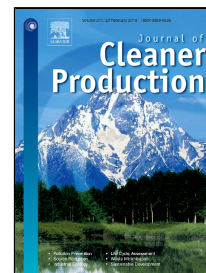
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**DEVELOPING A GREEN CITY ASSESSMENT SYSTEM USING COGNITIVE
MAPS AND THE CHOQUET INTEGRAL**

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DEVELOPING A GREEN CITY ASSESSMENT SYSTEM USING COGNITIVE MAPS AND THE CHOQUET INTEGRAL

ABSTRACT

Equitable human well-being and environmental concerns in urban areas have, over the years, become increasingly challenging issues. This trend is related to both the complexity inherent in the multiple factors to be considered when evaluating eco-friendly cities (*i.e.*, green cities) and the way this type of city's sustainability depends on many evaluation criteria, which hampers all decision-making processes. Using a multiple criteria decision analysis (MCDA) approach, this study sought to develop a multiple-criteria model that facilitates the evaluation of green cities' sustainability, based on cognitive mapping techniques and the Choquet integral (CI). Taking a constructivist and process-oriented stance, the research included identifying evaluation criteria and their respective interactions using a panel of experts with specialized knowledge in the subject under analysis. The resulting framework and its application were validated both by the panel members and a parliamentary representative of the Portuguese ecology party "Os Verdes" (The Greens), who confirmed that the evaluation system created distinguishes between cities according to how strongly they adhere to "green" principles. The advantages and limitations of the proposed framework are also discussed.

Keywords: Green Cities; Sustainability; Social Responsibility; MCDA; Cognitive Maps; Choquet Integral.

1. INTRODUCTION

Since 2008, more than half of the world's total population has lived in urban areas. According to the United Nations' projections (*cf.* United Nations, 2014), by 2030, all major regions of the developing world will have more urban than rural dwellers, and, by 2050, fully two-thirds of these regions' inhabitants are likely to live in urban areas. This represents a momentous change in both relative and absolute terms, that clearly will lead to higher population density with consequent repercussions for the sustainable development of cities (Redman and Jones, 2005; Fernandes *et al.*, 2018).

Therefore, to minimize the effects caused by these population movements, experts have made it increasingly evident that strategic measures need to be implemented to balance urban and environmental policies. The development of more green areas in cities has become an even more pertinent and opportune policy. These spaces' presence brings improvements in terms of both residents' quality of life and the harmonization of intrinsic elements and features of these locations (Govindan *et al.*, 2016; Fernandes *et al.*, 2018).

In this specific context, the concept of green cities has emerged significant. These are generally defined as cities that develop in a socially responsible manner, simultaneously respecting environmental, social, and economic issues. This concept seems to be important for urban planners, administrative authorities, citizens and society at large, and involves more than just concentrating on parks or gardens, implying significant ameliorations in cities at various levels that take into account various decision-making criteria. The assessment of green cities is thus a complex decision problem involving various decision-making dimensions. Although many researchers have repeatedly focused on this topic (*cf.* Givoni, 1991; Nicholson-Lord, 2003; Tzoulas *et al.*, 2007; Zhou and Rana, 2012), their evaluation methods are still characterized by limitations regarding the choice and weighting of criteria. Therefore, the present study sought to develop an evaluation system that demystifies and simplifies the assessment of green cities, allowing the following questions to be answered:

- Which are the relevant criteria in the assessment of green cities?
- How can multiple criteria be aggregated to obtain a synthetic indicator of green cities' sustainability?

Given the complexity of the topic in question, this research was based on the multiple criteria decision analysis (MCDA) approach, combining methods of structuring and evaluating the decision problem based on multiple criteria. As stated by Bana e Costa *et al.* (1997: 30), "*in contrast to the more classical [...] approaches, the MCDA framework facilitates learning about the problem and the alternative courses of action, by enabling people to consider their values and preferences from several points of view*". Assuming a process-oriented stance, this is exactly the orientation followed in this study. The participating decision makers were provided with a conceptually coherent and empirically valid framework to analyze green cities, which was created based on their values and professional experience. More specifically, cognitive maps were used to identify and select the evaluation criteria, and the Choquet Integral (CI) was employed to

model the different interactions and/or synergies between the criteria included in the assessment system.

Cognitive mapping is a well-established problem-structuring method that brings together uncertainty, different perspectives, conflicts of interest, and multiple decision makers, allowing decision problems to be structured quite intuitively (Ackermann and Eden, 2001; Jalali *et al.*, 2017; Ribeiro *et al.*, 2017). The CI, in turn, is a non-additive MCDA operator that can be used whenever the aggregation of partial scores through conventional additive measures is not possible due to criteria interdependency (Choquet, 1954), which seems to be the case for assessments of green cities. Although both methods have been successfully applied in different decision-making contexts (*cf.* Ferreira *et al.*, 2017 and 2018), a survey of the literature uncovered no evidence of their integrated use in the specific context under study. This means that a major part of this paper's contribution is precisely bound with the dual methodology used, and the added flexibility and comprehensiveness offered by the integrated use of cognitive mapping and the CI, allowing us to contribute to the extant literature on urban planning and sustainability, green cities, performance evaluation, and operational research/management science (OR/MS).

The remainder of this paper is structured as follows. The next section contextualizes the problem in question through a concise review of the relevant literature. Section three discusses the methodologies applied (*i.e.*, cognitive maps and CI), while section four presents the results obtained and their validation. Section five concludes the paper by highlighting this study's contributions and limitations, followed by suggestions for future research.

2. RELATED LITERATURE AND RESEARCH GAP

Quality of life, the well-being of the general population, and, consequently, the sustainability of cities are increasingly considered important topics and, for this reason, more frequently addressed.

In recent years, economic agents have been more overtly and strongly engaged in disclosing their social performance and implementation of socially responsible conduct. Although no widely accepted conceptualization of socially responsible conduct is yet available (*cf.* Govindan *et al.*, 2014; Rita *et al.*, 2018), its need has strengthened the belief

that the notion of social responsibility should be interpreted in a broader sense including, on the one hand, stakeholders and, on the other hand, shareholders of companies (for a more detailed discussion, see Davis (1973), Sethi (1975), and Carrol (1999)). According to the European Commission (2001), organizations need to ensure different levels of both internal and external social responsibility when implementing socially responsible actions. This expectation shows that companies are increasingly entrusted with assuring a balance between respecting fundamental human rights, combating fraud and corruption, zealously protecting consumers, and fostering an interest in environmental conservation.

