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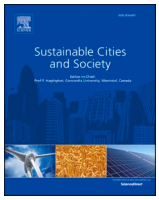

Towards sustainable cities: A sustainability assessment study for metropolitan cities in Turkey via a hybridized IT2F-AHP and COPRAS approach

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ABSTRACT

Accelerating trends of urbanization enforce the integration of sustainability principles into urban planning in a local scale to foster prosperity for the next generation of cities. This study incorporates fifty-three indicators on economic, social, environmental, and institutional dimensions to develop a Sustainable Cities Index (SCI) and assess the sustainability performance of thirty metropolitans in Turkey over 2010-2018. Turkish metropolitans constitute an appealing case study due to the rapid urbanization within the same time span. To answer how new metropolitans have been doing and whether they perform better than formerly declared metropolitans in Turkey, we propose a novel methodology with three stages that hybridizes Interval Type-2 Fuzzy Analytical Hierarchy Process (IT2F-AHP) and Complex Proportional Assessment of Alternatives (COPRAS). The former captures a high degree of uncertainty due to the subjective weight assignment by the experts, while the latter calculates aggregate scores for 30 cities. Finally, we conduct posthoc analyses to examine the significance of the urbanization policies in Turkey on the SCI scores. Thus, the study provides valuable insights into urbanization practices and encourages local administrations to spend more effort balancing the benefits and costs of public policies on sustainability.

1. Introduction

Sustainability assessment has become increasingly vital for rapidly developing megacities facing accelerating social, economic, and environmental challenges (Mapar et al., 2020). The remarkable growth in urbanization around the megacities has started to cause detrimental impacts on the environment and society. According to the United Nations (UN) (2019), the world's urban population grew at an average rate of 2.54% per year, increasing from 0.8 billion to 4.2 billion from 1950 to 2018. Furthermore, the proportion of the urban population is forecasted to increase from 55% in 2018 to 68% by 2050 (UNCTAD, 2018; UNDP, 2020). Emerging countries are the main drivers of this increase. Although megacities provide better living opportunities, they also exhaust natural resources and create environmental degradation, lack of sufficient health, social conflicts (Li et al., 2009). Thus, public administrations are expected to maintain a balance between economic activity, population growth, infrastructure and services, pollution, waste, and noise to allow a harmonized evolvement of an urban system (Hiremath et al., 2013; Mori and Yamashita, 2015).

To achieve this balance, the UN promotes one of the sustainable development goals (SDGs), i.e., "*sustainable cities and communities*" (SDG 11), in implementing sustainable policies in megacities (UNDP, 2020). However, this achievement depends on a successful integrated assessment and management of economic, social, environmental, and institutional activities (Yigitcanlar, Dur, and Dizdaroğlu, 2015). Therefore, since the Rio Summit held in 1992, nations and municipalities have introduced policies at metropolitan regions to take integrated actions aiming to overcome economic, social, and environmental challenges (Basiago, 1998; Camagni, 2002; UNCSD, 2002).

In this respect, different sustainable assessment tools have emerged over the last decades, such as indicators and indices to help policymakers. Indicator-based approaches have contributed the most to building integrated sustainable systems (Hiremath et al., 2013). These indicators guide megacities in developing conditions that would be

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conducive to sustainability (Mangi et al., 2020; Michael, Noor, & Figueroa, 2014). However, setting a list of adequate indicators in a complex metropolitan system is a highly challenging task (Ruá, Huedo, Civera, & Agost-Felip, 2019; Zavadskas et al., 2007). The indicators should be well-founded, limited in number, broad in coverage, obtainable at a reasonable cost, and should integrate the qualities associated with the interactions of economic, social, institutional, and environmental dimensions for an equitable, liveable, and viable development (Dahl, 2012; Scipioni et al., 2009; Tanguay et al., 2010). To this end, besides international organizations' efforts, more initiatives should be introduced by public administrations, business communities, and non-governmental organizations (NGOs) (MacGillivray et al., 1998).

Although there are numerous studies on the sustainability performance of cities in developed countries, there are relatively few works focusing on emerging economies due to the infancy of the indicator-based approach in these countries (Andersen et al., 2020; Mangi et al., 2020; Mapar et al., 2020; ICS & SDSN, 2021; REDS, 2020). Turkey is one of them. It has experienced significant growth in urbanization over the last five decades. As a result, cities in Turkey accommodate over 75 percent of the population, and they face increasing environmental and social challenges requiring a broad range of sustainable measures. According to the 10th Development Plan of Turkey, the most significant urban problems are insufficient numbers of descent housing units, traffic congestion, lack of safety and infrastructure, social cohesion, immigration, and environmental degradation (Alarslan, 2018). The World Bank Group has also supported sustainable development in Turkey by expanding financing under the "Sustainable Cities Project". The program aims to improve cities' economic, environmental, and social sustainability by enabling municipalities to access funds for their priority investments (World Bank 2019).

All these efforts have led to the development of different indicators for assessing sustainability and shaping new practices towards better urbanization in Turkey. However, few studies have been held on sustainable cities until now, particularly focusing on a single year (Gazibey et al., 2014; Yildirim et al., 2017). However, sustainability is a long-ranging concept. Intending to contribute to the extant literature, the present study builds on the indicator-based approach and uses fifty-three selected indicators to compare the sustainability performance of thirty metropolitan cities in Turkey throughout 2010-2018. It incorporates economic, social, environmental, and institutional dimensions and evaluates the forerunners and laggards of the Turkish metropolitans on each dimension of sustainability. The metropolitan cities in Turkey constitute an appealing case for research due to rapid urbanization and fundamental changes in administrative regulations in the country during the study's sample period. With the enactment of Law No. 6360 in 2012, the number of metropolitan municipalities has increased from 16 to 30 to accelerate development momentum in rural areas. The law enforced in 2014 also expanded the administrative boundaries of 14 additive municipalities. Thus, the present study provides a viable case to examine the effect of administrative policy changes on sustainability.

To compare the sustainability of the metropolitan cities, it is necessary to reveal in which fields some metropolitans are doing better than others (Voula, 2005). In this respect, formulating clearly articulated methods for measuring sustainability is a prerequisite, and the selection and relative evaluation of indicators play a vital role in doing so (Hiremath, 2013). However, many studies oversimplify this issue and follow a rather direct approach with equal importance attached to the selected evaluation metrics, which received severe criticism (Chen & Zhang, 2020; Munier, 2011; Van de Kerk & Manuel, 2008; Zoeteman, Mommaas, & Dagevos, 2016). Obviously, the subjective nature of the evaluation process necessitates a more careful approach that considers different types of uncertainties, such as subjectivity and vagueness of evaluation weights. To this end, this study proposes a holistic approach to build a systematic evaluation framework for measuring sustainability performance. The study combines two Multi-Criteria Decision Making (MCDM) methods, IT2F-AHP (Yilmaz, Kusakci, Tatoglu, Icten, & Yetgin, 2019) and COPRAS (Alinezhad & Khalili, 2019; Zagorskas, Burinskienė, Zavadskas, & Turskis, 2007). This novel approach is expected to help manage complex data set and provide adequate results for the sustainability assessment of metropolitans. In this frame, this study also develops a composite assessment index considering all aspects of sustainability performance simultaneously at the metropolitan level in an integrated manner on Turkish setting covering the largest time span to systematize the evaluation of the sustainability of megacities in several dimensions.

Based on the sustainability scores obtained, this study attempts to address the following issues: (i) The impact of GDP per capita of Turkish cities on their sustainability performance, (ii) the impact of population on the sustainability of Turkish metropolitans, (iii) the difference between the sustainability performances of formerly established and newly declared metropolitans, and (iv) the difference between the sustainability performances of new metropolitans during the pre- and post-metropolitan periods. The analysis compiles a sample of 30 megacities for four reasons. First, most of the population in Turkey live in these cities and are more exposed to sustainability-related problems. Second, for some indicators, data are available only for metropolitans. Third, most large cities have adopted sustainability strategies. Finally, working at the metropolitan level allows determining the responsibilities of all parties involved, and the actions are easier to control (Campbell, 1996). Thus, the findings are expected to provide valuable insights for public administrations and policymakers to identify indicators further to improve sustainable practices in urban areas.

The rest of the study is organized as follows: Section 2 reviews the literature, while Section 3 provides background information about the Turkish efforts on sustainable urban development. Section 4 describes the data and methodology. Section 5 performs a detailed analysis of the sustainability indicators for Turkish metropolitan cities and discusses the empirical results. Finally, Section 6 concludes the study with insights for policymakers and highlights directions for future research.

2. Literature review

Since the early 1970s, concerns on environmental matters and social challenges from rapid urbanization have placed sustainability at the core of the scholarly discussion. Selected recent studies and their methodologies and findings are summarized in Table A5. Many researchers have focused on three pillars of sustainability, i.e., economic, social, and environmental, called "the triple bottom line" in evaluating sustainability performance (Basiago, 1998; Feleki et al., 2018; Liang et al., 2016; Scipioni et al., 2009; Slaper and Hall, 2011; Visvaldis et al., 2013; Zoeteman et al., 2015). Furthermore, some others have inserted the fourth dimension, i.e., governance or institutional effectiveness in this scheme (Caldas et al., 2018).

Institutions and scholars have used different indicators to assess sustainability performance in providing information for planning and decision making at the local level (Koroneos, Nanaki, and Xydis, 2012; Munier, 2011; Yigitcanlar and Dur, 2010. In a study held in Rio de Janeiro, De La Rocque and Shelton-Zumpano (2014) indicated a need for a multi-sector partnership to achieve sustainability, including the local level ones. Hence, indicators should inspire the views of municipalities and communities to reflect the multi-dimensional impact in decision-making (Olewiler, 2006). For instance, city administrations in Germany inform people by putting sustainability goals on their websites, emphasizing the role of partnership in attaining the targets in local communities (Meschede, 2019). In their study on four municipalities of Ontario, Stuart et al. (2016) argued that policy-based approaches to sustainability should consider more socially oriented strategies focused on promoting community involvement, inclusive decision-making, socio-ecological civility, and long-term integrative planning.

To deal with these challenges, many institutions have made efforts to establish effective indicators to guide sustainable development (Agol

et al., 2014; Dizdaroglu, 2017). For instance, International Institute for Sustainable Development raises Bellagio Principles for selecting assessment indicators (Hardi and Zdan, 1997). These principles emphasize that the selection of indicators and assessment methods should be based on a clear understanding of economic development, ecological conditions, and social well-being. The indicators should also be adaptive, responsive to changes, be clear in assigning responsibility and providing ongoing support in decision-making. The OECD (2001) adopted three basic principles in setting environmental assessment indicators: policy relevance for users, analytical soundness, and measurability. This approach organizes indicators as a causal chain, in which social and economic developments exert pressure on the environment and, in turn, on human health and ecological systems. The World Bank initiated Global City Indicators Program to help cities in performance monitoring by providing a framework to facilitate consistent collection of indicators (Shen and Zhou, 2014). The Program proposes 53 indicators across 22 themes into two broad categories: city services and life quality (World Bank, 2008).

However, there is a practical difficulty in working with numerous metrics due to the lack of or poor-quality data. Liu et al. (2012) indicated that sustainable urbanization is a dynamic, multi-dimensional progress that does not follow a consistent pattern across different stages. Therefore, a manageable set of indicators addressing different areas should be produced Marcotullio (2001). The empowerment of local government is important to seriously deal with that struggle since they are involved in implementing many policies (Caldas et al., 2018).

Prior studies conducted on urban sustainability have used different set of indicators to exhibit the sustainability image of cities. Lynch et al. (2011) reviewed 22 systems with 377 indicators and identified 145 indicators to measure sustainable urban development. Shen, Ochoa, Shah and Zhang, (2011) examined nine different practices and proposed four dimensions: environmental, economic, social, and governance. Huang et al. (1998) identified 80 indicators through the participation of NGOs for measuring Taipei's urban sustainability. In a similar study on Taipei, Liang et al. (2016) indicated that all positive dimensions of economic, environmental, and social impacts exerted significant positive effects on urban sustainability, while negative dimensions did not. Gustavson, Lonergan, and Ruitenbeek (1999) selected 23 indicators to address environmental, social, economic, and institutional dimensions. Yigitcanlar and Dur (2010) established an urban sustainability evaluation model in which infrastructure, land use, environment, and transport are the key indicators. Other studies have addressed sustainability performance indicators from a perspective of a particular urbanization domain (Tsai, 2010; Zhang, Wu, and Shen, 2011).

Some of the indicators may not be applied in practice, particularly in emerging countries. Therefore, as Visvaldis et al. (2013) suggested, the indicators should be practically relevant. Similarly, some indicators cannot be used due to data unavailability. Finally, it is important to note that cities are not independently sustainable. They rely on other areas beyond their boundaries for supply of resources, disposition of wastes, emission of pollutants, and indirect use of ecosystem services (Bithas and Christofakis, 2006; Camagni, Capello, and Nijkamp, 1998; Visvaldis et al., 2013). Thus, it is necessary to focus on the dependencies of cities on other areas to assess sustainability (Mayer, 2008).

Beside indicators, many studies have drawn attention to the lack of formally established methods pertaining to sustainable development indicators (Belnap, 1998; Dale & Beyeler, 2001; Legrand et al., 2007; Niemeijer and De Groot, 2008). These studies recognize the importance of defining transparent and rigorous selection criteria to increase the value of indicators. Dennis and Guio (2004) suggested that the indicators should have the following properties: (1) capturing the responsive behavior to policy intervention, (2) being measurable in a comparable way, and (3) not imposing a burden disproportionate to its benefits. Similarly, Dizdaroglu (2017) argues that the dilemma in measuring the sustainability of any municipality stems from the collection of reliable data. Thus, a framework that suggests logical groupings for related sets of information to assist their integration is required (Moldan and Billharz, 1997).

Apparently, there are multiple ways to assess the sustainability of megacities, and different methods lead to different results. In this frame, choosing sensitive indicators that signal progress is vital (Hezri, 2004; Valentin and Spangenberg, 2000; Zavadskas et al. (2007). Some studies employ sophisticated techniques such as Analytic Hierarchy Process (AHP), Multi Criteria Decision Making (MCDM), COPRAS, Fuzzy Logic, Weighted Linear Combination (WLC), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to assess the sustainability of cities (Chen & Zhang, 2020; Graymore et al., 2009; Ramya and Devadas, 2019; Yiğitcanlar et al., 2015; Zagorskas et al, 2007; among others). Other studies argue that there is a need to aggregate the indicators into a composite index to provide a simplified, coherent, and multidimensional view of the sustainability of cities and allow making comparisons between them (Mapar, 2020; Mayer, 2008; Mori and Christodoulou, 2012).

There are relatively few studies on the sustainability of cities in Turkey. Gulcan and Aldemir (2008) compared two provinces in the Aegean region (Aydin and Denizli) in terms of economic and socio-cultural factors. They indicated that economic factors are not sufficient to evaluate sustainability. Hence, the cities need to incorporate other factors like cultural values, and networks. Gazibey et al. (2014) analyzed the sustainability performance of 81 cities in Turkey using social, economic, and environmental indicators and employing the TOPSIS method. Their results showed that Kocaeli, Istanbul, and Ankara are the top three sustainable cities. Yıldırım et al. (2017) examined the perception level of local government staff on environmental sustainability tools in Istanbul by focusing on their evaluation of the Local Agenda 21 indicators, i.e., social activities, renewable energy projects, energy productivity projects, green transportation, and waste management. The results indicated that strategy-based implementations such as sustainable planning and participatory policies are more successful than project-based ones.