Carrol (1991) suggests that the concept of social responsibility involves four levels: economic, legal, ethical, and philanthropic issues. Intrinsically related to this stratification is the conceptualization of sustainability as complex but basically focused on social, energy-related, economic, and environmental matters. For this reason, sustainability is mostly explained in terms of sustainable development, which, as stated in the Brundtland Report (1987), means “*to ensure that it [development] meets the needs of the present without compromising the ability of future generations to meet their own needs*” (United Nations, 1987: 41). While a considerable range of possible definitions have been developed for sustainability, sustainable development is currently the most commonly used (*cf.* Robinson, 2004; Dobrovolskienė *et al.*, 2017; Fernandes *et al.*, 2018).

Given the importance of the subject under study and the concepts involved, society at large has shown a growing interest in the concept of environmental education, as teaching this topic has become an increasingly more prominent activity, especially in civic, personal, and social development education. This has caused various authors (*cf.* Govindan *et al.*, 2014) to affirm that environmental education entails not only learning about issues, but even more so changing behaviors and attitudes. For this reason, experts believe that schools should play a fundamental role in addressing this topic, attempting to instill in society as a whole the behaviors (*e.g.*, recycling) required of environmentally responsible citizens. Various entities – referred to as “green organizations” – have worked together to inform the general population about environmental issues and the benefits to be derived. These groups have conducted awareness-raising campaigns that encourage the practice of “small” good deeds in favor of the environment, highlighting the positive repercussions of these actions on the ecosystem (Latif *et al.*, 2013).

According to the Asian Development Bank (2014), the notion of green cities arose from a combination of social responsibility, sustainability, and green energy generation. Green cities can thus be defined in general terms as “*the contemporary name for which*

areas develop in [... a] manner that is socially responsible, and environmentally and economically sustainable” (Asian Development Bank, 2014: 4). The insertion and/or development of additional green areas close to metropolitan areas have socioeconomic impacts as green cities promote more effective microclimate regulation and more efficient control of pollution and soil erosion (Roseland, 1997). Other benefits are a substantial reduction in noise production and significant improvements in the health of residents in urban areas, producing long-term ecological, social, and economic benefits (*cf.* Givoni, 1991; Tzoulas *et al.*, 2007; Zhou and Rana, 2012; Gong *et al.*, 2016; Rosol *et al.*, 2017).

Various studies (*e.g.*, Faria *et al.*, 2018; Fernandes *et al.*, 2018; Marques *et al.*, 2018; Oliveira *et al.*, 2018) have revealed a strong propensity in the general population to acquire housing located close to green cities, citing improvements in quality of life (*i.e.*, physical and mental well-being). This motivation overrides any significant increase in the price of land and housing (for further discussions of these issues, see Ulrich *et al.* (1991), Campbell (1996), Mwendwa and Giliba (2012), and Noor *et al.* (2015)). Therefore, a reputation as a green city can be said to represent a considerable asset at various levels, for society at large and the cities themselves.

To ensure the assessment and/or management of these areas, municipalities have had to implement strategic measures that assure the sustainability of green cities. This has made using multiple-criteria methodologies even more pertinent as they facilitate assessments of these cities’ profiles through a combination of environmental, economic, and social factors (Campbell, 1996; Roseland, 1997; Breuste *et al.*, 2008; James *et al.*, 2009; Marques *et al.*, 2018; Fernandes *et al.*, 2018). As noted by Liu *et al.* (2016), this evaluation process should enable investigations of whether green cities remain sustainable and capable of attenuating the negative effects of urban environments. *Table 1* presents some methods that have been used over the years to appraise green cities, identifying these approaches’ contributions and limitations regarding the process of assessing these cities and the development and/or insertion of green spaces.

Table 1: Related Studies: Contributions and Limitation

Author	Method	Contributions	Limitations Recognized by Authors
Fang and Ling (2003)	Noise reduction model – barrier effect	<ul style="list-style-type: none"> ▪ Demonstrates the importance of quantitative factors (e.g., visibility, height, width, and length of tree belts) to reducing noise. ▪ Enables assessing whether placing bushes and trees with low bifurcation has a stronger effect on reducing noise pollution, as well as the distance they are placed from the source of noise. 	<ul style="list-style-type: none"> ▪ Influence of weather conditions on propagation of sound means measurements always have to be taken under the same weather conditions. ▪ Difficult to measure the density of vegetation belts.
Hien and Jusuf (2008)	Green rate and green plot ratio calculation	<ul style="list-style-type: none"> ▪ Reinforces the need to increase green zones based on planning that correctly takes into account the location of buildings. ▪ Strengthens the need to increase green zones within buildings, using the top of building as places for planting vegetation. ▪ Reinforces the need for greater selection of plants, enabling a higher density of green zones. 	<ul style="list-style-type: none"> ▪ Lack of sufficient quantitative data to determine the characteristics of vegetation that should be placed in these spaces. ▪ Insertion of large-scale green zones in small locations appears unrealistic.
Huang and Yeh (2008)	Max-min and fuzzy Delphi – analytic hierarchy process (AHP)	<ul style="list-style-type: none"> ▪ Identifies the weight of the main categories – ecology, green zones, materials, solid waste, and conservation of water quality and energy – as well as the weight of the corresponding items to be taken into consideration during the construction of roads in cities with numerous green zones. 	<ul style="list-style-type: none"> ▪ Study focused only on technical indicators.
Coutts <i>et al.</i> (2010)	Geographic information system (GIS)	<ul style="list-style-type: none"> ▪ Highlights the importance of measuring the accessibility of green zones from the cities, especially if they have high population density. ▪ Confirms that these zones' proximity to cities correlates with lower mortality indices. 	<ul style="list-style-type: none"> ▪ Indications only of the extension and quantity of green zones that exist in each municipality and fails to present any other details relative to their accessibility from and/or proximity to urban zones.

Artmann (2014)	Multi-attribute decision method using AHP	<ul style="list-style-type: none"> Provides evidence of the importance of city planning and design strategies, showing that the insertion of green zones is especially beneficial because it reduces climate change and helps water infiltration processes. 	<ul style="list-style-type: none"> Slow processes because the treatment of data requires a meticulously thorough examination.
Baró <i>et al.</i> (2014)	I-Tree Eco model	<ul style="list-style-type: none"> Demonstrates that levels of carbon dioxide recorded in green cities are substantially lower than in heavily urbanized cities. 	<ul style="list-style-type: none"> Results obtained by estimates and not precise quantifications. Uncertainty levels in the quantification of rates of removal of pollution from the air due to the complexity of the evaluation process. Need to implant green zones in larger areas of cities.
Kechebour (2015)	Analysis of static and dynamic models	<ul style="list-style-type: none"> Facilitates a quantitative assessment of the costs inherent to the insertion and/or development of green spaces in urban environments. 	<ul style="list-style-type: none"> High cost of execution.
Noor <i>et al.</i> (2015)	GIS and hedonic pricing method	<ul style="list-style-type: none"> Improves the analysis and determination of prices of housing quite close to green cities. 	<ul style="list-style-type: none"> Variables included in estimates to be determined before the model itself is estimated.
Liu <i>et al.</i> (2016)	Building neighborhood green index (BNGI) model	<ul style="list-style-type: none"> Enables an assessment of the most appropriate distribution of green zones in relation to the configurations established by the construction of buildings, based on four factors: the proximity of green zones, construction of buildings, height of buildings, and green index 	<ul style="list-style-type: none"> Lower number of insertion of green zones in areas with a high number of buildings. BNGI only facilitates obtaining relative values and not absolute values.
Lasarte-Navamuel <i>et al.</i> (2018)	Quantile regression with instrumental variables	<ul style="list-style-type: none"> Estimates household energy consumption depending on the type of city: compact city versus sprawled urban areas. Identifies urban structures more efficiently in terms of energy sustainability. 	<ul style="list-style-type: none"> Analysis done only on Spanish cases, so conclusions could change depending on national and/or local factors. Data limitations when implementing control variables.

An analysis of the research included in *Table 1* shows that the results derived from a correct assessment and management of green cities are crucial to the sustainability of these cities and their residents' increased quality of life. However, these previous studies quite clearly have limitations that fall into two broad categories: how evaluation criteria are defined for green city assessments and how these same criteria's weights are calculated and aggregated (*cf.* Faria *et al.*, 2018; Fernandes *et al.*, 2018). This analysis also suggested that potentially important criteria have not been considered, thereby affecting the proposed models' explanatory power.

Notably, a wide-range of different green city performance criteria can be found in the literature, including, among others, safety, technology usage, carbon productivity, rates of air and water pollution, crime rates, land resources usage, and green innovation initiatives (for a deeper discussion and further examples, see Marques *et al.* (2018), Oliveira *et al.* (2018), Rita *et al.* (2018)). It is worth noting, however, that the extant literature seldom presents a rational explanation for the inclusion and aggregation of these indicators in the respective evaluation frameworks (*cf.* Fernandes *et al.*, 2016; Rita *et al.*, 2018).

To address these issues, the present study used cognitive mapping to facilitate a comprehensive definition of decision criteria to be included in the evaluation framework. As Eden (2004), Carayannis *et al.* (2018) and Faria *et al.* (2018) note, cognitive maps promote the exchange of ideas and experiences, boost a deeper understanding of decision situations and uncover the cause-and-effect relationships among criteria, allowing questions such as “why does this happen?” to be answered. The CI, in turn, was employed to globally assess or evaluate green cities in terms of multiple criteria. The integrated use of these two methodologies holds great potential to deal with complex criteria structures such as the assessment of green cities. The next section presents a brief discussion of the methodologies used in this study.

3. METHODOLOGY

3.1 Problem Structuring and Cognitive Mapping

Cognitive maps are tools used to assist decision-making processes, enabling for the structuring of decision problems as these maps provide an integrated approach to the

configuration and appraisal of such problems. More specifically, these maps permit the two processes of structuring and evaluating to interact in a progressive, natural, and continuous manner (Mackenzie *et al.*, 2006; Montibeller *et al.*, 2008). As noted by Eden (2004: 673), “*the term ‘cognitive mapping’ is [...] used to describe the task of mapping the person’s thinking about the problem or issue*”.

Tegarden and Sheetz (2003) state that this approach entails a graphic representation of specific problems, through which, as Ribeiro *et al.* (2017) argue, interests, values, principles, and beliefs can be represented. These refer to epistemological approaches that enable individuals to structure and organize their thoughts. Thus, cognitive maps are quite often considered valuable tools in the development of collective thought when seeking to obtain answers and/or clarifications in negotiation processes or, in short, when structuring decision problems (*cf.* Mackenzie *et al.*, 2006; Damart, 2010; Jalali *et al.*, 2016).

After confirming these maps’ interactivity, versatility, and simplicity, Fiol and Huff (1992) suggest that cognitive maps can be classified into three major groups: (1) identity maps; (2) categorization maps; and (3) cause-and-argumentation maps. Regardless of their configuration (*i.e.*, graphic representation, algebraic matrix, list, or text), a major feature is how these maps show the existing cause-and-effect relationships between the concepts portrayed (Eden, 2004; Eden and Ackermann, 2004). Tegarden and Sheetz (2003: 114) note that, “*essentially, the cognitive map is the graph composed of nodes and links ([i.e.] relationships) connecting the nodes. A cause map is essentially the cognitive map where the relationships are restricted to causal relationships [... namely], each relationship in the map is restricted to the may-lead-to, has-implications-for, supports, or cause-effect type of relationship*”. These cause-and-effect relationships are portrayed through arrows, which are associated with a positive or negative sign, according to the type of causality identified (Eden, 2004; Montibeller *et al.*, 2008).

Based on these features, cognitive maps can be used to promote discussion between the decision makers involved in the decision-making support process. In addition, these maps reduce the rate of omitted criteria, and stimulate learning through an understanding of the cause-and-effect relationships between concepts (for a more in-depth theoretical discussion, see Mackenzie *et al.* (2006), Damart (2010), Ferreira *et al.* (2012), Jalali *et al.* (2016) and Azevedo and Ferreira (2017)).

3.2 Choquet Integral

According to Campos and Bolaños (1992) and Wang (2011), the CI was introduced by Gustave Choquet, in 1953. At that time, its purpose was defined as “*to integrate functions with respect to [...] fuzzy measures*” (Shieh *et al.*, 2009: 5101). This meant that the CI was interpreted as a non-additive aggregation method (NAM). As Labreuche and Grabisch (2003), Tan and Chen (2010), and Wang (2011) note, the CI can be considered an appropriate substitute for a weighted arithmetic mean in the aggregation of interdependent criteria.

Ralescu and Adams (1980) further report that the use of NAM methods became recurrent when deterministic and/or probabilistic models proved unable to provide a realistic description of decision-making processes. Gürbüz (2010: 291) states that “*CI is [a] fuzzy integral and considers the interactions between k out of n criteria of the problem which is called the k -additivity property*”. This implies that the main objective of the CI is to determine the weight derived from the combination of criteria so that this can facilitate modeling the existing interactions between them (see also Tan and Chen [2010]). That said, “*the success [of the CI] depends on an appropriate representation of fuzzy measures, which captures the importance of individual criterion or their combination*” (Demirel *et al.*, 2010: 3945).