Based on the recent trend in urban sustainability, there has been little agreement on the representative indicators of sustainability. As a result, most studies have tended to focus on evaluation scores rather than metrics. This study adopts four pillars of sustainability, i.e., economic, social, environmental, and institutional, and develops a composite assessment index (Sustainable Cities Index) to measure the sustainability performance of megacities in Turkey in an integrated manner. It proposes a three-stage methodological framework integrating two MCDM methods, namely IT2F-AHP and COPRAS. IT2F-AHP component provides a handy tool for prioritizing sustainability indicators based on experts' personal opinions, while the latter method aggregates benefit and cost criteria into a single score in a simple but effective way. The proposed method helps reach measurable results and compares the state of sustainability performance between different metropolitan cities. The research methodology includes four main parts; i) determine the relative importance of indicators through an interview with the experts, ii) use IT2F-AHP and COPRAS to build a sustainability assessment index, and iii) assess the sustainability performance of metropolitan cities in Turkey. Another significant issue primarily neglected in the literature is the long-term trends in the sustainability assessment. This study covers a larger time frame and addresses the effects of policy changes on the sustainability performance of Turkish cities.

3. Sustainable urban development in Turkey

Sustainable urban development has been thoughtfully considered in Turkey since the mid-2000. In the 9th and 10th Development Plans, the government introduced policies to address sustainable development in urban areas. In parallel, an Integrated Urban Development Strategy and Action Plan was enacted in 2010 (OECD, 2017). The government also made a significant attempt to mitigate disaster risks by enacting The Law of Transformation of Areas under the Disaster Risks in 2012 (Güzey,

Table 1
The SDG Index Score and SDG 11 Score and Progress of Turkey (2017-2019)

Year	SDGIndexScore	RegionalAverageScore	Ranking in SDG Index	SDG 11Score	SDG 11Positioning	Progressin SDG 11
2017	68.5	77.7	67/157	81.8	Challenges Remain	Moderate increase
2018	66.0	76.9	79/156	73.2	Significant Challenges Remain	Stagnating
2019	68.5	77.7	79/162	70.4	Significant Challenges Remain	Stagnating

Source: SDG Index and Dashboards Reports 2017, 2018, 2019. Sustainable Development Solutions Network

Table 2
SDG 11 - Sustainable cities and communities (Performance of Turkey)

SDG 11 Parameters	2017	2018	2019
The annual mean concentration of particular matter of fewer than 2.5 microns of diameter (PM) (μg/m3)	35.6	36.4	44.3
Improved water source, piped (% urban population with access)	100.0	98.6	98.6
Satisfaction with public transport (%)	57.0	57.0	57.8
Rent overburden rate (%)	NA	NA	NA

Source: SDG Index and Dashboards Reports 2017, 2018, 2019. Sustainable Development Solutions Network

2016). In waste management, Turkey has generated strategy-based projects, i.e., zero waste, sustainable environmental management systems, and Energy Efficiency. In transportation services, there are ongoing projects, i.e., development of infrastructure for public transportation, smart traffic systems, and reducing emissions in traffic.

To build upon these policies, Turkey has made great efforts towards making its cities more sustainable, smart, inclusive, and well planned. The World Bank, the European Union (EU), the Ministry of Environment and Urban Planning, and municipalities jointly launched the Sustainable Cities Program aiming to improve economic, financial, environmental, and social sustainability of cities. In the first phase, ten municipalities are selected to benefit from technical assistance provided by the EU, including Antalya, Balikesir, Denizli, Kahramanmaras, Kayseri, Malatya, Mardin, and Mugla, accounting for one-tenth of the cities in the country. Implementing these programs has contributed to the development of practicing sustainable urbanization and has provided valuable data for conducting this study. Table 1 provides the progress of Turkey in terms of the SDG Index score calculated by Sustainable Development Solutions Network (SDSN) and the country's SDG 11 positioning. The figures show that the country's performance for SDG 11 is stagnating for the years 2018 and 2019 and significant challenges remain to be solved in the future (SDSN, 2017, SDSN, 2018, SDSN, 2019). A similar study held by SDSN Mediterranean (2019) also showed that Turkey ranks the 16th country in meeting SDG 11 goal among the Mediterranean countries by 2019 with a score of 70.4.

Given the size and nature of services offered by metropolitan municipalities, the social, economic, and environmental consequences of their transformation into smart cities is substantial. With the enactment of Law No. 6360 in 2012, the number of metropolitan municipalities in Turkey has increased from 16 to 30. This regulation entered into force in 2014 and expanded the administrative boundaries of these municipalities, leading the urban population to reach 92% in 2018 compared to 73% in 2015. This regulation enforced local governments to seek more innovative and creative solutions for accessing SDG 11 goals (Akyildiz, 2017). In this frame, Turkey has taken preventive measures such as waste management, soil pollution control, and air quality to mitigate the negative impacts of urbanization. Areas covered by SDG 11 such as access to housing, urban transportation, mitigation of disaster risks, protecting the cultural heritage, improving the access of disadvantaged groups to urban services are also comprehensively regulated in the relevant legislations.

For instance, the number of sanitary landfills for solid waste management increased to 88 as of 2019, providing services to 62.3 million people in 1,160 municipalities. Similarly, 75% of the municipal population received services for wastewater treatment in 2016. The number of air quality monitoring stations increased from 36 in 2007 to 253 in 2017. The rail system length completed in 2013-2018 was 160 km, bringing the total line length to 700 km. Around 970 million passengers are carried annually by rail lines. As of 2018, public rail transport systems are operated in 12 metropolises. While there is considerable progress for meeting SDG 11, further improvement is needed for other areas in metropolitans, as shown in Table 2. According to a recent report published by the Global Goals for Sustainable Development in 2019, the compliance level for SDG 11 in terms of the institutional framework and project inventory is lower than policy strategy, legislation, and implementation states.

4. Methodology and Data sample

4.1. Methodology

We use a hybrid research strategy that combines qualitative, quantitative, and exploratory research strategies. Verbal expressions of the experts are collected through introductory interviews and structured survey forms. The resulting data are then used for IT2F-AHP. IT2F-AHP and COPRAS stage follows a quantitative strategy while the posthoc analysis uses the exploratory strategy to explore the determinants of sustainability scores and gain insights on the effect of administrative policies on these scores. The interviews with the field experts were done during March-June 2019, followed by the compilation of experts' priorities on sustainability indicators. The data collection and validation from various sources lasted almost six months, the second half of 2019.

Initially, a comprehensive review is needed to elaborate an evaluation scheme. In addition, we cover all possible components and categories of sustainable development by grouping the indicators according to the economic, environmental, social, and institutional dimensions consistent with other similar studies (Kwatra et al., 2016). Finally, we use indicators upon which a consensus exists in the literature to facilitate comparison with other studies to build a Sustainable Cities Index (SCI).

Sustainability indices force institutions and governments to question their standards and act as "driving forces" for public policymaking (Barbosa Araripe-Silva et al., 2018). However, the validity of these indices heavily depends on how their components are weighted and aggregated. To this end, we integrate two MCDM methods to obtain the subjective weights of indicators and overall scores of metropolitan cities. The application of MCDM methods to sustainability-related decision--making problems is blossoming due to their ability to handle a multitude of sustainability indicators while evaluating alternatives. The integration of different MCDM methods has become a common practice to exploit the strengths of each technique at various stages of the decision-making process.

This study proposes a three-stage methodological framework integrating two MCDM methods, namely IT2F-AHP and COPRAS. The first component is used to extract the relevance of different dimensions of sustainability. AHP is a well-established tool for prioritizing the evaluation criteria (Yilmaz et al., 2019). The conventional tool for handling uncertainty in MCDM problems is type-1 fuzzy sets. However, the level of uncertainty due the subjective human judgment varies from precise numeric judgment to vague personal perception. This fact necessitates extending the concept of fuzziness where type-2 fuzzy (T2F) sets come to the aid as they can handle more uncertainty and produce more robust

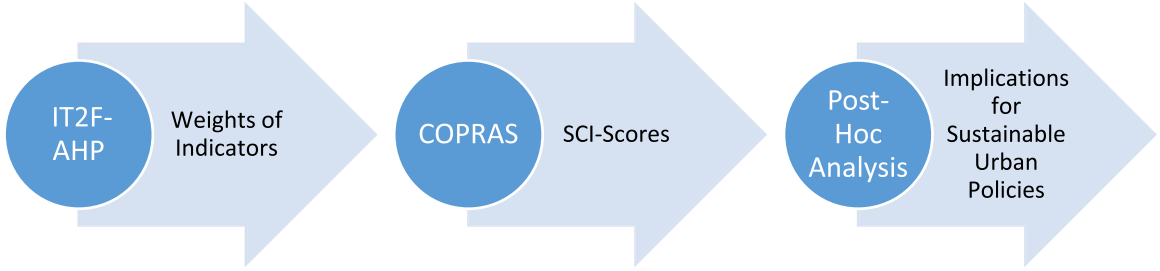


Fig. 1. Proposed Methodology

Table 3
Linguistic expressions and their IT2F peers

Linguistic term	Trapezoidal interval type-2 fuzzy sets
Absolutely strong (AS)	$\widetilde{\widetilde{AS}} = ((7,8,9,9;1,1),(7.2,8.2,8.8,9;0.8,0.8))$
Very strong (VS)	$\widetilde{\widetilde{VS}} = ((5,6,8,9;1,1),(5.2,6.2,7.8,8.8;0.8,0.8))$
Fairly strong (FS)	$\widetilde{\widetilde{FS}} = ((3,4,6,7;1,1),(3.2,4.2,5.8,6.8;0.8,0.8))$
Slightly strong (SS)	$\widetilde{\widetilde{SS}} = ((1,2,4,5;1,1),(1.2,2.2,3.8,4.8;0.8,0.8))$
Exactly equal (E)	$\widetilde{\widetilde{E}} = ((1,1,1,1;1,1),\ (1,1,1,1;1,1))$
Slightly weak (SW)	$\widetilde{\widetilde{SW}} = 1/\widetilde{\widetilde{SS}} = ((0.200,0.250,0.500,1;\ 1,1),$ $(0.208,0.263,0.454,0.833;\ 0.8,0.8))$
Fairly weak (FW)	$\widetilde{\widetilde{FW}} = 1/\widetilde{\widetilde{FS}} = ((0.143,0.167,0.250,0.333;\ 1,1),$ $(0.147,0.172,0.238,0.312;\ 0.8,0.8))$
Very weak (VW)	$\widetilde{\widetilde{VW}} = 1/\widetilde{\widetilde{VS}} = ((0.111,0.125,0.167,0.200;\ 1,1),$ $(0.114,0.128,0.161,0.192;\ 0.8,0.8))$
Absolutely weak (AW)	$\widetilde{\widetilde{AW}} = 1/\widetilde{\widetilde{AS}} = ((0.111,0.111,0.125,0.143;\ 1,1),$ $(0.111,0.114,0.122,0.139;\ 0.8,0.8))$

results (Görener et al., 2017). More precisely, unlike classic fuzzy sets, the membership function is also defined via a fuzzy set in interval T2F sets. Thus, IT2F-AHP is a promising approach for evaluating the relative importance of sustainability dimensions, handling a high level of uncertainty originating from vague and subjective assessment of the membership degrees of the indicators by the field experts (Görener, Ayvaz, Kuşakcı, & Altınok, 2017).

The second component, COPRAS, is a simple but effective method to calculate Turkish metropolitan cities' SCI rankings. COPRAS is a viable alternative to assess the effect of maximizing and minimizing indices of positive and negative attributes on the ranking scores separately (Alinezhad & Khalili, 2019; Narayanamoorthy, Ramya, Kalaiselvan, Kureethara, & Kang, 2020). Due to its simplicity, COPRAS has become a preferred methodology for MCDM problems in different fields (Rabbani, Zamani, Yazdani-Chamzini, & Zavadskas, 2014). In this method, the influence of benefit and cost criteria on the evaluation result is considered separately. So, the final ranking of an alternative is a function of these two (Alinezhad & Khalili, 2019). As reported in the literature, the COPRAS method provides some advantages compared to many other MCDM techniques, such as, (i) more straightforward structure and less calculation time, and (ii) simultaneous consideration of the ratio to the idea- best solution and the ideal-worst solution (Büyüközkan, Karabulut, & Mukul, 2018; Rabbani et al., 2014).

Finally, posthoc analysis will be conducted based on the SCI scores to give insights into Turkey's urbanization policies and practices (Fig. 1).

4.1.1. Interval Type-2 Fuzzy AHP

It goes without saying that there are considerable variations among the views of researchers on the primary dimensions of sustainability assessment of cities. Thus, the use of Type-2 Fuzzy set based AHP is justified by capturing a high degree of uncertainty associated with vague verbal expressions (Dorfeshan, Mousavi, Mohagheghi, & Vahdani, 2018; Görener, Ayvaz, Kuşakcı, & Altınok, 2017).

Preliminaries of IT2F sets are presented in the studies of Yilmaz, Kusakci, Tatoglu, Icten, & Yetgin (2019) and Kahraman, Sarı, & Turanoğlu (2012). To avoid losing the focus of the study, we direct the interested reader to these articles. A recent IT2F-AHP model was presented by Kahraman et al. (2012), which provides a basis for our study.

The main steps of IT2F-AHP are described below:

Step 1.1. Construct the problem hierarchy.

Step 1.2. Given m experts, construct m fuzzy pairwise comparison matrices, $\widetilde{\widetilde{A}}^{k}$, where $k = 1,\ldots,m$. $\widetilde{\widetilde{A}}^{k}$ is constructed as a matrix of nxn trapezoidal IT2F sets.

$$\widetilde{\widetilde{A}}^{k} = \begin{bmatrix} 1 & \widetilde{\widetilde{a}}^{k}_{12} & \ldots & \widetilde{\widetilde{a}}^{k}_{1n} \\ \widetilde{\widetilde{a}}^{k}_{21} & 1 & \ldots & \widetilde{\widetilde{a}}^{k}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{\widetilde{a}}^{k}_{n1} & \widetilde{\widetilde{a}}^{k}_{n2} & \ldots & 1 \end{bmatrix} \quad (1)$$

where $\widetilde{\widetilde{a}}_{ji}$ is reciprocal $\widetilde{\widetilde{a}}_{ij}$.

Here, we note that upper and lower membership functions of an IT2F set are type-1 membership functions. A trapezoidal IT2F set, $\widetilde{\widetilde{A}}_i$, is denoted as;

$$\widetilde{\widetilde{A}}_i = \left(\widetilde{A}_i^{U}, \widetilde{A}_i^{L}\right) = \left(a_{i1}^{U}, a_{i2}^{U}, a_{i3}^{U}, a_{i4}^{U}; H_1\left(\widetilde{A}_i^{U}\right), H_2\left(\widetilde{A}_i^{U}\right)\right), \left(a_{i1}^{L}, a_{i2}^{L}, a_{i3}^{L}, a_{i4}^{L}; H_1\left(\widetilde{A}_i^{L}\right), H_2\left(\widetilde{A}_i^{L}\right)\right)$$

here $H_j(\widetilde{A}_i^{U})$ denotes the membership value of the element $a_{i(j+1)}^{U}$ in the upper trapezoidal membership function, $\widetilde{A}_i^{U}, 1 \le j \le 2$, whereas $H_j(\widetilde{A}_i^{L})$ denotes the membership value of the element $a_{i(j+1)}^{L}$ in the lower trapezoidal membership function $\widetilde{A}_i^{L}, 1 \le j \le 2$, $H_1(\widetilde{A}_i^{U}) \in [0,1], H_2(\widetilde{A}_i^{U}) \in [0,1], H_1(\widetilde{A}_i^{L}) \in [0,1]$, $H_2(\widetilde{A}_i^{L}) \in [0,1]$ and $1 \le i \le n$.

The linguistic expressions used in the pairwise comparison matrix and their respective IT2F set peers are given in Table 3.