Choquet (1954), Shieh *et al.* (2009), and Tan and Chen (2010) suggest that, from a technical point of view, a fuzzy measure in X refers to a function $\mu: P(X) \rightarrow [0,1]$ if and only if it complies with Conditions (1) and (2):

$$\mu(\emptyset) = 0, \mu(X) = 1 \text{ (limit condition)} \quad (1)$$

$$\text{If } A, B \in P(X) \text{ and } A \subseteq B, \text{ then } \mu(A) \leq \mu(B) \text{ (monotonicity condition)} \quad (2)$$

However, Ralescu and Adams (1980) argue that, for μ to be considered a non-additive measure, Premises (3) and (4) should also be observed:

$$\{A_n\} \subseteq P, A_1 \subseteq A_2 \subseteq \dots \subseteq A_n \in P \Rightarrow \mu\left(\bigcup_{n=1}^{\infty} A_n\right) = \lim_{n \rightarrow \infty} \mu(A_n) \quad (3)$$

$$\{A_n\} \subseteq P, A_1 \supseteq A_2 \supseteq \dots \supseteq A_n \in P \Rightarrow \mu\left(\bigcap_{n=1}^{\infty} A_n\right) = \lim_{n \rightarrow \infty} \mu(A_n) \quad (4)$$

In line with this, Torra *et al.* (2016) state that μ refers to a submodular non-additive measure if $\mu(A) + \mu(B) \geq \mu(A \cup B) + \mu(A \cap B)$ and to a supermodular non-additive measure if $\mu(A) + \mu(B) \leq \mu(A \cup B) + \mu(A \cap B)$ – for any $A, B \subseteq P$, respectively. Thus, the CI of f in relation to μ in A is referred to as $(C)\int_A f d\mu$ and defined according to Formula (5) (Ouyang and Li, 2004).

$$(C)\int_A f d\mu = \int_0^\infty \mu(A \cap F_\alpha) d\alpha \quad (5)$$

in which:

- f represents a non-negative measurable function of real value defined in X
- $F_\alpha = \{x | f(x) \geq \alpha\}$, for any $\alpha > 0$

If $(C)\int_A f d\mu < \infty$, (C) is referred to as integrable (Wang, 2011). Consequently, if (X, P, μ) represent a fuzzy measure space with $\{f_1, f_2, \dots, f_n\} \subseteq F$ and $A, B \in P$, F is the set of all non-negative measurable functions of real value defined in X . The CI will have the following Properties (6 to 11) (Wang, 2011):

$$\text{If } \mu(A) = 0, \text{ then } (C)\int_A f d\mu = 0 \quad (6)$$

$$(C)\int_A c d\mu = c \cdot \mu(A) \quad (7)$$

$$\text{If } f_1 \leq f_2, \text{ then } (C)\int_A f_1 d\mu \leq (C)\int_A f_2 d\mu \quad (8)$$

$$\text{If } A \subset B, \text{ then } (C)\int_A f d\mu \leq (C)\int_B f d\mu \quad (9)$$

$$(C)\int_A (f + c) d\mu = (C)\int_A f d\mu + c \cdot \mu(A) \quad (10)$$

$$(C)\int_A c \cdot f d\mu = c \cdot (C)\int_A f d\mu \quad (11)$$

in which c represents a positive constant.

According to Wang (2011), since the CI integrates a set of monotone, non-additive, and non-linear integrals, the most important property of the CI involves the non-additivity of μ , as defined by Formula (12):

$$(C)\int_A(f + g)d\mu \neq (C)\int_A f d\mu + (C)\int_A g d\mu \quad (12)$$

in which f and $g \in F$. Finally, Murofushi and Sugeno (1991) affirm that the underlying monotony of the CI can also be defined by Formula (13):

$$(C)\int_A f d\mu \leq (C)\int_A g d\mu, \text{ whenever } f \leq g \quad (13)$$

Given the above features, NAM methods have been increasingly used, especially the CI, as a tool to support decision-making processes. One of the CI's key features is the capability to deal with the interdependence among different decision criteria. This thus means more transparent results can be obtained as the CI permits the aggregation of cardinal information (Krishnan *et al.*, 2015). Mühlbacher and Kaczenski (2016: 33) state that, as a result, “the [CI ...] is [a] non-additive model that ensures commensurability between criteria”. Although the CI technique is not without its limitations, Demirel *et al.* (2010) persuasively argue that the CI is an excellent tool for solving complex problems that include intercorrelated qualitative and quantitative criteria, which seems to be the case for assessments of green cities.

Although other MCDA techniques (*e.g.*, Analytic Network Process (ANP) or Decision Making Trial and Evaluation Laboratory (DEMATEL)), could have been applied in this study context, it is worth noting that earlier research carried out by Weber and Borchering (1993), Belton and Stewart (2002), and Zhou and Ang (2009), seems to suggest that no superior method exists and that the choice of method strongly depends of the decision context. Indeed, most of the studies carried out so far point to the fact that each method has strengths and weaknesses, making it very difficult to prove that one methodology is superior to others in supporting the decision-making process. It is known, for instance, that ANP and DEMATEL allow rankings of alternatives to be obtained in the context of criteria interdependency; but cannot consider the aspiration level of alternatives as in other MCDA methods (*e.g.*, VIKOR and CI) (*cf.* Si *et al.*, 2018).

In the present study, three major factors impacted the choice of methods, namely: (1) cognitive mapping and CI are two well-established methods, recognized for being simple and facilitating decision making across several organizational contexts; (2) two of the CI's key features are the capability to include qualitative and quantitative criteria and to deal with the interdependence between them during the aggregation process of cardinal information, allowing more realistic results to be obtained; and (3) despite the relative popularity of each of these methods, their integrated use is far more scarce, and no prior evidence has been found reporting the combined use of cognitive mapping and the CI in this study context, allowing for the novelty of the proposed framework.

4. APPLICATION AND RESULTS

The model developed in this study is the result of applying a combination of cognitive mapping and the CI. This integrated approach facilitated the development of a system that assesses green cities in a simple, transparent, and structured way. The application of these techniques required face-to-face meetings with a group of decision makers specializing in environmental concerns, which permitted a definition and meticulous analysis of the decision problem in question. This study relied, therefore, on the collaboration of a panel of seven decision makers (*i.e.*, environmental engineers, urban architects, environmentalists, and Lisbon City Council personnel), who have been developing their professional activity, national and internationally, over the past 2-3 decades. The group was formed after a 3-month period of intensive contacts, and the members participated voluntarily in two work sessions lasting approximately four hours each.

According to the literature, no ideal number of members has yet been defined for decision groups, but it should fall between 5 and 12 (*cf.* Ackermann and Eden, 2001; Jalali *et al.*, 2016). The process-oriented stance of our study should be highlighted here. The panel members were selected not to achieve representativeness but rather to maintain a strong focus on process (Bell and Morse, 2013). This means that the panel was formed to bring together the knowledge and experience of experts in green cities, both to create new insights and to use these to construct an evaluation framework, which should be seen as a learning mechanism and not as an end in itself or a tool to prescribe optimal solutions. Although this means the results of the present study can be considered somewhat idiosyncratic (for details on the urban planning in Portugal, see Tulumello (2016)), the

procedures followed can work well with different panels and in varied contexts (*cf.* Ormerod, 2013). This is a reflection of the constructivist and process-oriented logic assumed from the beginning, which allows producing parallel findings in any part of the world (*cf.* Faria *et al.*, 2018; Pires *et al.*, 2018).

Besides the panel of decision makers, the group sessions were also attended by two facilitators (*i.e.*, two of the authors of this paper), who were responsible for guiding the process and recording the results. Again, the entire process underlying this study followed a constructivist epistemological approach based on a perspective of continuous learning. To this end, the decision makers were given opportunities to make adjustments and recommendations regarding their value judgments and/or points of view.

4.1 Group Cognitive Map

Bana e Costa *et al.* (1997) and Moraes *et al.* (2010) note that the structuring phase is the most important stage of the entire decision-making process. The cited authors also argue that this phase is the best time for formulating the problem under analysis. Accordingly, the first group session of the present study was used to structure the problem based on the development of a cognitive map.

To ensure that the methodologies applied were clear to the panel of decision makers, the facilitators gave a brief presentation of the study's principal objectives and the concepts underlying the Strategic Options Developed and Analysis (SODA) methodology, which was developed by Ackermann and Eden (2001) and makes use of cognitive mapping. Next, the panel of decision makers were asked the following trigger question: "*Based on your professional values and experience, what features should the best green cities have?*". This enabled the application of the "post-its technique" (Ackermann and Eden, 2001) in which the decision makers wrote out the criteria they considered pertinent to developing a green city of the highest quality, based on their points of view and value judgments. The process was constrained by the following rules: (1) each post-it note should feature one and only one criterion; and (2) whenever a criterion embodies a negative connection, this should be represented by a minus sign (–) in the upper right hand corner of the post-it note (*cf.* Jalali *et al.*, 2016; Ribeiro *et al.*, 2017).

Having written down a significant number of criteria, the decision makers were asked to work together to group the post-it notes into clusters (CTRs) – known in this field of research as "areas of concern". This exercise was carried following Eden's (1994)

methodological guidelines and, through a long process of exchanging and/or discussing ideas, eight CTRs were defined, namely: people; mobility; water; energy efficiency; biodiversity; waste; governance; and innovation. After placing the criteria allocated to each one of the areas of concern in hierarchical order from most to least important and determining the cause-and-effect relationships between them, the data collected were processed using the *Decision Explorer* software (www.banxia.com). This produced the group cognitive map presented in *Figure 1*, which was subsequently provided to the decision makers for debate, revision, and validation.

The analysis represented by *Figure 1*, which shows the way the group structured the decision problem under study, indicated that, apart from the defined CTRs, other criteria were considered essential to the evaluation of green cities. These were green culture, health, and quality of life, which were considered crucial additions to the cognitive map. In this regard, it is worth highlighting that cognitive maps are extremely versatile problem-structuring tools, which can change over time and be updated periodically. This means that criteria can always be added to or removed from the clusters according to the decision makers' knowledge and perceptions.