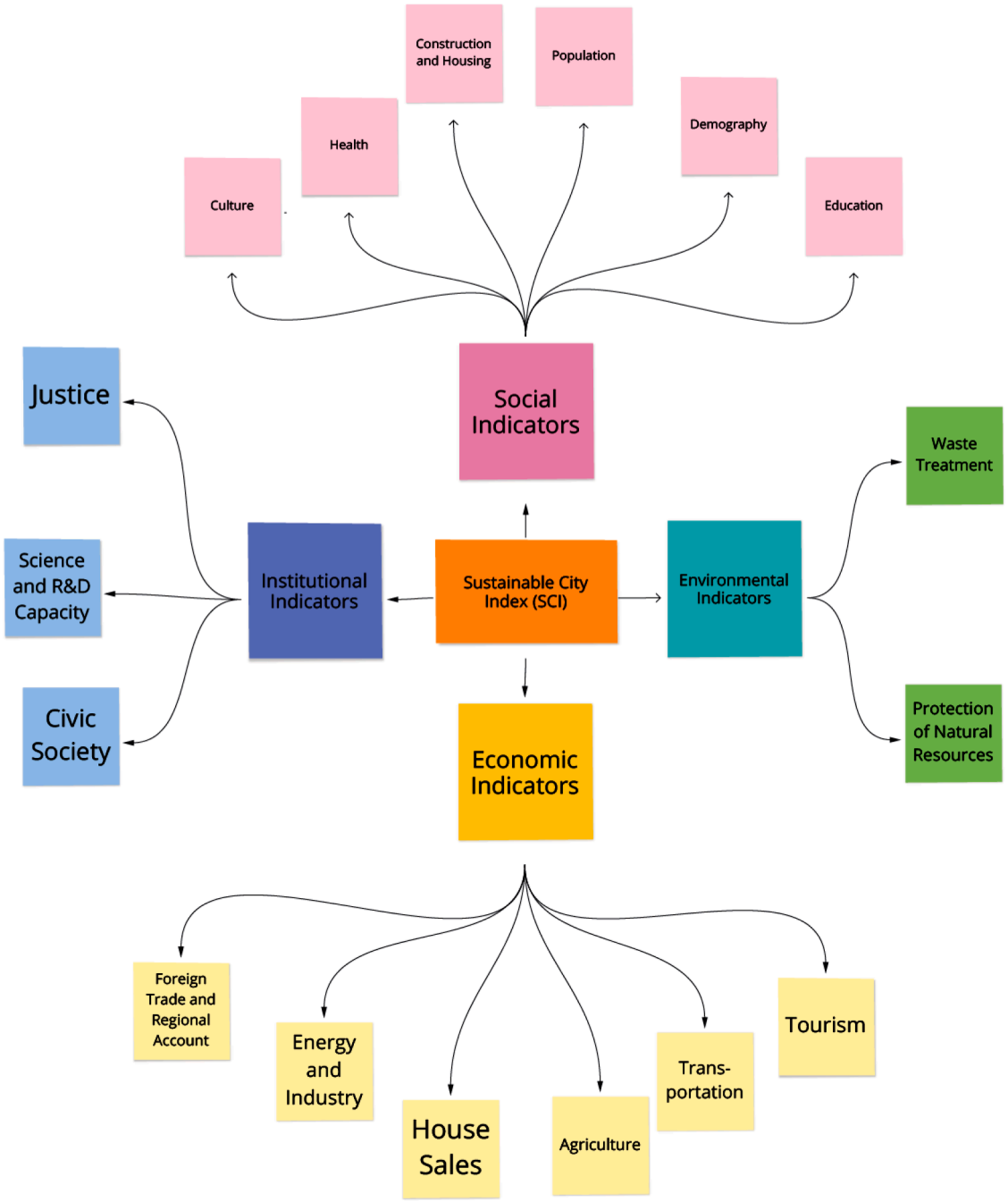


Fig. 2. Dimensions and indicator groups for sustainability assessment

Step 1.3. Examine the consistency of the fuzzy pairwise comparison matrices. The fuzzy reciprocal matrices are defuzzified and checked for consistency in this step.

After obtaining the crisp reciprocal matrix, A^k the consistency index, CI^k for k^{th} decision-maker is calculated and compared with the random consistency index RI, values suggested by Saaty (1987), where the Consistency Ratio, $CR^k = CI^k/RI$, may not exceed 10%.

Step 1.4. Aggregate the pairwise comparisons of m decision-makers, $\tilde{\tilde{r}}_{ij}$, by using the geometric mean.

$$\tilde{\tilde{r}}_{ij} = \left[\tilde{\tilde{a}}_{ij}^{1} \ldots \otimes \tilde{\tilde{a}}_{ij}^{k} \otimes \ \ldots \ \otimes \tilde{\tilde{a}}_{ij}^{m}\right]^{1/m} \tag{2}$$

Step 1.5. Estimate the fuzzy weights for each criterion. The IT2F weight of the j^{th} sub-dimension, $\tilde{\tilde{w}}_j$, is calculated as follows:

$$\tilde{\tilde{w}}_j = \tilde{\tilde{r}}_j \otimes \left[\tilde{\tilde{r}}_1 \oplus \ldots \oplus \tilde{\tilde{r}}_j \oplus \ldots \oplus \tilde{\tilde{r}}_n\right]^{-1} \tag{3}$$

Step 1.6. Calculate the ranking value, $Rank(\tilde{\tilde{w}}_j)$, to obtain defuzzified weight, w_i, each attribute:

$$w_j = \mathrm{Rank}\left(\tilde{\tilde{w}}_j\right) \tag{4}$$

4.1.1. COPRAS

COPRAS ranks the alternatives based on the values of significance considering preferable (maximizing) and non-preferable (minimizing) attributes. The main steps of the method are given below.

Step 2.1. Given l alternatives and n criteria, the decision matrix X is formed in Eq 5:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{ij} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{l1} & x_{l2} & \dots & x_{ln} \end{bmatrix} \tag{5}$$

where x_{ij} is the evaluation of the i^{th} alternative for the j^{th} attribute. Please note that the attribute weights are obtained with IT2F-AHP, $w = [w_1, \dots, w_n]$.

Step 2.2. The normalized values, x^*_{ij}, are formulated with Eq. 6.

$$x^*_{ij} = \frac{x_{ij}}{\sum_{i=1}^{l} x_{ij}} \tag{6}$$

Step 2.3. The weighted normalized values of the decision matrix, d_{ij}, are calculated with Eq. 7.

$$d_{ij} = x^*_{ij} w_j \tag{7}$$

Step 2.4. For each alternative i, n attributes are divided into two groups, t benefit and p cost attributes, where $t+p=n$. The sum of the positive attributes, S_{i+}, and the negative attributes, S_{i-}, are found by;

$$S_{i+} = \sum_{j=1}^{t} d_{ij} \tag{8}$$

$$S_{i-} = \sum_{j=t+1}^{n} d_{ij} \tag{9}$$

Step 2.5. The relative importance of each alternative, Q_i, is calculated as;

$$Q_i = S_{i+} + \frac{\sum_{i=1}^{l} S_{i-}}{S_{i-} \sum_{i=1}^{l} 1 \Big/ S_{i-}} \tag{10}$$

Step 2.6. For each alternative, the performance index is defined by the following equation.

$$P_i = 100\left(\frac{Q_i}{Q_{max}}\right) \tag{11}$$

4.2. Data sample

An indicator system for sustainable urban development should incorporate the processes and strengths of a city's progress and reflect the status of urban economy and environment and ecological and social construction. The indicators should be subject to the following primary principles: maturity, objectivity, independence, measurability, accessibility, dynamics, and relative stability (Button, 2002; Repetti and Desthieux, 2006). However, the whole indicator-based system must be able to respond to changes over time.

This study focuses on quantitative indicators across a wide range of socio-economic, environmental, and institutional factors to assess the sustainability performance of Turkey's metropolitans. In this frame, an indicator is a variable that represents an attribute of a system. It may be used to assess the current and future conditions and trends in making a comparison across megacities. After reviewing several reports and studies and analyzing the available data, we compiled fifty-three indicators categorized into four main dimensions: 14 economic indicators, 26 social indicators, five environmental indicators, and eight institutional indicators. Table A1 in the Appendix shows the indicators, dimensions, indicator groups, reference studies, and data sources, while Fig. 2 illustrates the dimensions and indicator groups for the evaluation.

We used secondary data from different sources, including the Turkish Statistical Institute (TSI), the (Ministry of Culture and Tourism 2021), and the Ministry of Internal Affairs. The data includes fifty-three variables for the years 2010 to 2018. The sample covers 30 metropolitan municipalities in Turkey (see Table A2 and A3).

Table 4
IT2F weights of the main dimensions and indicator groups

Main Sustainability Dimensions	
Economic Indicators	{(0.23, 0.27, 0.36, 0.42; 1, 1), (0.24, 0.28, 0.35, 0.40; 1, 1)}
Social Indicators	{(0.19, 0.22, 0.29, 0.33; 1, 1), (0.19, 0.23, 0.28, 0.32; 0.80, 0.80)}
Environmental Indicators	{(0.24, 0.28, 0.36, 0.41; 1, 1), (0.24, 0.28, 0.35, 0.40; 0.80, 0.80)}
Institutional Indicators	{(0.09, 0.10, 0.14, 0.18; 1, 1), (0.09, 0.11, 0.14, 0.17; 1, 1)}
Economic Indicators	
Foreign Trade	{(0.14, 0.19, 0.32, 0.41; 1, 1), (0.15, 0.20, 0.30, 0.39; 0.8, 0.8)}
Energy and Industry	{(0.16, 0.21, 0.34, 0.44; 1, 1), (0.17, 0.22, 0.32, 0.42; 0.8, 0.8)}
House Sales	{(0.04, 0.06, 0.09, 0.13; 1, 1), (0.05, 0.06, 0.09, 0.12; 0.8, 0.8)}
Agriculture	{(0.11, 0.14, 0.23, 0.30; 1,1), (0.12, 0.15, 0.22, 0.28; 0.8, 0.8)}
Tourism	{(0.09, 0.11, 0.18, 0.24; 1, 1), (0.09, 0.12, 0.17, 0.22; 0.8, 0.8)}
Transportation	{(0.06, 0.07, 0.12, 0.17; 1,1), (0.06, 0.08, 0.12, 0.16; 1, 1)}
Social Indicators	
Demography	{(0.10, 0.13, 0.18, 0.23; 1, 1), (0.11, 0.13, 0.18, 0.22; 0.8, 0.8)}
Education	{(0.22, 0.28, 0.40, 0.48; 1, 1), (0.23, 0.29, 0.38, 0.46; 1, 1)}
Construction and Housing	{(0.05, 0.06, 0.09, 0.12; 1, 1), (0.05, 0.06, 0.09, 0.11; 0.8, 0.8)}
Culture	{(0.13, 0.16, 0.24, 0.29; 1, 1), (0.13, 0.17, 0.22, 0.28; 1, 1)}
Population	{(0.05, 0.06, 0.08, 0.11; 1, 1), (0.05, 0.06, 0.08, 0.10; 0.8, 0.8)}
Health	{(0.12, 0.15, 0.21, 0.26; 1,1), (0.13, 0.16, 0.20, 0.25; 1, 1)}
Environmental Indicators	
Waste Treatment	{(0.54, 0.58, 0.63, 0.66; 1, 1), (0.55, 0.58, 0.62, 0.66; 1, 1)}
Protection of Natural Resources	{(0.36, 0.38, 0.42, 0.44; 1, 1), (0.36, 0.38, 0.41, 0.43; 1, 1)}
Institutional Indicators	
Justice	{(0.40, 0.48, 0.65, 0.76; 1, 1), (0.42, 0.50, 0.63, 0.74; 1, 1)}
Science and Technology	{(0.20, 0.23, 0.32, 0.38; 1, 1), (0.20, 0.24, 0.30, 0.37; 0.8, 0.8)}
Civic Society	{(0.12, 0.14, 0.19, 0.24; 1, 1), (0.13, 0.15, 0.19, 0.23; 1, 1)}

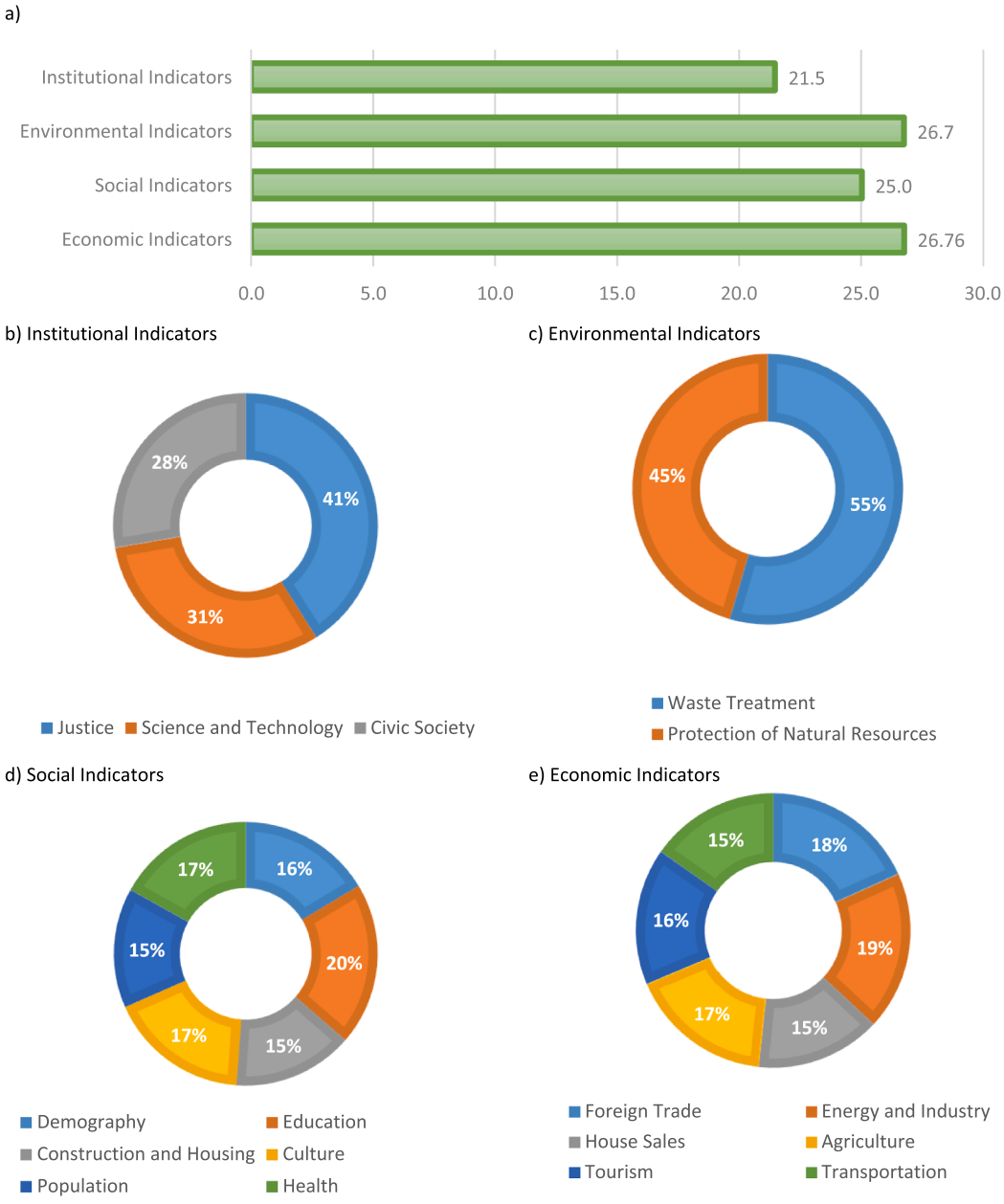


Fig. 3. (a-e): Weights obtained with IT2F-AHP for the main dimensions and indicator groups

Finally, it is evident that the sustainability performance of a metropolitan city can be assessed by using numerous indicators based on the experts' different perspectives and professional backgrounds. In this respect, generating a purposive evaluation tool requires using indicators for which data is available for the targeted time frame and scope through reliable sources. Consequently, there might be relevant indicators, yet they must be left out of the coverage in this study due to data unavailability.

5. Empirical results

5.1. Relative aggregated weights of dimensions and indicator groups of SCI with IT2F-AHP

Since an indicator can be described or measured in different ways, we ensured that the descriptions and units of measurement used to allow the definition of clear and distinct indicators. We followed the steps (1.1-1.6) described in Subsection 4.1.1 to calculate the relative importance of indicator groups with IT2F-AHP. Based on experts' opinions and a comprehensive literature review, we depicted the problem hierarchy in Fig. 2. Then, we consulted 16 field experts (out of 35 requests) on the sustainability of cities to get their views on the relative importance of selected indicators through a structured form.

As stated before, we employed IT2F-AHP method and collected the subjective evaluations of experts, i.e., city planners, architects, academicians of the related fields, and senior managers from Metropolitan City of Istanbul, by using IT2F scale used in Görener, Ayvaz, Kuşakcı, & Altınok (2017). Then, using Eq. 3, we obtained the IT2F weights of the main dimensions and indicator groups subject to this study, as shown in Table 4.

Table 5
Descriptive statistics of selected indicators

	Indicator (*i*)	Weight (w_i)	Min	Max	Mean	Median	Kurtosis	Skewness	Standard Deviation
Economic	1.1.1 Total exports (thousand USD) per number of enterprises	0.98%	0.66	185.31	32.08	23.03	4.08	1.82	32.14
	1.1.2 Total imports (thousand USD) per number of enterprises	0.98%	1.19	586.00	34.16	18.63	50.03	5.56	52.85
	1.2.1 Total electricity consumption per capita (kWh)	5.00%	656.00	8792.04	2850.56	2590.26	3.44	1.67	1550.92
	1.3.1 Number of house sales (first sale) per 100,000	1.97%	139.65	1839.18	790.91	738.72	0.89	0.81	305.31
	1.3.2 Number of house sales (total) per 100,000	1.97%	199.94	3705.42	1660.45	1569.09	-0.05	0.47	710.13
	1.4.1 Total number of enterprises per population per 1000 inhabitant	0.98%	22.42	70.39	42.74	42.64	0.01	0.09	10.68
	1.5.1 Value of crop production (thousand TL) per population	1.13%	0.02	4.66	1.68	1.65	0.16	0.50	0.97
	1.5.2 Value of livestock (thousand TL) per population	1.13%	0.02	5.78	1.07	0.88	7.59	2.16	0.79
	1.5.3 Value of animal products (thousand TL) per population	1.13%	0.01	1.85	0.35	0.28	6.21	2.00	0.26
	1.5.4 Value of total agricultural production (thousand TL) per population	1.13%	0.05	8.80	3.09	3.01	0.85	0.56	1.54
	1.6.1 Number of overnights per population	4.31%	0.21	37.11	2.66	0.67	14.22	3.85	6.72
	1.7.1 Number of road motor vehicles per 1,000 inhabitants	4.08%	65.14	510.10	246.69	249.46	-0.32	0.10	98.56
	1.8.1 GDP per capita (USD)	0.98%	3404.00	20726.00	9643.67	8985.50	0.35	0.83	3756.89
	1.8.2 Gold Deposit Account per population	0.98%	14.48	664.53	161.58	134.39	3.22	1.55	108.14
Social	2.1.1 Infant mortality rate (per thousand)	0.68%	1.00	19.60	10.36	9.75	0.33	0.71	2.93
	2.1.2 Life expectancy at birth (years)	0.68%	74.46	81.00	78.28	78.12	0.59	0.05	1.06
	2.1.3 Crude birth rate (per thousand)	0.68%	7.00	34.70	17.18	15.40	1.27	1.35	5.40
	2.1.4 Crude death rate (per thousand)	0.68%	2.90	8.90	5.19	5.20	-0.09	0.34	1.25
	2.1.5 Total fertility rate (number of children)	0.68%	1.38	4.57	2.21	1.93	2.38	1.67	0.66
	2.2.1 Number of students per classroom	1.00%	17.36	51.59	26.39	25.03	1.87	1.20	5.75
	2.2.2 Number of students per teacher	1.00%	10.90	29.40	16.23	15.57	1.42	1.15	3.47
	2.2.3 Literacy rate (%)	1.00%	88.52	98.91	95.87	96.99	0.23	-1.12	2.52
	2.2.4 Enrolment rate in primary school, 2012 and after-net (%)	1.00%	88.59	102.09	95.49	95.22	-1.48	-0.02	3.82
	2.2.5 Enrolment rate in primary education (primary school+lower secondary education), 2012 and after-net (%)	1.00%	79.66	100.13	97.39	97.14	27.35	-3.07	1.95
	2.3.1 Number of buildings according to construction permit per total number of households	1.85%	0.30	127.71	7.34	5.96	129.88	10.28	9.12
	2.3.2 Number of dwelling units according to construction permits per 100,000 inhabitants	1.85%	134.18	3084.25	1179.90	1097.37	0.40	0.77	551.45
	2.4.1 Number of the books per number of the users of public libraries	0.54%	0.21	3.30	0.85	0.77	4.89	1.82	0.47
	2.4.2 Number of the libraries per 100,000 users of public libraries	0.54%	1.42	14.52	5.43	5.23	1.34	1.00	2.54
	2.4.3 Number of works in museums per number of visitors for museums	0.54%	0.01	6.61	0.51	0.31	29.21	4.73	0.79
	2.4.4 Number of museums per 100,000 inhabitants	0.54%	0.06	0.95	0.25	0.20	4.35	1.99	0.18
	2.4.5 Number of movie houses per 100,000 inhabitants	0.54%	0.48	5.98	2.61	2.39	0.34	0.63	1.05
	2.4.6 Number of cinema audiences per 1,000 population	0.54%	28.79	1512.10	596.59	589.41	-0.21	0.39	302.56
	2.4.7 Number of theatre halls per 100,000 inhabitants	0.54%	0.00	2.08	0.75	0.65	-0.22	0.64	0.44
	2.4.8 Number of theatre audiences per 1,000 inhabitants	0.54%	0.00	226.82	67.08	52.58	0.46	1.04	50.76
	2.5.1 Rate of net migration (%)	1.23%	-46.67	32.47	0.58	0.54	2.75	-0.20	9.53
	2.5.2 Population density (per one square kilometer)	1.23%	30.03	2899.87	232.67	112.54	23.44	4.91	484.51
	2.5.3 Elderly dependency ratio (%)	0.61%	2.00	21.69	12.06	11.77	-0.20	0.25	3.56
	2.5.4 Annual growth rate of population (per thousand)	1.23%	-14.84	39.09	14.37	13.49	0.64	-0.12	9.59
	2.6.1 Number of physicians per 1,000 population	2.12%	1.00	3.00	1.67	2.00	-0.61	0.06	0.55
	2.6.2 Number of hospital beds per 100,000 population	2.12%	114.00	485.00	274.26	264.50	0.53	0.65	73.38
Environmental	3.1.1 Rate of population served by waste services (%)	4.86%	82.00	100.00	97.49	99.00	4.56	-2.29	3.95
	3.1.2 Rate of population served by wastewater treatment plants (%)	4.86%	2.35	100.00	64.39	73.00	-0.59	-0.73	28.24
	3.1.3 Rate of population served by water supply network (%)	6.08%	73.00	100.00	96.73	99.00	5.55	-2.40	5.29
	3.2.1 Rate of population served by sewerage system (%)	4.86%	50.00	100.00	85.14	86.25	-0.31	-0.55	11.00
	3.2.2 Number of protected area per 100 K inhabitant	6.08%	0.72	110.58	26.89	23.89	4.01	1.84	21.69
Institutional	4.1.1 Total number of the cases in the courts per 1,000 inhabitants	4.40%	13.65	138.48	76.32	77.44	1.30	-0.29	22.38

(*continued on next page*)

Table 5 (*continued*)

Indicator (*i*)	Weight (w_i)	Min	Max	Mean	Median	Kurtosis	Skewness	Standard Deviation
4.1.2 Convicts received into prison by province where the crime was committed per 1,000 inhabitants	4.40%	0.33	4.56	2.25	2.16	-0.45	0.30	0.94
4.2.1 Number of Master's students per 100,000 inhabitants	1.68%	14.04	1369.93	346.82	239.14	1.50	1.42	298.15
4.2.2 Number of Ph.D. students per 100,000 inhabitants	1.68%	1.40	474.73	84.90	45.09	3.68	1.98	96.56
4.2.3 Number of Professors per graduate students	1.68%	0.02	1.31	0.22	0.18	13.88	2.77	0.15
4.2.4 Number of Scimago listed institutions per university	1.68%	0.00	1.50	0.55	0.50	-1.04	0.20	0.34
4.3.1 Number of NGOs per 1,000 inhabitants	2.97%	0.37	2.03	1.21	1.22	-0.48	-0.04	0.37
4.3.2 Total NGO revenues per 100,000 inhabitants (TL) per GDP	2.97%	0.95	23.71	4.82	3.69	6.52	2.31	3.86

Table 6
Correlation Matrix for four pillars of sustainability

			Economic	Social	Environmental	Institutional
Spearman's rho	Economic	Correlation Coefficient	1.000	.664**	.445**	-.273**
		Sig. (2-tailed)	.	.000	.000	.003
		N	120	120	120	120
	Social	Correlation Coefficient	.664**	1.000	.326**	-.051
		Sig. (2-tailed)	.000	.	.000	.577
		N	120	120	120	120
	Environmental	Correlation Coefficient	.445**	.326**	1.000	-.305**
		Sig. (2-tailed)	.000	.000	.	.001
		N	120	120	120	120
	Institutional	Correlation Coefficient	-.273**	-.051	-.305**	1.000
		Sig. (2-tailed)	.003	.577	.001	.
		N	120	120	120	120

*. Correlation is significant at the 0.01 level (2-tailed).

Table 7
Normality tests

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Sustainability	.153	240	.000	.876	240	.000
Economic	.181	240	.000	.745	240	.000
Social	.057	240	.058	.976	240	.000
Environmental	.158	240	.000	.890	240	.000
Institutional	.125	240	.000	.915	240	.000

a. Lilliefors Significance Correction

Defuzzified weights are depicted in Figs. 3(a-e) for the main dimensions of sustainability and indicator groups under these dimensions, which are calculated by Eq. 4. The aggregated weight of a specific indicator is then calculated by multiplying the weights of the dimension and that of the indicator group that the indicator belongs to, respectively.

The results indicate that the experts most assess the economic and environmental aspects of urban sustainability. However, the obtained weights slightly differ, suggesting that experts' overall view on the issue is well balanced (Fig. 3a). This confirms that the sustainability of a city can be secured only if an equilibrium among these partially contradicting objectives is achieved. Considering the weights assigned to indicator groups under institutionalization, the justice system receives the lion's share, yet other indicators also play a vital role in evaluating institutional sustainability (Fig. 3b). Figs. 3(c-e) show that environmental, social, and economic indicators contribute almost equally to the overall score.

5.2. Descriptive statistics and Sustainable Cities Index scores with COPRAS

Given the weights of the indicators, w_i, obtained with IT2F-AHP method in the previous stage, we follow the aforesaid steps to calculate the SCI scores of Turkish metropolitan cities with COPRAS method. First, we build a raw data matrix for 30 alternatives, $\boldsymbol{X}$, which is a matrix with 30 rows (the number of cities) and 53 columns (the number of indicators) (see Eq. 5). After the matrix is normalized based on the cities, we obtain the weighted normalized values using Eqs. 6 and 7. The sum of the positive and negative indicators, S_{i+} and S_{i-}, are calculated with Eqs. 8 and 9, respectively. Finally, we use Eqs. 10 and 11 to determine the SCI scores of Turkish metropolitan cities for each year.

Table 5 summarizes descriptive statistics, while Table 6 presents the correlation matrix among the four dimensions scores of sustainability. The values in Table 5 display that there is a high level of standard deviation in GDP, electricity consumption, number of house sales, number of dwelling units, and population density among the metropolitans. Specifically, kurtosis and skewness demonstrate a non-normality distribution.

As shown in Table 6, there is a high level of positive correlation between economic and social pillar (0.66) and environmental pillar (0.45) scores. Social and environmental scores are also positively correlated (0.33). Interestingly, the institutional score is negatively correlated with the economic dimension (-0.27). Thus, there is a close relationship between the economic dimension and social and environmental dimensions. An increase in economic activity, i.e., production, agriculture, foreign trade, tourism, leads to a better social life, i.e., higher life expectancy and lower infant mortality besides advanced educational, health, and cultural standards. Economic sustainability also facilitates accessing water supply and sewerage services for inhabitants. This result is consistent with the findings of the study held by Bosporus

Table 8
Ranking of Turkish metropolitans according to the Sustainable Cities Index

	2015 Score	Rank		2016 Score	Rank		2017 Score	Rank		2018 Score	Rank
Adana	0.5559	25	↑	0.5780	24	↓	0.5814	25	→	0.5354	25
Ankara	0.7294	4	→	0.7455	4	→	0.7737	4	→	0.7209	4
Antalya	1.0000	1	↓	0.9722	2	↓	1.0000	1	→	1.0000	1
Aydın	0.6833	7	→	0.6997	7	↑	0.7089	5	→	0.6953	5
Balıkesir	0.6364	16	↑	0.6552	14	↓	0.6570	15	↑	0.6388	13
Bursa	0.6376	15	↓	0.6408	16	↑	0.6571	14	↓	0.6147	18
Denizli	0.6667	9	↓	0.6795	10	↑	0.6967	9	→	0.6683	9
Diyarbakır	0.5314	27	→	0.5287	27	→	0.5340	27	↓	0.5165	28
Erzurum	0.6442	12	↓	0.6421	15	↓	0.6505	16	↑	0.6395	12
Eskişehir	0.8530	3	→	0.8591	3	→	0.8424	3	→	0.8024	3
Gaziantep	0.6034	21	↑	0.6382	17	↓	0.6279	19	→	0.6103	19
Hatay	0.5645	24	↓	0.5719	25	↑	0.6004	23	↑	0.5801	22
İstanbul	0.6411	13	↓	0.6222	20	↑	0.6391	18	↓	0.5899	20
İzmir	0.6535	11	↓	0.6598	12	↑	0.6708	11	→	0.6423	11
K. Maraş	0.5674	23	→	0.5781	23	↓	0.5941	24	→	0.5579	24
Kayseri	0.6357	17	↑	0.7281	5	↓	0.6592	13	↓	0.6201	17
Kocaeli	0.7121	5	↓	0.6956	8	↑	0.7087	7	↑	0.6899	6
Konya	0.6810	8	↓	0.6940	9	↑	0.7069	8	↑	0.6868	7
Malatya	0.6292	18	→	0.6308	18	↑	0.6647	12	↓	0.6268	16
Manisa	0.6047	20	↑	0.6260	19	↑	0.6492	17	↑	0.6340	14
Mardin	0.5123	28	↓	0.4911	29	→	0.4960	29	→	0.5010	29
Mersin	0.5989	22	↑	0.6134	21	→	0.6146	21	→	0.5871	21
Muğla	0.9770	2	↑	1.0000	1	↓	0.9378	2	→	0.9211	2
Ordu	0.5050	29	↑	0.5199	28	→	0.5201	28	↑	0.5336	26
Sakarya	0.6589	10	↓	0.6612	11	↑	0.6872	10	→	0.6468	10
Samsun	0.6400	14	↓	0.6003	22	→	0.6136	22	↓	0.5632	23
Şanlıurfa	0.5405	26	→	0.5390	26	→	0.5391	26	↓	0.5270	27
Tekirdağ	0.6860	6	→	0.7129	6	↑	0.7110	5	↓	0.6858	8
Trabzon	0.6149	19	↑	0.6571	13	↓	0.6254	20	↑	0.6308	15
Van	0.4573	30	→	0.4816	30	→	0.4848	30	→	0.4796	30

University in 2011.