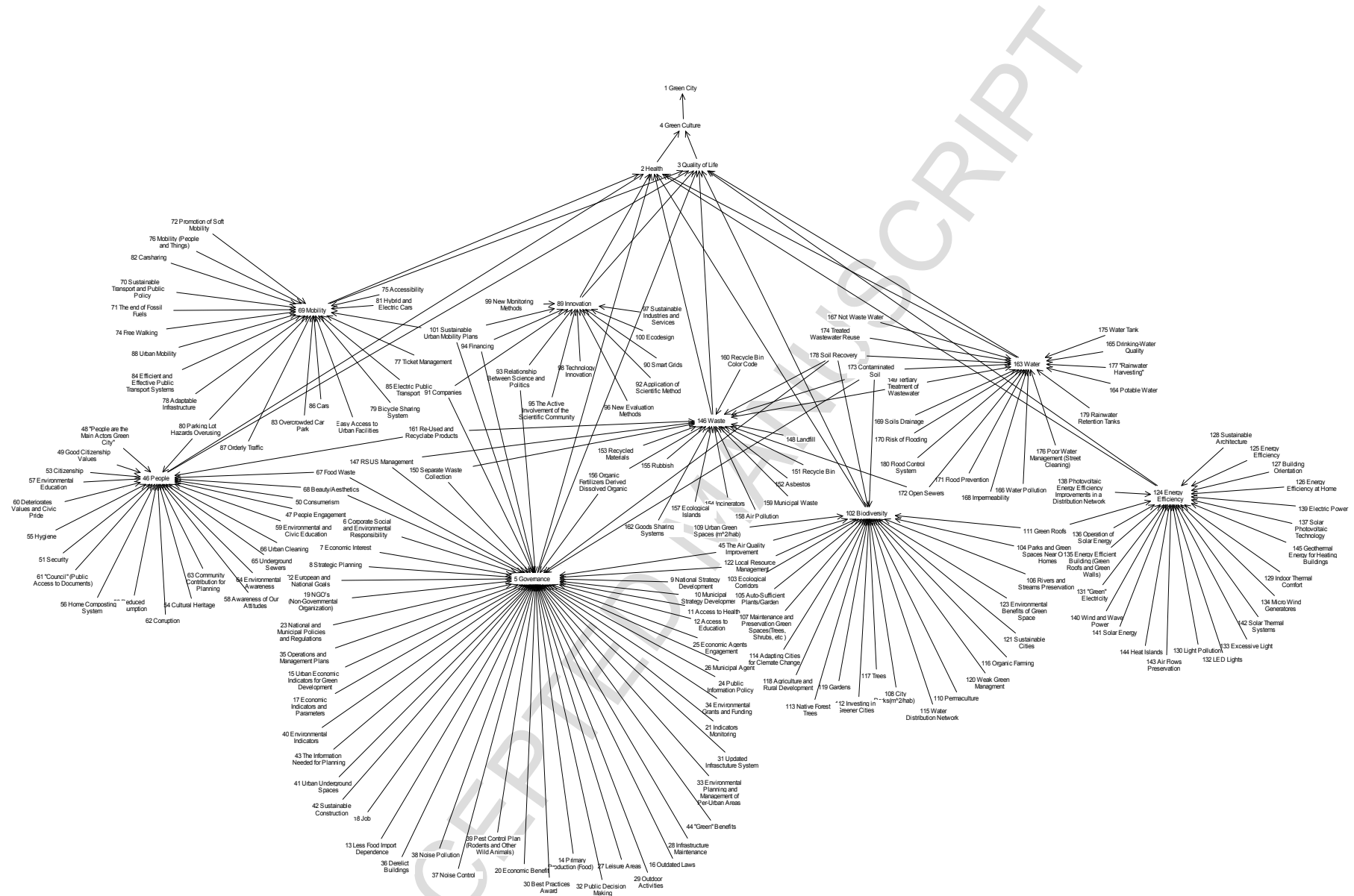


Figure 1: Group Cognitive Map

This reinforces the assertion that cognitive mapping is one of the most versatile tools to assist the structuring of complex decision problems. Because the maps can be dynamic, they allow previous experiences and accumulated knowledge (even from different individuals) to be reflected in the decision-making framework, and the sequential nature of the decisions to be made explicit. As Eden (2004) notes, this can be done through the cause-and-effect links between variables, where each variable is in fact composed of a number of sequential decisions. The use of cognitive maps in the current study allowed the opinions of different decision makers to be aggregated, creating a framework that was shared by all, and within which cause-and-effect relationships between criteria could be detected and understood. Although subjective in nature, this allowed the exchange of ideas and experiences to be promoted, facilitating the identification and selection of the CTRs included in our evaluation system.

The importance of group dynamics and negotiation to clarify complex decision situations should also be highlighted, namely because they allow individuals to confront different opinions and to reach more consensual solutions. In this sense, as discussed by Belton and Stewart (2002), the interactive nature of the integrated use of cognitive mapping and the MCDA approach allows decision makers to enter into decision dimensions that would not be possible to reach in other ways. Having discussed and validated the group cognitive map, the next stage of the process consisted of applying the CI.

4.2 Application of CI

Having completed the structuring phase, the evaluation phase was started. This phase was completed in a second group session. This began with a brief explanation of the method to be applied (*i.e.*, the CI) and ways that it has proven to be relevant to solving the decision problem under study. Next, based on the group cognitive map (see *Figure 1*), the panel of decision makers was presented with a matrix that reflected all the possible combinations derived from the eight CTRs in the cognitive map. Regarding this part of the process, Choquet (1954) states that the number of possible combinations requires the specification of 2^n parameters, which, in the case of the decision problem under study, presumes the existence of 256 possible combinations (*i.e.*, $2^8 = 256$).

Table 2 shows the matrix of possible interactions, in which “Bad” represents a negative performance and “Good” a positive performance. To indicate the different

combinations expressed by the matrix, the panel of decision makers used the group cognitive map to help them identify how the different CTRs were interconnected. In order to complete the last column of *Table 2*, the facilitators posed various questions to the panel members (e.g., “How would you assess the hypothetical scenario of a green city in which only the criterion of people is evaluated as good while the rest of the criteria are considered bad?”). This enabled the panel to score the 256 possible combinations using a nominal scale from 0 to 10 points, in which the value 0 corresponds to a totally undesirable situation, the value 5 to an average situation, and the value 10 to an extremely desirable situation. However, the score attributed to the combinations of attributes could rise or fall, since no precedents had been set for these relationships (Ferreira *et al.*, 2017). *Table 2* presents just a few examples of the combinations analyzed. The scores for the 256 combinations can be obtained from the corresponding author upon request.

Table 2: Matrix of Interactions

#	CTR01 People	CTR02 Mobility	CTR03 Water	CTR04 Energy Efficiency	CTR05 Biodiversity	CTR06 Waste	CTR07 Governance	CTR08 Innovation	Score
1	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	0
2	Good	Bad	Bad	Bad	Bad	Bad	Bad	Bad	3
3	Bad	Good	Bad	Bad	Bad	Bad	Bad	Bad	1
4	Bad	Bad	Good	Bad	Bad	Bad	Bad	Bad	1
5	Bad	Bad	Bad	Good	Bad	Bad	Bad	Bad	1
6	Bad	Bad	Bad	Bad	Good	Bad	Bad	Bad	2
7	Bad	Bad	Bad	Bad	Bad	Good	Bad	Bad	1
8	Bad	Bad	Bad	Bad	Bad	Bad	Good	Bad	3
9	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Good	1
...
67	Bad	Good	Bad	Good	Bad	Good	Bad	Bad	2
...
256	Good	Good	Good	Good	Good	Good	Good	Good	10

To illustrate, the 67th line, with the bad-good-bad-good-bad-good-bad-bad combination, was given two points. In the session, the question asked of the decision makers, in this case, was as follows: “How would you assess the hypothetical scenario of a green city in which only the criteria of mobility, energy efficiency, and waste are evaluated as good while the criteria of people, water, biodiversity, governance, and

innovation are considered bad?”. The result was an undervaluation of this combination of CTRs, as the score given (*i.e.*, only two points) was less than the sum of the values attributable to each of the criteria separately (*i.e.*, $1 + 1 + 1 = 3$). This effect could be explained by possible negative externalities derived from the combination of the five CTRs of people, water, innovation, governance, and biodiversity.

In a second stage of the session, the decision makers were asked to complete a brief survey and provide a score for each of the CTRs for the principal district capitals of mainland Portugal and the archipelagos of Madeira and the Azores. The experts again used a nominal scale from 0 to 10 points, on which the value 0 corresponds to a totally undesirable situation and the value 10 to an extremely desirable situation. Once the survey had been completed, the CI was calculated for the 20 cities in question. However, in order for this to be possible, the first step was to aggregate the attributed scores based on the weight established by the panel of decision makers for each of the CTRs, as shown in *Table 3*. *Figure 2* presents an example of the results, in this case Lisbon’s partial performance.