The results of the Shapiro-Wilk test in Table 7 show that sustainability data for Turkish metropolitans for the years 2011-2018 are not normally distributed. This necessitates non-parametric tests for further analysis. Therefore, we conducted the Mann-Whitney U test to explore the differences in sustainability performance between the formerly declared and new metropolitans and Wilcoxon Signed Ranks tests to discover the pre and post-period sustainability performance of new metropolitans.

5.3. *Sustainable Cities Index ranking scores*

As mentioned before, the primary aim of this study is to develop a comprehensive index to measure the sustainability performance of Turkish metropolitans and rank them accordingly (Table A4). Sustainable Cities Index (SCI) includes the dimensions of social, economic, institutional, and environmental indicators . Table 8 presents the ranking of metropolitans in the SCI and the changes in ranking from one year to another.

The results are pretty interesting. Antalya appears at the top of the list, followed by Muğla and Eskişehir in ranking. This may be explained by the fact that Antalya and Muğla are two important tourist destinations in Turkey, attracting millions of tourists every year. Thus, they may be more conscious of implementing sustainability policies. The weakest attribute of these two metropolitans is the institutional dimension. A similar argument may be inserted for Eskişehir. The latter has been run by the same municipality administration since 1999 and has been modernized to a great extent by implementing sustainable policies. However, one should note that higher performance of Eskisehir comes particularly from social and environmental policies, while it has comparatively lower performance in the economic dimension. This result is in line with the findings of previous studies

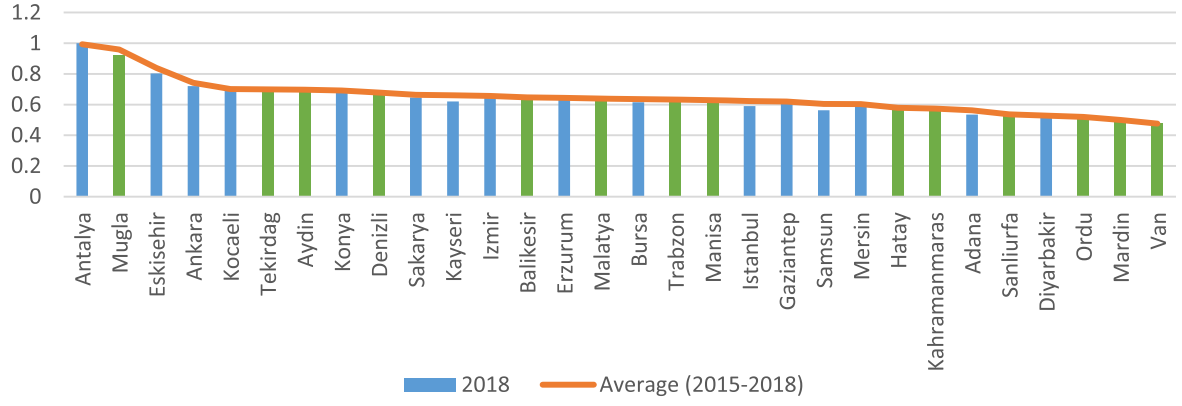


Fig. 4. The average sustainability scores of metropolitans (2015-2018 versus 2018)

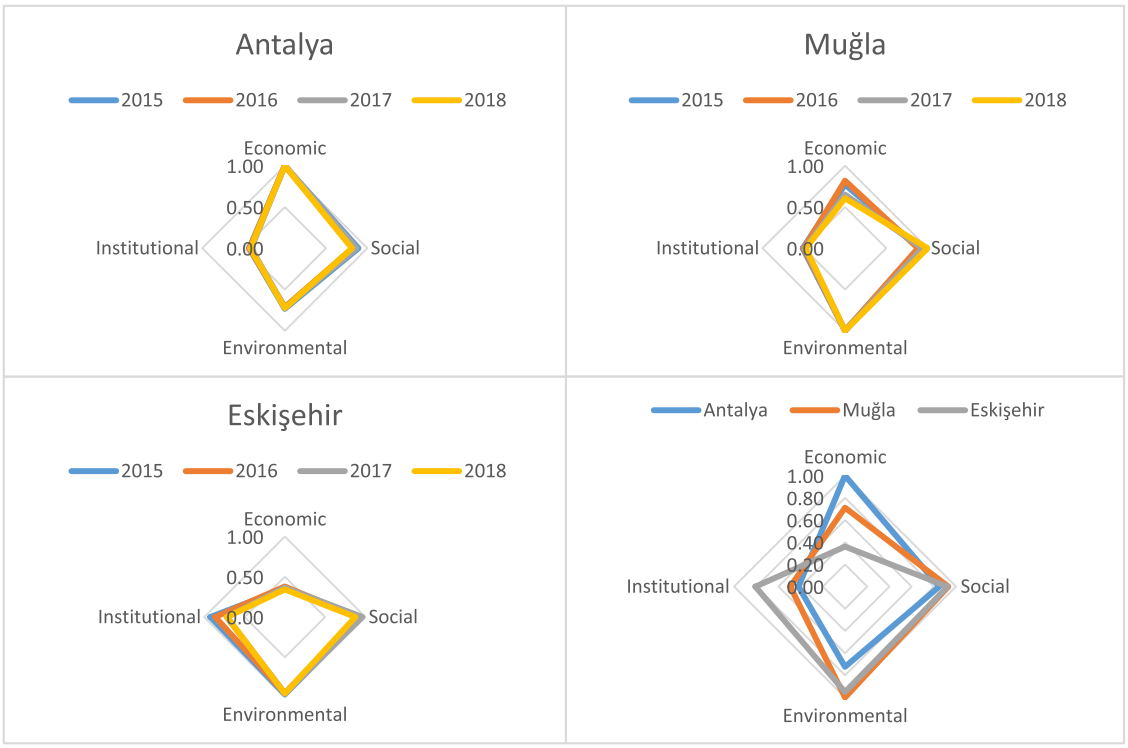


Fig. 5. A comparison of the best performing metropolitans in terms of different dimensions

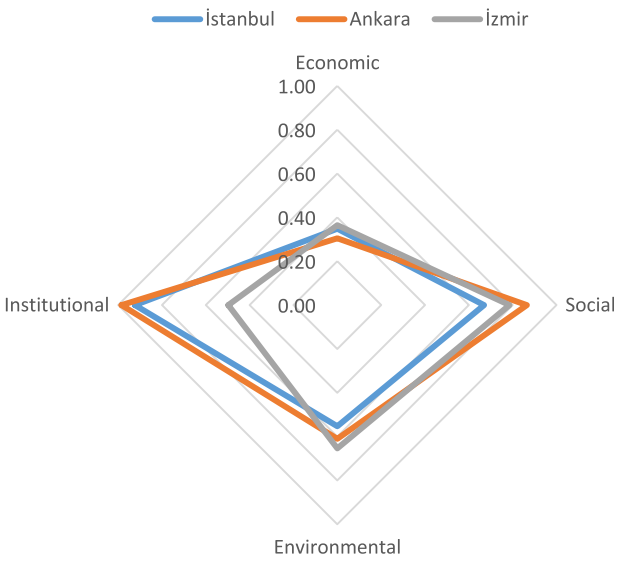


Fig. 6. : A comparison of the relative performance of İstanbul, Ankara, and Izmir

(EDAM-TÜRKONFED, 2016; Türkiye İş Bankası 2015).

Among the three big metropolitans, Ankara, the capital of Turkey, is ranked as the fourth most sustainable city, while the other two most populated metropolitans, Istanbul, and Izmir, are ranked below, Istanbul between 13th and 20th positions, and Izmir around 11th in ranking. However, when we analyze the performance of Ankara, the social, economic, and environmental performance of Ankara is moderate. On the other hand, Izmir has performed better than Ankara, particularly in the economic and environmental dimensions. Finally, Istanbul performs relatively better than Izmir only in the institutional dimension.

Most of the metropolitans located at Turkey's Eastern and Southeastern regions, namely Van, Mardin, Diyarbakir, Sanlıurfa are ranked at the bottom of the SCI throughout the years. This result is in line with the findings of the study held by Bosporus University in 2011. Among these cities, Diyarbakir has been a metropolitan since 1993 but still has the lowest performance almost in all dimensions. This may be because of the prevailing challenging conditions in the region due to terrorist attacks. Another reason is that the metropolitan intensively allows immigrants coming from surrounding cities, especially from the country's borders. Therefore, the recent wave of immigration may create significant urbanization problems, such as social conflicts, high unemployment rates, crowded classrooms.

Fig. 7. : Sustainability of Turkish metropolitans in 2018

Another interesting finding in Table 8 is that Adana, the fifth most-populated metropolitan in Turkey, is ranked as 25th in sustainability performance. Adana finds a place for itself in the last quartile except for the environmental dimension in all other dimensions. This may be explained by the negative immigration of local people and positive immigration of foreign immigrants with disadvantaged backgrounds to this city. However, this result needs further exploration. Moreover, Gaziantep is unexpectedly positioned in the last quartile among metropolitans in the social dimension, which can also be explained by the high immigration rates observed after the humanitarian crisis in Syria.

When we refer to the ranking of metropolitans in the middle cluster, the results are very dispersed due to different levels of urbanization, social, and environmental development level, depending on the size of the cities and their regional importance. Although Ordu is among the lowest performing metropolitans it has shown noticeable progress since it recently became a metropolitan municipality in 2014. Manisa has also increased its performance during the sample period. Remarkably, Muğla, Aydın, and Tekirdağ hold the second, fifth, and eighth place in 2018 among the cities announced as metropolitans in 2014.

Fig. 4 displays the average score of metropolitans from 2015 to 2018 and only the year 2018 for the formerly declared (blue columns) and new metropolitans (green columns). The scores for the years 2015 to 2018 do not differ significantly from the scores of 2018. The web charts in Fig. 5 provide a more comprehensive analysis for the most sustainable three metropolitans, namely Antalya, Muğla, and Eskişehir. There has been a slight increase in all dimensions in 2016 and 2017, while the trend became downward in 2018. Each of these metropolitans seems to be strong in one dimension. Antalya performs better in the economic dimension, while Eskişehir creates a difference by its institutional performance. Muğla has a more balanced picture.

Since a comparison among the highest populated metropolitans may reveal insightful results, we check whether there is a significant difference between the economic and environmental performance of Ankara, İstanbul, and İzmir. The results in Fig. 6 show that Ankara performs better than its rivals on social and institutional dimensions, while Izmir is the lowest performer among them in the institutional dimension. The

Fig. 8. Economic sustainability of Turkish metropolitans in 2018

Fig. 9. Environmental sustainability of Turkish metropolitans in 2018

finding is in line with the results of Zoeteman et al. (2015). It suggests that there is a need to develop policies based on understanding the structural and territorial changes in these metropolitans. Thus, the sub-indicators should be inserted and assessed independently to solve causal factors in these metropolitans. This will also help policymakers take corrective actions for specific sub-set of indicators and improve the overall and dimension-based sustainability scores.

The geographical distribution of the metropolitans with the highest SCI scores is also noteworthy. Although there is a pretty observable variation across the regions, the results in Fig. 7 show that Antalya, Muğla, Eskişehir, Ankara, Aydın, Kocaeli, Konya, Tekirdağ, and Denizli whose sustainability scores in 2018 are 0.65 and above are situated at the western part of the country. On the other hand, Adana, Şanlıurfa, Diyarbakir, Mardin and Van that have the lowest scores (0.55 or lower) are located in the eastern part.

The results also show that metropolitans located in the Mediterranean and Aegean regions perform better in economic sustainability, whereas metropolitans in Central Anatolia area have a better performance in the environmental dimension. In addition, the Aegean and Black Sea regions outperform in social performance, while Central Anatolia is good in institutional dimension. Thus, there is no single region that dominates in all aspects. In this context, we believe that the geographical distribution of industrial, agricultural, and transportation policies and services play a vital role in increasing the economic, social, environmental, and institutional sustainability performance of metropolitan cities in Turkey. The Aegean and Central Anatolia regions have the highest average performance according to the aggregate scores. Figs. 8, 9, 10, and 11 present dimensional pictures of the 30 metropolitans in 2018, while Fig. 12 shows regional progress on four dimensions.

5.4. GDP per capita and sustainability performance

The sustainability of a metropolitan highly depends upon the economic resources available for that city. Therefore, economic sustainability is essential not only for socio-economic development but also for environmental protection. Grossman and Kureger (1995) claimed that most of the pollution problems began to improve after increasing GDP per capita. The results in Fig. 13 indicate a positive and significant

Fig. 10. Social sustainability of Turkish metropolitans in 2018

Fig. 11. Institutional sustainability of Turkish Metropolitans in 2018

relationship between GDP per capita and sustainability scores across metropolitans. Thus, metropolitans with higher income levels have shown better sustainability performance. This result is in line with the findings of previous studies (Caldas et al., 2018; Kara, 2019; Kwatra et al., 2016).

The quality of life improves, and community awareness to preserve the environment is enhanced in metropolitans after reaching a certain level of economic prosperity. When the income grows, people tend to think beyond their basic needs. They look forward to better surroundings. If the basic level living conditions are achieved, the government can direct the necessary resources to develop better practices for environmental protection, higher education, and infrastructural support. Thus, governmental authorities should use this result to make further improvements in metropolitans to increase regional prosperity.

Besides the overall sustainability score, the GDP per capita has different levels of correlations with economic (0.77), social (0.52), and environmental (0.33) dimensions. However, the interrelation between GDP per capita and institutional dimension is weak. Therefore, increasing GDP per capita enhances social life in terms of educational, health, and social standards and gradually facilitates environmental-friendly attempts as suggested by the environmental Kuznets curve (Kwatra et al., 2016; Mori and Yamashita, 2015; Mori and Christodoulou, 2021; Vogel, 1999; Zoeteman et al., 2016). The latter proposes a hypothesized relationship between indicators of environmental degradation and per capita income. In the early stages of economic growth, pollution emissions increase, and environmental quality declines. Still, beyond some level of per capita income (which varies for different indicators) the trend reverses so that at high-income levels, economic growth leads to environmental improvement. This implies that environmental impacts or emissions per capita are an inverted U-shaped function of per capita income (Stern, 2018).

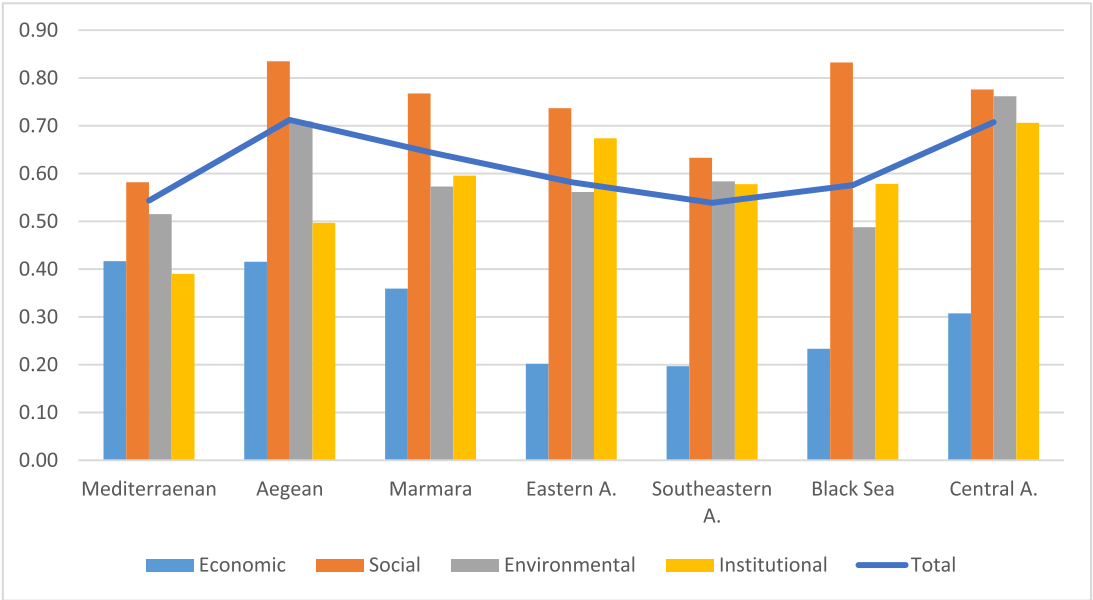


Fig. 12. The average scores of metropolitans according to the regions

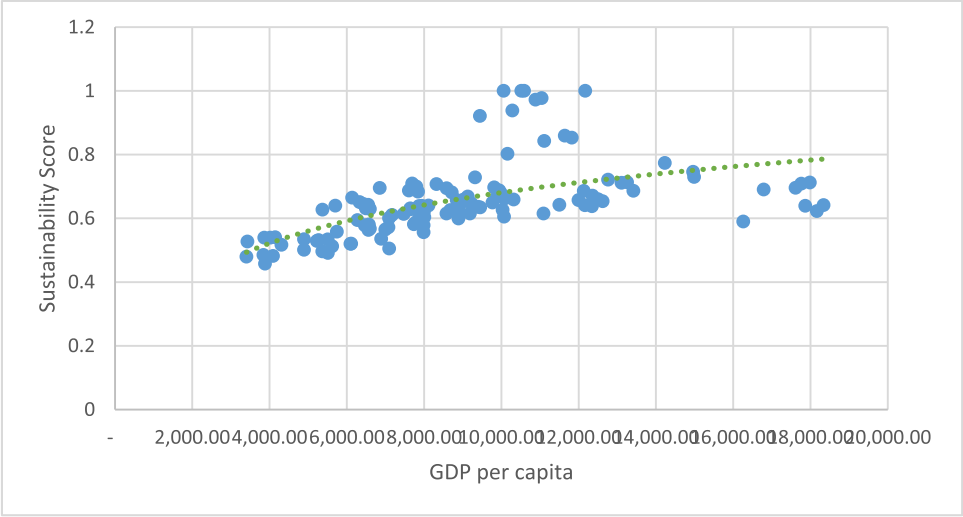


Fig. 13. The relationship between sustainability score and GDP per capita

5.5. Population and sustainability performance

According to the correlation results, there is no strong relationship (0. 13) between the population size of a metropolitan area and its overall sustainability performance. The megacities performing at the very top (i. e., with an Index score > 60.0) are generally mid-size urban areas, but there is significant variation across the spectrum. This result is in line with the findings of SDSN for the US cities in 2019 (SDSN, 2019).

We also performed the same analysis for population density measured by inhabitants per square km across the metropolitans. The results show that economic and environmental pillar is significantly correlated with population density at a level of 0.21 and -0.27, respectively. As shown in Fig. 14, there is a slight decrease in environmental performance with increasing population density. Thus, metropolitans with the highest ecological sustainability performance are those with the least inhabitants per square km.

5.6. Sustainability performance of the formerly declared and new metropolitans

To analyze the performance of the metropolitans between 2015 and 2018, it is essential to compare the performance of the formerly declared and new metropolitans as some of the cities became metropolitans in 2014. Table 9 presents the Mann-Whitney test results. The results show a significant difference between the performance of cities that have already been metropolitan and those recently announced. As expected, the formerly declared metropolitans get significantly higher scores in overall, environmental, and institutional performance, while there is no difference between the economic and social sustainability performances of the formerly declared and new ones. When we compare the scores on a yearly basis, we notice that the difference in environmental performance between the formerly declared and new metropolitans is decreasing. However, institutional performance in new metropolitans is still far behind the formerly declared ones.

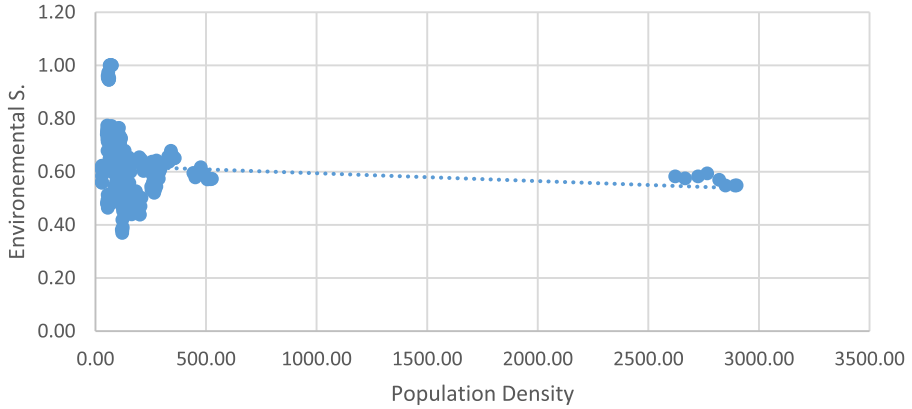


Fig. 14. Correlation between population density and environmental sustainability

Table 9
The results of Mann-Whitney U test for the formerly declared and new metropolitans

	Overall	Economic	Social	Environmental	Institutional
Mann-Whitney U	1294.500	1542.000	1711.000	1076.000	1373.000
Wilcoxon W	2890.500	3138.000	3307.000	2672.000	2969.000
Z	-2.617	-1.315	-.426	-3.766	-2.204
Asymp. Sig. (2-tailed)	.009	.188	.670	.000	.028

Table 10
The results of Wilcoxon Signed Rank test for paired samples

	TotalPost vs.Pre-metropolitan	Eco.Post vs.Pre-metropolitan	Soc.Post vs.Pre-metropolitan	Env.Post vs.Pre-metropolitan	Inst.Post vs.Pre-metropolitan
Z	-4.446[b]	-5.172[b]	-3.336[c]	-.432[c]	-.873[c]
Asymp. Sig. (2-tailed)	.000	.000	.001	.666	.383

5.7. Sustainability performance in the pre and post periods of new metropolitans

In our study, among the 30 cities, 14 of them became metropolitan in 2014. Therefore, we checked whether there is a significant difference in the pre and post sustainability performance of these new 14 cities. Table 10 shows the results of the Wilcoxon Signed Rank test for paired samples. The results indicate that the sustainability performance of the new metropolitans has been significantly improving in overall, economic, and social sustainability performance, while there is no significant improvement in environmental and institutional dimensions. This result is not surprising since new metropolitans have been promoted by supportive government policies on industrial and agricultural production and construction sectors. Moreover, the number and quality of educational, cultural, and health care institutions keep increasing in metropolitan cities. However, achieving significant outcomes on environmental and institutional aspects requires more time and effort.

6. Conclusions and discussions

Sustainability has emerged as a planning and decision-making concept from its roots of ecological thinking and social dynamics, and it has widely been applied to urban development (Hiremath et al., 2013). In this frame, governments, communities, international and non-governmental organizations have been increasingly concerned with setting up mechanisms for monitoring sustainability performance in metropolitans since success in implementing SDGs depends on ensuring ownership and policy coherence at national and local levels. The latter has a critical and comparatively advantageous role in implementing SDGs as they provide direct services to citizens.

Ongoing discussions in many countries underline the need to employ an effective system to measure sustainable indicators in monitoring, evaluating, and comparing sizable cities, since the latter should remain in a healthy condition over time in terms of economic, social, and environmental dimensions (Mori & Yamashita, 2015). This approach also supports and assists decision-makers in identifying policies for implementing sustainable urbanization and coping with associated emerging problems (Eckerberg & Mineur, 2003).

To reach that goal, indicators play a vital role in revealing what fields a city is doing better than others. Therefore, they contribute to making a city's sustainable urbanization more visible and transparent, aid in evaluation, help construct and harmonize data, provide relevant information to decision-makers, stimulate communication, and promote citizen empowerment and participation. Thus, it is essential to focus on these issues dynamically and come up with solutions that will make the megacities worth living in. This could be carried out by performing an indicator-based evaluation.

This study addresses the sustainability performance of 30 metropolitans in Turkey by examining fifty-three indicators. We propose a novel methodology with three stages hybridizing two MCDM methods. The first stage applies IT2F-AHP to determine the relative importance of indicators. IT2F-AHP is a proper tool to capture high degree of uncertainty due to the subjective weight assignment by the field experts. In the second stage, we employ COPRAS that integrates the weights and values of indicators for 30 cities and calculates the aggregate scores for the cities using a data set throughout 2010-2018. The rationale behind our approach is to rank metropolitans by indicators that would allow the broadest possible coverage of the integrated components of sustainable development and the categories that comprise them. Finally, we conduct a posthoc analysis to examine the significance of urbanization policies in Turkey on the derived scores.

The results show that the sustainability level of urbanization differs among metropolitans in the economic, social, environmental, and institutional dimensions. Antalya appears at the top of the list in the ranking of Sustainable Cities Index, followed by Muğla and Eskişehir. This may not be surprising since these cities are Turkey's most important tourist destinations attracting millions of tourists every year. However, one should note that some severe situations such as the Covid-19 pandemic may influence the advantages of these cities and damage sustainability performance if it continues for a long time. Among the three highest populated metropolitans, Ankara is ranked as the fourth most sustainable city per overall SCI score, while Istanbul and Izmir show relatively lower performance. Izmir has performed better than Ankara, particularly in economic and environmental dimensions, while Istanbul performs better than Izmir only in the institutional dimension.

The findings also indicate a positive and significant relationship between GDP per capita and sustainability scores across metropolitans. This is not surprising since the targets of SDG 11 are heavily related to the targets of SDG 8 (economic growth and employment) and SDG 9 (industry, innovation, and infrastructure). Thus, all policies implemented in these areas have substantial impacts on improving the sustainability performance of metropolitan cities. On the other hand, we did not find a strong relationship between the population size of a metropolitan area and its sustainability performance.

When we compare the performance of the formerly declared and new metropolitans, the results show a significant difference between them. The formerly declared metropolitans get significantly higher scores in overall, environmental, and institutional performance, while there is no

difference between the economic and social sustainability performances of the formerly declared and new metropolitans. One should also note that the geographical distribution of agricultural, industrial, and transportation policies and services also play an essential role in increasing the progress in all dimensions of sustainability for metropolitan cities in Turkey.

6.1. Managerial implications

Sustainability assessment proposes a scientifically based and operationally applicable approach to local and national administrations and helps policymakers decide what actions they should take to make cities more sustainable (Yigitcanlar et al., 2015). However, designing and developing metropolitans in a sustainable way does not guarantee the long-term resilience of that environment. Changing attitudes, policy emphases, and technological shifts, amongst others, may re-shape sustainable urban life.

Since the urban environment involves the management of many different forms of expertise from decision-makers with different disciplinary and professional backgrounds, the sustainability enhancement in metropolitans is a difficult task (Evans & Marvin, 2006; Petts et al., 2008). Consequently, there is a need for tools that enable planners and designers to increase the resilience of sustainability in megacities without incorporating much burden into the local administration and people. Further, finding a way to tackle with insights would offer decision-makers involved in planning, design, ecology, engineering, transport, education, health a method for working together to assess the sustainability of megacities. In this sense, the municipalities should implement large-scale forward-looking projects tailored to local contexts (Hunt et al., 2008).

The results could also provide valuable insights for decision-makers in balancing the four dimensions of sustainable development. The policymakers can use the proposed methodology to compare metropolitans on the sustainability scales. Istanbul that scores high on institutional fronts but at the cost of severe degradation of environmental resources, is a good example. There is a clear need for policy interventions for reducing the environmental footprints of socio-economic activities in the city. The SCI also highlighted the least sustainable metropolitans in the country that show strains on all four legs of sustainability. In this frame, public authorities should put particular emphasis on the development of these metropolitans, particularly in the Eastern and Southeastern regions. Thus, decision-makers at the local level can use this information to set priorities, build shared visions about the future of the metropolitans, and design critical pathways to move towards this vision. As suggested by Almusaed & Almssad, (2019), coordination between local, regional, and national authorities should be strengthened to establish a balanced partnership at metropolitan level between megacities and rural areas to accomplish this goal.

Finally, yet significantly, based on sustainability scores, policy instruments based on fiscal incentives can be designed to promote sustainable initiatives across the metropolitans. For example, annual central budgetary allocations made to the different cities can be handled based on the sustainability performance of the respective cities. The Sustainable Cities Index can also be used for future planning and assessing the sustainability of metropolitan cities under different future growth scenarios. Last but not least, the results may shed light on policies that generate awareness among the public towards sustainable development issues.

6.2. Validation of the Results

Another interesting point worth discussing is the robustness of the model. To this end, we recomputed the SCI scores with another MCDM method to validate the cities' obtained rankings. TOPSIS is one of the most preferred and classical tools for ranking purposes (Çelikbilek and Tüysüz, 2020). Accordingly, we hybridized IT2F-AHP with TOPSIS instead of COPRAS and calculated SCI scores in the four sustainability dimensions. The obtained scores and the ranking orders of the cities with both methods are visualized in Fig. A1(a-g). The analysis unveils that the results largely overlap in all four dimensions. The most successful cities highlighted by the proposed approach are also ranked at the top of the list by TOPSIS.

Similarly, the cities with comparatively poor performance in economic, social, environmental, and institutional dimensions coincide in both methods. The slight differences in the rankings and scores may be associated with the evaluation mechanisms that these methods employ. We accept that the scores and rankings cannot be exactly reproduced with TOPSIS, as it relies on different normalization and distance measures. Hence, the rankings have been largely validated with TOPSIS.

6.3. Limitations and future research

We acknowledge that the indicator-based approach has a subjective nature. The selection of complementary indicators covering various aspects of sustainability may enrich the results. The constraints of accessibility and data availability are also significant problems for municipalities. This situation occasionally dictates the use of less than maximally efficient indicators to capture sustainable development on the metropolitan scale. Constraints of accessibility also affect the proportion of indicators in integrated components. Availability of more reliable and consistent data sets will help analyze the indicators' trends and thereby measure the megacities' sustainability.

Nonetheless, it should be noted that this is a relatively new field that will surely benefit from ongoing and future local initiatives. Moreover, the lack of a systematic method for establishing indicators is also a major reason for contributing to the limited effectiveness of indicators. Thus, future research in this area should focus on sustainable urban indicator variables spanning all relevant dimensions of metropolitans.

Although the present study provides a comparative assessment of sustainability across megacities, it does not detail region-specific issues that could significantly impact a particular metropolitan. The methods developed to measure sustainability at the national scale generally fail at the local scale to effectively measure progress towards sustainability, highlighting the need for new methodologies to assess local sustainability (Graymore et al., 2008). Future studies may focus on developing city-level sustainability indices based on bottom-up approaches considering the city-specific issues. This study also does not discuss the influence of unexpected conditions such as the Covid-19 pandemic on the sustainability performance of metropolitan cities. Further research may elaborate on this topic.

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.