Table 3: CI Calculation for Lisbon

1) Partial Performance		2) Accumulated Value Calculation		3) Choquet Integral Calculation	
	Lisbon			Variation	Choquet
CRT03 - Water	7	1		0	0
CRT08 - Innovation	7	2		1	2
CTR01 - People	6	4		0	0
CTR06 - Waste	6	5		0	0
CTR07 - Governance	6	6		1	6
CTR02 - Mobility	5	7		1	7
CTR04 - Energy Efficiency	4	7		0	0
CTR05 - Biodiversity	4	10		4	40
	55				

55

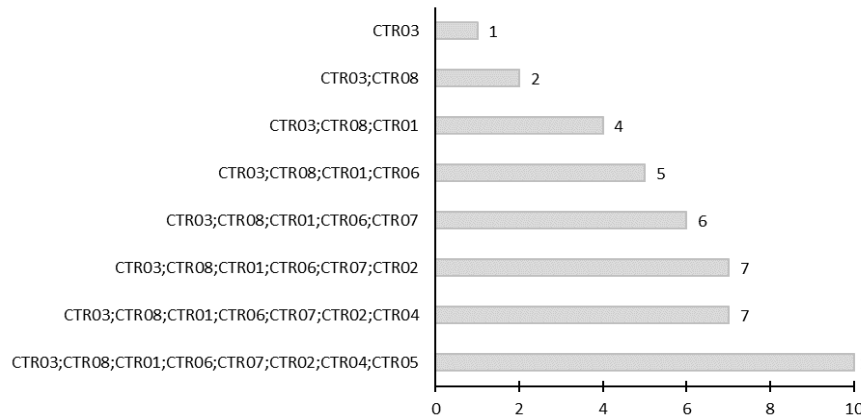


Figure 2: Partial Performance of Lisbon

The results of the analysis shown in *Figure 2* indicate that the majority of the CTRs obtained a grade equal to or higher than five. This means that, in general, Lisbon is considered to be quite close to the hypothetical scenario of the best green city, especially with respect to CTR03 (*i.e.*, water) and CTR08 (*i.e.*, innovation), as both were scored as seven. However, the panel of decision makers thought that, in terms of CTR04 (*i.e.*, energy efficiency) and CTR05 (*i.e.*, biodiversity), Lisbon is below the norm, and thus this city received only four points for these criteria. The final result was 55 points. This analysis was carried out for the remaining cities under study. *Figure 3* illustrates the ranking obtained, which was examined, discussed, and validated by the panel of specialists.

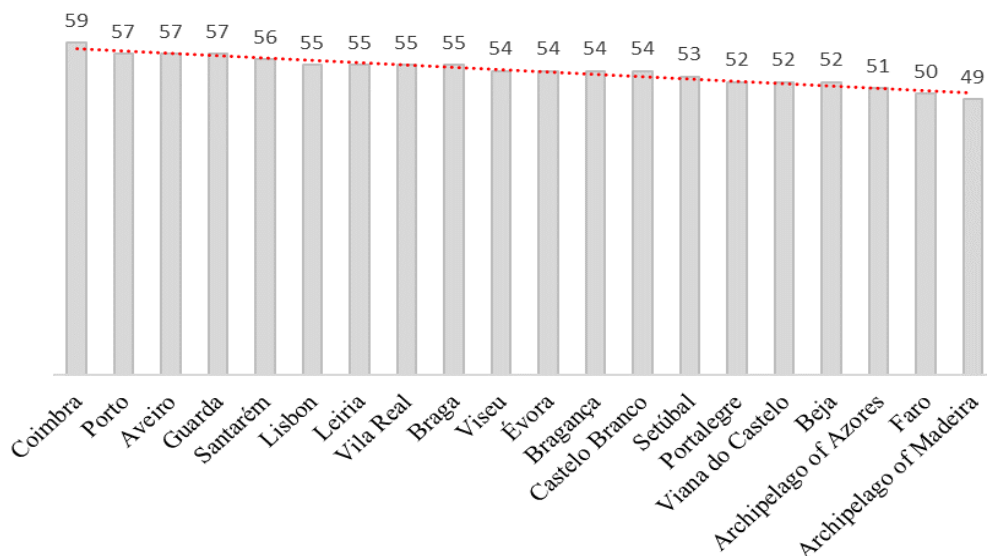


Figure 3: Overall Results of Performance Evaluation

According to the decision makers' point of view and the CI calculations, Coimbra comes the closest to a hypothetical green city of the highest quality, with 59 points. This city is followed by Oporto, Aveiro, Guarda, and Santarém with between 57 and 56 points, revealing that these are considered attractive green cities. The capital city of the archipelago of Madeira has the lowest score of 49 points, which can be explained by the low performance scores given for specific CTRs. Having determined the ranking of alternative scenarios, the study continued with the phase of validating the results and making recommendations.

4.3 Final Validation, Recommendations, and Managerial Implications

After the evaluation phase and analysis of the results were completed, a final session was conducted to validate the results obtained. For this last work session, a parliamentary representative of the Portuguese ecology party "Os Verdes" (The Greens) was asked to participate in this study. This person was suggested by the Assembly of the Republic personnel due to her leadership and involvement in national and international projects in this study context. Notably, this person's opinion was considered of great importance because she possesses specialized knowledge in the subject under study and was considered a neutral participant in the process since she had not participated in any previous sessions.

The final session was held at the Assembly of the Republic in Lisbon. Basically, it was based on a non-coded interview that followed the guidelines provided by Faria *et al.* (2018) and Marques *et al.* (2018). The session lasted approximately one hour, and it was structured to achieve the following five objectives. The first was to obtain a brief overview of the current techniques and practices used in the evaluation of green cities. The second was to get feedback on the integrated use of cognitive maps and the CI to improve the current interpretation of the decision problem under study, as well as the importance of analyzing various combinations of CTRs when assessing the performance of green cities. The third objective was to discuss the results achieved, while the fourth was to analyze the practical application of the proposed evaluation created and requirements for its implementation. The last objective was to identify the advantages of the proposed assessment system compared with other green city assessment techniques.

After the session's objectives were outlined for the interviewee, the interview started with a brief discussion of the current evaluation practices' limitations and

summary of the methodology applied. This was followed by an analysis of both the group cognitive map produced by the panel of decision makers and the matrix of interactions between CTRs filled out in the second group session. The next stage of the final session was the interviewee's analysis of and comments on the results achieved.

The ecology party representative found that *“some of the scores given, namely, for the mobility and governance criteria (i.e., CTR02 and CTR07, respectively) may be slightly overvalued, particularly for the district of Faro, Portalegre, Vila Real, and Bragança”* (in her own words). The interviewer explained that, as a result of the constructivist epistemological logic assumed in this study, the approach used focuses on the process so that, at any time, adjustments can be made to the system to improve the results. In addition, this part of the final session was especially important in terms of clarifying the ranking of alternatives obtained.