Appendix

Table A1
Selected indicators, references, and data sources

Dimension	Indicator Group	Indicator	Unit	References	Data Source	Impact
Economic (1)	Foreign Trade (1.1)	Total Exports (1.1.1)	in thousand USD per enterprise	Common Spatial Data Infrastructure (CSDI)	TSI	Positive
		Total Imports (1.1.2)	in thousand USD per enterprise	CSDI	TSI	Positive
	Energy (1.2)	Electricity consumption (1.2.1)	kWh/capita	Araripe-Silva et al. (2018); Li et al. (2009); Michael et al. (2014); Huang, (2016); Scipioni et al. (2009)	TSI	Positive
	House Sales (1.3)	House sales (first sale) (1.3.1)	Item number per 100.000 person	Liang et al. (2016); Zoeteman et al. (2015); Michael et al. (2014)	TSI	Positive
		House sales (total) (1.3.2)	Item number per 100.000 person	Liang et al. (2016); Zoeteman et al. (2015) Michael et al. (2014)	TSI	Positive
	Industry (1.4)	Number of enterprises (1.4.1)	Item number per 1000 person	Scipioni et al. (2009); Zoeteman et al. (2015); Gulcan & Aldemir (2008); Li et al. (2009)	TSI	Positive
	Agriculture (1.5)	Crop production value (1.5.1)	in thousand TL per capita	CSDI	TSI	Positive
		Value of livestock (1.5.2)	in thousand TL per capita	CSDI	TSI	Positive
		Value of animal products (1.5.3)	in thousand TL per capita	CSDI	TSI	Positive
		Value of agricultural production (1.5.4)	in thousand TL per capita	CSDI	TSI	Positive
	Tourism (1.6)	Number of overnights of citizens & foreigners (1.6.1)	In days per capita	Liang et al. (2016); Scipioni et al. (2009); Visvaldis et al. (2013); Li et al. (2009); Liang et al. (2016)	TSI & Ministry of Culture and Tourism	Positive
	Transportation (1.7)	Number of road motor vehicles (1.7.1)	Item number per 1000 person	Michael et al. (2014); Caldas et al. (2018)	TSI	Positive
	Regional Account (1.8)	GDP per capita (1.8.1)	in USD per capita	Slaper (2011); Liang et al. (2016); Huang (2016); Scipioni et al. (2009); Araripe-Silva. et al. (2018); Gulcan & Aldemir (2008); Li et al. (2009)	TSI	Positive
		Gold deposit account (1.8.2)	per capita	Experts' opinion	TSI	Positive
Social (2)	Demography (2.1)	Infant mortality rate (2.1.1)	per thousand	Huang (2016); Araripe-Silva et al. (2018); Visvaldis et al. (2013)	TSI	Negative
		Life expectancy at birth (2.1.2)	in years	Slaper (2011); Visvaldis et al. (2013)	TSI	Positive
		Crude birth rate (2.1.3)	per thousand	Experts' opinion	TSI	Positive
		Crude death rate (2.1.4)	per thousand	Visvaldis et al. (2013)	TSI	Negative
		Total fertility rate (2.1.5)	Number of children	Experts' opinion	TSI	Positive
	Education (2.2)	Number of students per classroom (2.2.1)	primary school and lower secondary education	Basiago (1999); Liang et al. (2016); Visvaldis et al. (2013); Zoeteman et al. (2015) Michael et al. (2014)	TSI	Negative
		Number of students per teacher (2.2.2)	primary school and lower secondary education	Basiago (1999); Liang et al. (2016); Visvaldis et al. (2013); Zoeteman et al. (2015)	TSI	Negative
		Literacy rate (2.2.3)	%	Basiago (1999); Liang et al. (2016); Caldas et al. (2018); Araripe-Silva et al. (2018); Visvaldis et al. (2013); Zoeteman et al. (2015) Michael et al. (2014)	TSI	Positive
		Enrolment rate in primary school (2.2.4)	%	Basiago (1999); Liang et al. (2016); Visvaldis et al. (2013); Zoeteman et al. (2015)	TSI	Positive
		Enrolment rate in primary education (2.2.5)	% primary school and lower secondary education	Basiago (1999); Liang et al. (2016); Visvaldis et al. (2013); Zoeteman et al. (2015)	TSI	Positive
	Construction and Housing (2.3)	Number of building according to construction permit (2.3.1)	per household	Basiago (1999); Liang et al. (2016); Olewiler (2006)	TSI	Positive
		Number of dwelling units according to construction permit (2.3.2)	per 100.000 inhabitants	Basiago (1999); Liang et al. (2016); Olewiler (2006)	TSI	Positive
	Culture (2.4)	Number of the books (2.4.1)	per public library user	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
		Number of the libraries (2.4.2)	per 100.000 public library user	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive

(*continued on next page*)

Table A1 (*continued*)

Dimension	Indicator Group	Indicator	Unit	References	Data Source	Impact
		Number of works in museums (2.4.3)	per museum and ruin visitor	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
		Number of museums (2.4.4)	per 100.000 inhabitants	Scipioni et al. (2009); Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
		Number of cinemas (2.4.5)	Per 1000 inhabitants	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
		Number of cinema audiences (2.4.6)	Per 1000 inhabitants	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
		Number of theatre halls (2.4.7)	per 100.000 inhabitants	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
		Number of theatre audiences (2.4.8)	Per 1000 inhabitants	Basiago (1999); Liang et al. (2016); Zoeteman et al. (2015)	TSI	Positive
	Population and Migration (2.5)	Net migration rate (2.5.1)	per thousand	Araripe-Silva et al. (2018)	TSI	Positive
		Population density (2.5.2)	per one square kilometre	Caldas et al. (2018); Araripe-Silva et al. (2018); Gulcan & Aldemir (2008); Graymore et al. (2009)	TSI	Negative
		Elderly dependency ratio (2.5.3)	(%)	Scipioni et al. (2009)	TSI	Negative
		Annual growth rate (2.5.4)	per thousand	Araripe-Silva et al. (2018); Gulcan & Aldemir (2008); Graymore et al. (2009) Michael et al. (2014)	TSI	Positive
	Health (2.6)	Number of physicians (2.6.1)	per 1.000 inhabitants	Slaper (2011); Basiago (1999); Caldas et al. (2018); Scipioni et al. (2009); Zoeteman et al. (2015)	TSI	Positive
		Number of hospital beds (2.6.2)	per 100.000 inhabitants	Slaper (2011); Basiago (1999); Scipioni et al. (2009); Araripe-Silva et al. (2018); Zoeteman et al. (2015)	TSI	Positive
Environmental (3)	Waste Treatment (3.1)	Rate of population served by waste services in municipal population (3.1.1)	%	Caldas et al. (2018); Huang (2016); Slaper (2011); Liang et al. (2016); Scipioni et al. (2009); Visvaldis et al. (2013); Zoeteman et al. (2015); Li et al. (2009); Olewiler (2006)	TSI	Positive
		Rate of population served by wastewater treatment plants in municipal population (3.1.2)	%	Caldas et al. (2018); Huang (2016); Slaper (2011); Liang et al. (2016); Scipioni et al. (2009); Visvaldis et al. (2013); Zoeteman et al. (2015); Li et al. (2009); Olewiler (2006); Michael et al. (2014)	TSI	Positive
		Rate of population served by water supply network in municipal population (3.1.3)	%	Caldas et al. (2018); Huang (2016); Liang et al. (2016); Scipioni et al. (2009); Araripe-Silva et al. (2018); Visvaldis et al. (2013); Zoeteman et al. (2015); Li et al. (2009); Olewiler (2006)	TSI	Positive
	Protection of Natural Resources (3.2)	Rate of population served by sewerage system in municipal population (3.2.1)	%	Caldas et al. (2018); Huang (2016); Slaper (2011); Scipioni et al. (2009); Visvaldis et al. (2013); Zoeteman et al. (2015); Li et al. (2009); Olewiler (2006)	TSI	Positive
		Protected natural area (3.2.2)	m^2 per 100.000 inhabitants	Caldas et al. (2018); Huang (2016); Liang et al. (2016); Visvaldis et al. (2013); Zoeteman et al. (2015); Li et al. (2009)	TSI, Ministry of Environment and Urbanization	Positive
Institutional (4)	Justice (4.1)	Total number of the cases in the courts (4.1.1)	per 1.000 inhabitants	Scipioni et al. (2009)	TSI	Negative
		Convicts received into prison by province where the crime was committed (4.1.2)	per 1.000 inhabitants	Scipioni et al. (2009)	TSI	Negative
	Science and Technology (4.2)	Number of Master students (4.2.1)	per 100.000 inhabitants	CSDI	Higher Education Council of Turkey, TSI	Positive
		Number of Ph.D. students (4.2.2)	per 100.000 inhabitants	CSDI	Higher Education Council of Turkey, TSI	Positive
		Number of Professors (4.2.3)	per graduate student	CSDI	Higher Education Council of Turkey, TSI	Positive
		Number of Scimago listed institutions (4.2.4)	per university	CSDI	https://www.scimagojr.com/, TSI	Positive
	Civic Society (4.3)	Number of NGOs (4.3.1)	per 100.000 inhabitants	Visvaldis et al. (2013); Michael et al. (2014)	https://www.sivilt oplum.gov.tr/	Positive
		NGO revenues per year (4.3.2)	per 100.000 inhabitants	Visvaldis et al. (2013); Michael et al. (2014)	https://www.sivilt oplum.gov.tr/	Positive

Table A2
Sustainability scores of Turkish metropolitans for each pillar from 2011 to 2014

	2011				2012				2013				2014			
Cities	**Eco.**	**Soc.**	**Env.**	**Inst.**	**Eco.**	**Soc.**	**Env.**	**Inst.**	**Eco.**	**Soc.**	**Env.**	**Inst.**	**Eco.**	**Soc.**	**Env.**	**Inst.**
Adana	0.23	0.48	0.65	0.45	0.23	0.73	0.63	0.46	0.24	0.77	0.64	0.43	0.24	0.72	0.64	0.43
Ankara	0.32	0.63	0.65	1.00	0.31	0.92	0.63	1.00	0.30	0.97	0.64	0.91	0.30	0.96	0.64	0.92
Antalya	1.00	0.58	0.74	0.40	1.00	0.91	0.75	0.43	1.00	0.94	0.75	0.43	1.00	0.89	0.76	0.43
Aydin	0.43	0.50	0.63	0.45	0.42	0.80	0.62	0.48	0.41	0.82	0.65	0.45	0.42	0.86	0.68	0.48
Balikesir	0.40	0.54	0.60	0.52	0.39	0.76	0.60	0.55	0.38	0.79	0.60	0.53	0.39	0.81	0.60	0.56
Bursa	0.33	0.50	0.61	0.53	0.32	0.77	0.59	0.56	0.31	0.80	0.60	0.54	0.31	0.81	0.62	0.55
Denizli	0.37	0.55	0.66	0.55	0.37	0.78	0.65	0.59	0.37	0.82	0.65	0.55	0.37	0.84	0.65	0.59
Diyarbakir	0.14	0.42	0.63	0.65	0.13	0.64	0.61	0.64	0.14	0.66	0.62	0.53	0.14	0.70	0.63	0.56
Erzurum	0.21	0.53	0.62	0.87	0.21	0.75	0.60	0.90	0.22	0.76	0.61	0.85	0.23	0.74	0.62	0.91
Eskisehir	0.34	0.70	0.96	0.94	0.34	1.00	0.95	0.99	0.35	1.00	0.96	0.87	0.34	1.00	0.97	0.93
Gaziantep	0.25	0.54	0.64	0.65	0.26	0.70	0.60	0.67	0.26	0.70	0.62	0.62	0.27	0.69	0.64	0.67
Hatay	0.28	0.40	0.54	0.61	0.28	0.62	0.53	0.59	0.28	0.70	0.54	0.54	0.28	0.70	0.56	0.57
Istanbul	0.34	0.51	0.58	0.87	0.33	0.75	0.57	0.99	0.34	0.78	0.58	1.00	0.34	0.73	0.59	1.00
Izmir	0.35	0.52	0.66	0.53	0.35	0.80	0.64	0.56	0.35	0.83	0.65	0.53	0.37	0.80	0.68	0.53
K. Maraş	0.22	0.41	0.51	0.57	0.22	0.62	0.50	0.57	0.24	0.71	0.50	0.55	0.25	0.73	0.51	0.59
Kayseri	0.28	0.52	0.77	0.57	0.27	0.82	0.75	0.60	0.27	0.89	0.75	0.56	0.28	0.87	0.76	0.58
Kocaeli	0.46	0.66	0.59	0.66	0.45	0.83	0.58	0.66	0.42	0.81	0.59	0.60	0.42	0.87	0.62	0.64
Konya	0.29	0.51	0.74	0.70	0.29	0.78	0.75	0.70	0.31	0.85	0.76	0.62	0.33	0.82	0.77	0.64
Malatya	0.22	0.52	0.67	0.78	0.21	0.81	0.65	0.80	0.21	0.84	0.63	0.74	0.20	0.81	0.62	1.00
Manisa	0.30	0.43	0.63	0.50	0.31	0.70	0.62	0.51	0.30	0.75	0.63	0.49	0.33	0.76	0.64	0.51
Mardin	0.15	0.40	0.54	0.64	0.16	0.62	0.54	0.62	0.17	0.66	0.53	0.53	0.17	0.90	0.52	0.55
Mersin	0.28	0.44	0.68	0.47	0.28	0.69	0.69	0.47	0.28	0.73	0.70	0.45	0.29	0.72	0.71	0.45
Mugla	0.77	0.50	1.00	0.43	0.78	0.88	1.00	0.50	0.73	0.92	1.00	0.47	0.76	0.97	1.00	0.50
Ordu	0.19	0.38	0.38	0.53	0.20	0.79	0.39	0.58	0.20	0.64	0.38	0.57	0.20	0.64	0.37	0.53
Sakarya	0.31	0.50	0.53	0.73	0.30	0.78	0.52	0.77	0.31	0.82	0.48	0.72	0.33	0.81	0.45	0.73
Samsun	0.24	0.47	0.48	0.85	0.25	0.71	0.47	0.83	0.25	0.74	0.46	0.74	0.25	0.72	0.46	0.57
Sanliurfa	0.16	0.39	0.63	0.86	0.16	0.63	0.62	0.79	0.16	0.65	0.59	0.69	0.16	0.67	0.56	0.72
Tekirdag	0.44	1.00	0.52	0.38	0.42	0.99	0.51	0.41	0.41	0.94	0.52	0.42	0.43	0.97	0.52	0.43
Trabzon	0.25	0.49	0.46	0.86	0.25	0.83	0.45	0.86	0.24	0.86	0.45	0.75	0.24	0.92	0.44	0.79
Van	0.13	0.41	0.48	0.54	0.12	0.78	0.48	0.63	0.12	0.69	0.49	0.56	0.11	0.68	0.51	0.62

Table A3
Sustainability scores of Turkish metropolitans for each pillar from 2015 to 2018

	2015				2016				2017				2018			
Cities	**Eco.**	**Soc.**	**Env.**	**Inst.**	**Eco.**	**Soc.**	**Env.**	**Inst.**	**Eco.**	**Soc.**	**Env.**	**Inst.**	**Eco.**	**Soc.**	**Env.**	**Inst.**
Adana	0.25	0.71	0.64	0.45	0.27	0.73	0.63	0.45	0.27	0.75	0.63	0.41	0.24	0.64	0.63	0.41
Ankara	0.31	0.92	0.62	0.94	0.31	0.86	0.6	1	0.31	0.91	0.61	1	0.28	0.77	0.61	1
Antalya	1	0.89	0.74	0.43	1	0.82	0.71	0.43	1	0.87	0.72	0.41	1	0.81	0.73	0.42
Aydin	0.42	0.84	0.64	0.5	0.46	0.86	0.6	0.48	0.48	0.86	0.6	0.44	0.44	0.84	0.61	0.48
Balikesir	0.39	0.7	0.6	0.53	0.41	0.72	0.6	0.52	0.39	0.77	0.6	0.48	0.36	0.81	0.6	0.46
Bursa	0.33	0.8	0.61	0.59	0.34	0.77	0.59	0.58	0.35	0.84	0.58	0.53	0.32	0.72	0.57	0.55
Denizli	0.37	0.8	0.63	0.61	0.39	0.82	0.61	0.58	0.38	0.87	0.62	0.57	0.36	0.81	0.64	0.54
Diyarbakir	0.15	0.67	0.63	0.63	0.16	0.61	0.63	0.57	0.17	0.66	0.62	0.51	0.16	0.65	0.61	0.52
Erzurum	0.25	0.71	0.58	0.94	0.27	0.71	0.56	0.83	0.28	0.73	0.56	0.76	0.26	0.78	0.56	0.75
Eskisehir	0.36	0.95	0.96	0.93	0.38	0.91	0.95	0.87	0.37	0.96	0.95	0.72	0.34	0.88	0.95	0.72
Gaziantep	0.29	0.67	0.62	0.64	0.3	0.67	0.6	0.74	0.29	0.65	0.61	0.66	0.28	0.61	0.62	0.66
Hatay	0.29	0.66	0.54	0.56	0.29	0.64	0.52	0.6	0.31	0.66	0.53	0.6	0.28	0.64	0.54	0.59
Istanbul	0.36	0.74	0.57	0.96	0.35	0.68	0.55	0.95	0.36	0.7	0.55	0.89	0.33	0.56	0.55	0.9
Izmir	0.37	0.77	0.66	0.52	0.39	0.75	0.65	0.5	0.36	0.83	0.65	0.49	0.34	0.79	0.65	0.48
K. Maraş	0.27	0.72	0.5	0.62	0.28	0.73	0.48	0.59	0.28	0.77	0.5	0.57	0.26	0.72	0.51	0.51
Kayseri	0.28	0.75	0.73	0.58	0.46	0.76	0.71	0.56	0.29	0.82	0.72	0.52	0.27	0.7	0.74	0.53
Kocaeli	0.42	0.88	0.59	0.66	0.41	0.84	0.57	0.62	0.43	0.84	0.57	0.59	0.41	0.79	0.57	0.63
Konya	0.33	0.8	0.72	0.63	0.36	0.78	0.68	0.65	0.35	0.8	0.71	0.6	0.34	0.76	0.75	0.58
Malatya	0.23	0.8	0.62	0.77	0.24	0.79	0.62	0.69	0.25	0.82	0.63	0.73	0.22	0.78	0.65	0.69
Manisa	0.33	0.72	0.61	0.51	0.35	0.71	0.58	0.54	0.35	0.79	0.61	0.5	0.33	0.74	0.64	0.51
Mardin	0.17	0.74	0.5	0.61	0.2	0.57	0.5	0.55	0.2	0.62	0.51	0.46	0.17	0.63	0.56	0.5
Mersin	0.3	0.7	0.69	0.46	0.32	0.73	0.68	0.44	0.32	0.76	0.68	0.39	0.3	0.67	0.68	0.41
Mugla	0.77	0.9	1	0.51	0.82	0.88	1	0.5	0.65	0.94	1	0.49	0.61	1	1	0.48
Ordu	0.25	0.67	0.42	0.54	0.22	0.72	0.45	0.52	0.23	0.66	0.46	0.51	0.21	0.82	0.46	0.48
Sakarya	0.33	0.92	0.45	0.77	0.36	0.84	0.44	0.74	0.38	0.84	0.47	0.71	0.34	0.82	0.5	0.62
Samsun	0.26	0.71	0.5	1	0.27	0.74	0.54	0.64	0.28	0.81	0.53	0.59	0.25	0.72	0.52	0.55
Sanliurfa	0.17	0.68	0.56	0.75	0.18	0.64	0.55	0.7	0.18	0.66	0.55	0.63	0.17	0.64	0.54	0.64
Tekirdag	0.44	1	0.54	0.44	0.47	1	0.56	0.42	0.44	1	0.6	0.4	0.41	0.91	0.64	0.41
Trabzon	0.27	0.78	0.44	0.85	0.28	0.86	0.45	0.88	0.26	0.79	0.46	0.77	0.24	0.96	0.47	0.71
Van	0.11	0.61	0.49	0.61	0.16	0.62	0.46	0.56	0.15	0.61	0.47	0.56	0.13	0.65	0.47	0.58

Table A4
Overall sustainability scores of Turkish metropolitans from 2011 to 2018

Cities	2011	2012	2013	2014	2015	2016	2017	2018
Adana	0.55	0.54	0.54	0.54	0.56	0.58	0.58	0.54
Ankara	0.77	0.73	0.72	0.73	0.73	0.75	0.77	0.72
Antalya	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00
Bursa	0.66	0.60	0.60	0.62	0.64	0.64	0.66	0.61
Diyarbakir	0.66	0.50	0.49	0.51	0.53	0.53	0.53	0.52
Erzurum	0.62	0.62	0.62	0.64	0.64	0.64	0.65	0.64
Eskisehir	0.67	0.85	0.83	0.85	0.85	0.86	0.84	0.80
Gaziantep	0.52	0.59	0.58	0.61	0.60	0.64	0.63	0.61
Istanbul	0.65	0.62	0.62	0.63	0.64	0.62	0.64	0.59
Izmir	0.87	0.64	0.64	0.65	0.65	0.66	0.67	0.64
Kayseri	0.62	0.64	0.65	0.66	0.64	0.73	0.66	0.62
Kocaeli	0.56	0.70	0.67	0.70	0.71	0.70	0.71	0.69
Konya	0.63	0.67	0.68	0.69	0.68	0.69	0.71	0.69
Mersin	0.65	0.57	0.58	0.59	0.60	0.61	0.61	0.59
Sakarya	0.52	0.62	0.62	0.62	0.66	0.66	0.69	0.65
Samsun	0.65	0.58	0.57	0.53	0.64	0.60	0.61	0.56
Aydin	0.76	0.65	0.65	0.68	0.68	0.70	0.71	0.70
Balikesir	0.68	0.64	0.63	0.65	0.64	0.66	0.66	0.64
Denizli	0.64	0.66	0.65	0.67	0.67	0.68	0.70	0.67
Hatay	0.58	0.55	0.55	0.57	0.56	0.57	0.60	0.58
Kahramanmaras	0.49	0.50	0.52	0.55	0.57	0.58	0.59	0.56
Malatya	0.58	0.62	0.61	0.65	0.63	0.63	0.66	0.63
Manisa	0.94	0.58	0.58	0.61	0.60	0.63	0.65	0.63
Mardin	0.45	0.48	0.48	0.53	0.51	0.49	0.50	0.50
Mugla	0.63	0.96	0.93	0.97	0.98	1.00	0.94	0.92
Ordu	0.60	0.50	0.46	0.45	0.50	0.52	0.52	0.53
Sanliurfa	0.56	0.54	0.52	0.52	0.54	0.54	0.54	0.53
Tekirdag	0.78	0.65	0.64	0.66	0.69	0.71	0.71	0.69
Trabzon	0.60	0.60	0.58	0.61	0.61	0.66	0.63	0.63
Van	0.45	0.49	0.46	0.47	0.46	0.48	0.48	0.48

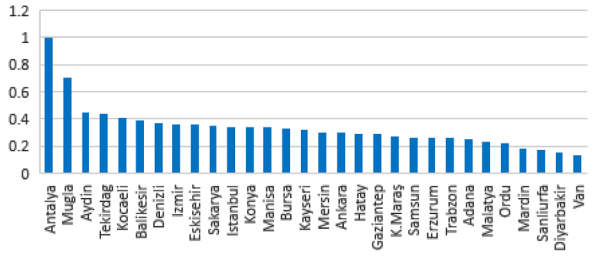
Table A5
Summary of selected studies on sustainability indicators/indices for metropolitan cities

Author(s) (Year)	Region(s) Covered	Method	Research Question/Objectives	Findings/Outcome
Valentin & Spangenberg (2000)	Iserlohn/ Germany	Literature Review, Case Study	To introduce a model focused on determining local sustainability indicators relevant for the Local Agenda 21 to reduce complexity around measurements	A model approaching common goals should be integrated into a more detailed set of indicators originated from Local Agenda 21.
Eckerberg & Mineur (2003)	Stockholm and Sundsvall/ Sweden	Case Study	To reveal the profile, function, and role of indicators concerning the environmental, social, and economic dimensions of sustainable development	The main problem is not about the indicators, yet how to make people participate in the processes.
Graymore et al. (2009)	Australia	Multiple Criteria Analysis (MCA)	To develop a framework assessing sustainability based on Geographic Information System to facilitate decision-making for regional authorities	An Index of Regional Sustainability Spatial Decision Support System (AIRS SDSS)
Scipioni et al. (2009)	Padua/Italy	Case Study	To assess the feasibility of "Dashboard of Sustainability" as a support tool through the Local Agenda 21 initiative	The Dashboard is applicable for the local level and clearly presents the change in sustainability performance over time.
Li et al. (2009)	Jining City/ China	Full Permutation Polygon Synthetic Indicator Method (FPPSI)	To formulate a tool focusing on local sustainable development with the aim of giving support to local agencies in ecological planning, and construction.	The local sustainable development tool based on FPPSI increases the quality of sustainability-related decisions at the local level.
Dahl (2012)		Literature Review	To measure strengths and weaknesses of local sustainable development indicators	The indicators are widely used and efficient at the national level, while the same achievement could not be achieved at the local level.
Mori & Christodoulou (2012)		Literature Review	To determine conceptual requirements for a City Sustainability Index (CSI) by reviewing existing major sustainability indices/ indicators such as EF, ESI, GPI, LPI	A sophisticated CSI is required to compare and contrast cities in terms of their impact on economic and environmental dimensions and living conditions.
Visvaldis et al. (2013)	Valmiera/ Latvia	KITCASP (Key Indicators of Territorial Cohesion and Spatial Planning)	To discuss how to specify sustainable development indicators suitable for small-scale towns	Indicators should be determined based on the priorities of today and tomorrow. Among 108 indicators for economic, environmental, and social dimensions, a key indicator set of 15 is designed.
Michael et al. (2014)	Malaysia, Taiwan, and China	Qualitative Method (Comparative Analysis)	To investigate and benchmark three Asian developing countries in terms of methods, frameworks, and indicators used to assess local sustainable development.	Malaysia, Taiwan, and China are in an attempt to integrate each sub-dimension (economic, social, and environmental development) into the calculation.

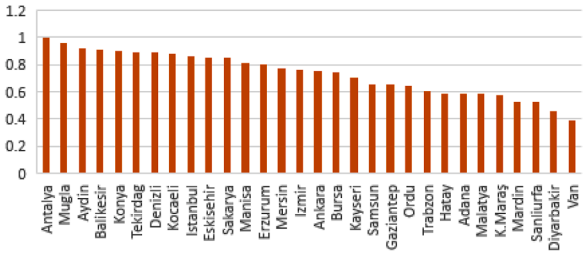
(*continued on next page*)

Table A5 (*continued*)

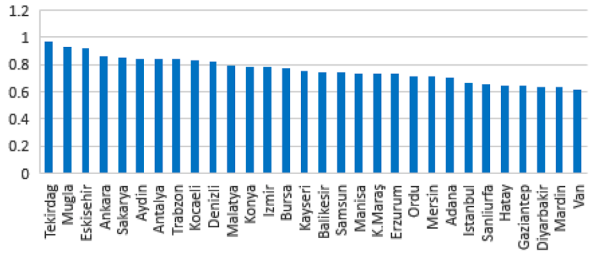
Author(s) (Year)	Region(s) Covered	Method	Research Question/Objectives	Findings/Outcome
Zoeteman et al. (2015)	Netherland	A comparative study of 403 municipalities based on 90 indicators	To develop a method introduced by Tilburg University and use it for a comprehensive assessment of sustainability at local and regional level	The concept of city typology such as "green", "old industrial", "sleep" is developed considering different backgrounds. There is a negative correlation between the population and sustainability.
Huang (2016)	China	Time-series Analysis of 10 provincial capitals (1978-2012)	To compare and contrast 10 Chinese megacities in terms of their sustainability performance in the 35th year of economic reform and open-door policy	With a strong focus on financial performance, China should take the trade-off between economic development and environmental sustainability into consideration.
Liang et al. (2016)	Taipei/Taiwan	Regression Analysis based on a survey (12-dimension/42-indicator mega-event impact measurement scale) of 1,628 host	To investigate how the 2010 Taipei International Flora Exposition affected the local community and their perceptions towards urban sustainability	Positive outcomes of the Exposition affected local sustainability positively and significantly, while negative outcomes did not create a significant impact.
Dizdaroglu (2017)		Literature Review	To reveal how sustainability assessment based on indicators influences public policy and decision-making	Even though selecting the most suitable tool, indicators, or methods remains unanswered, the scale influences judgment. Nevertheless, accessing the relevant data is the most painful step.
Araripe-Silva et al. (2018)	Ceara/Brazil	Confirmatory Factor Analysis, Spatial Econometric Modelling	To develop an index including four sub-dimensions and to measure inequalities at the municipality level.	The urban areas of the State of Ceará show better sustainable development.
Mapar et al. (2020)	Tehran/Iran	Exploratory Factor Analysis (EFA)	To develop a composite assessment index considering all aspects of health, safety, and environmental sustainability performance simultaneously in an integrated manner	The majority of Tehran municipalities need to review the plans and programs that are related to sustainable municipal development by considering district-centered health, safety, and environmental issues.
Chen & Zhang (2021)	Northeast China	TOPSIS-ORM (Order Relation Method), Weighted Average Operator (WAO)	To assess the reasons for sustainability fluctuation, factors influencing sustainability	Comparing the indicators demonstrated that economic indicators were the common limiting factors impeding sustainability in most shrinking cities. Additionally, the improvement in sustainability performance was attributed to the increase in the environmental dimension in Northeast China.



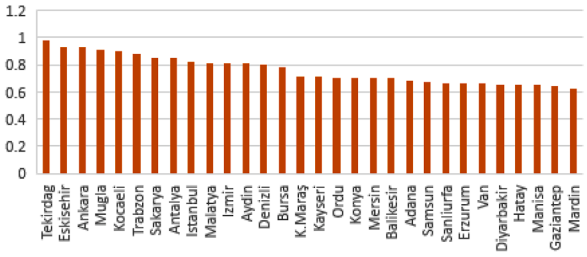
(a) Average economic sustainability rankings (2015-2018) (present study)



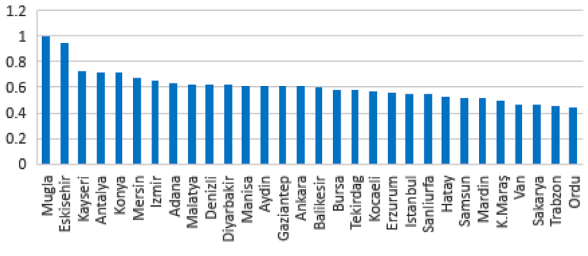
(b) Average economic sustainability scores (2015-2018) (TOPSIS)



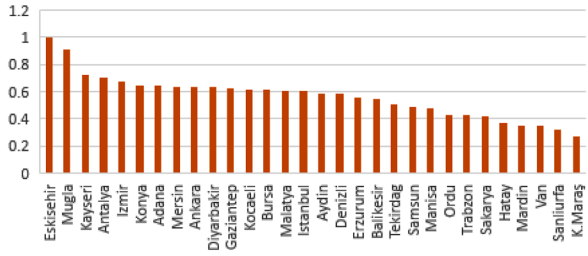
(c) Average social sustainability rankings (2015-2018) (present study)



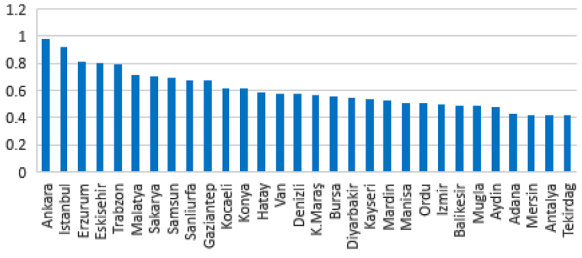
(d) Average social sustainability rankings (2015-2018) (TOPSIS)



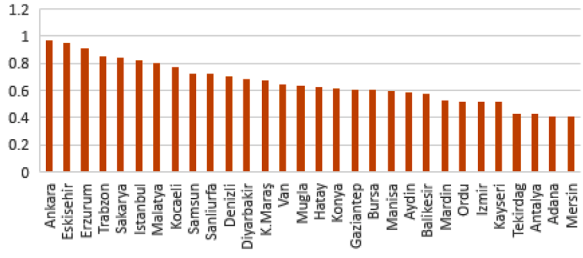
(e) Average environmental sustainability rankings (2015-2018) (present study)



(f) Average environmental sustainability rankings (2015-2018) (TOPSIS)



(h) Average institutional sustainability rankings (2015-2018) (present study)



(g) Average institutional sustainability rankings (2015-2018) (TOPSIS)

Fig. A1. (a-g): Comparison of average sustainability rankings (2015-2018) obtained COPRAS versus TOPSIS

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