After this explanation, the interviewee acknowledged four advantages related to the combined use of cognitive mapping and the CI. *“First, this approach allows more general conclusions to be obtained since the evaluation of green cities needs to be a holistic process. Second, the integrated approach facilitates the participation of experts with know-how in the field. Third, some flexibility is present in the results achieved as no “right” or “wrong” answers are possible due to the subjectivity inherent in MCDA approaches. Last, the results are easy to communicate and interpret due to the integrated and insightful analyses”* (also in her words).

The interviewee's main recommendation was that a more diversified panel of experts would be an added value in the evaluation of the different cities included. Although the evaluation system created is dependent on the value judgments and/or convictions and personal and professional experience of each actor involved, the interviewee understood that the proposal evaluation system is process-oriented (see Bell and Morse (2013), and Ormerod (2013)). By the same token, it facilitates making adjustments whenever these are considered pertinent or when the panel of decision makers changes. This stage of the session thus proved to be especially important in the validation of the practical value of the results obtained.

Although the panel members and independent interviewee did not find the proposed approach exempt of limitations, the participants gave quite positive feedback on the methodological techniques used to develop the present green city assessment system. These experts highlighted that the model applied facilitates the clear identification of CTRs needing improvement in each of the cities evaluated,

demonstrating that this is only possible through detailed analyses of different green city profiles. The results thus confirm the proposed system's managerial implications.

Following this, it is worth noting that the findings of the present research reinforce some of the results presented by Faria *et al.* (2018), Fernandes *et al.* (2018), Marques *et al.* (2018) and Rita *et al.* (2018), who used cognitive mapping to identify evaluation criteria in different green city dimensions and distinct urban planning assessment contexts. Some of the criteria identified were: safety; technology usage; carbon productivity; rates of air and water pollution; crime rates; land resources usage; and green innovation initiatives. However, the results obtained in the current study add to previous research in terms of the identification of more criteria, which are often overlooked. The structuring and analysis method followed not only allowed the deterrents to green cities to be prioritized, but also allows the effects of their interdependence to be analyzed, which is something traditional methods cannot typically provide.

In light of this reasoning, this paper makes important theoretical and practical contributions. Although the findings are idiosyncratic in nature, they can be an important starting point for other researchers and practitioners hoping to assess green cities; and should be used as a springboard for additional studies, complementing previous contributions in the field. From a methodological perspective, the contribution is two-fold: it comes both from the integration of the methodologies used, which is novel in this study context; and from the description of the process followed, which can allow for replications in other contexts and/or with different groups of experts, due to the process-oriented nature of the framework. Indeed, this integrated approach facilitated the development of a system that assesses green cities in a simple, transparent, and structured way. Again, no prior evidence reporting the combined use of cognitive mapping and the CI to evaluate green cities has been found, allowing for the novelty of our study.

In addition, it is worth noting that this proposal is not a substitute for statistical approaches. The intention in this paper was to adopt a complementary (more so than comparative) perspective; because as acknowledged in this section, the proposal is not without its own limitations. In this sense, its application by managers and decision makers can provide insights on key feedback loops in the system, which might otherwise go undetected by statistical approaches alone.

5. CONCLUSION

Large cities contain most of the world's population and contribute to economic growth, innovation, and social progress. However, large urban agglomerations also have to face critical questions such as social imbalances, infrastructure constrictions, or sustainability risks. It is increasingly evident that cities need to implement strategic measures capable of inverting the current negative trends in terms of the quality of life of urban populations. This problem arises from the unprecedented concentration of economic activities in urban areas, contributing to their increased importance. Although various studies have addressed this issue, an analysis of various assessment models previously implemented revealed that these have methodological limitations, which prompted the present effort to ameliorate the existing models and improve the decision-making processes in question.

In practical terms, the assessment of green cities is highly complex due to the broad range of criteria, which are quite often contradictory, that must be taken into account. Therefore, an integrated use of cognitive mapping and the CI was identified as highly pertinent to this study's objective, enabling the creation of an innovative system for evaluating green cities. No evidence was found of prior research combining these techniques (*i.e.*, cognitive maps and CI) for this specific purpose, allowing the first research question posed (*i.e.*, Which are the relevant criteria in the assessment of green cities?) to be answered.

The present study relied on the participation of seven decision makers who, after having developed the intended model, expressed great satisfaction with the results, stating that the methodologies applied foster greater transparency and simplicity in the process of assessing green cities. Through this process, eight relevant CTRs were identified: people; mobility; water; energy efficiency; biodiversity; waste; governance; and innovation. These CTRs subsequently enabled the calculation of the CI for the district capitals of mainland Portugal and the archipelagos of Madeira and the Azores, allowing the second research question posed (*i.e.*, How can multiple criteria be aggregated to obtain a synthetic indicator of green cities' sustainability?) to be addressed. Coimbra stood out as the most attractive green city in Portugal, in contrast to the capital of the archipelago of Madeira, which came the closest to undesirable conditions in terms of green cities.

While the advantages of the methodological techniques applied are clear, they are not exempt from limitations. More specifically, difficulties were experienced during the process of constituting the panel of decision makers due to the extensive availability and

commitment required from the members. In addition, the context-dependence of the proposal should be highlighted, which does not allow for extrapolations without proper adjustments. Still, this is arguably compensated by the process-oriented stance adopted, which allows each assessment system developed to be tailored to the specific characteristics of each country. The results obtained here can thus be used not only as a complement to previous work on green city assessments, but also as a springboard for additional, potentially comparative, studies.

In view of the ongoing need to perfect the available methods or approaches, three suggestions can be made for future research. First, similar studies need to be conducted to apply other MCDA techniques (for examples and suggestions, see Belton and Stewart (2002), and Zavadskas *et al.* (2014)), which should include subjecting the present results to sensitivity or robustness tests (a file containing all the analyses carried out in the present study is available upon request, allowing additional sensitivity and robustness tests to be easier). Second, comparative studies could be designed involving different methods, which would help identify the method best adapted to solving the decision problem and issues under analysis. Although methodological comparisons are clearly important and need to be encouraged, this was not an objective of the present research, and would likely constitute the basis for a separate paper altogether, requiring additional group meetings with the expert panel. Indeed, as with any research paper, time and space constraints had to be considered, and the focus the paper was on: (1) the value of the integration of the two techniques applied; and (2) the framework developed and applied using those techniques, with experts from the field. Last, software needs to be developed that could facilitate a faster extraction of results. Any enhancements and updates will be welcome improvements to the process of evaluating green cities.

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