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How are smart city policies progressing in Italy? Insights from SDG indicators

Roberta Barbieri [a,*], Benedetta Coluccia [b], Francesco Natale [a]

[a] Department of Economic Sciences, University of Salento, Via Monteroni, snc, Lecce, LE 73100, Italy
[b] Department of Management and Economics, Pegaso Telematic University, Centro Direzionale Isola F2, Naples, NA 80143, Italy

A R T I C L E I N F O

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A B S T R A C T

With the rise of global urbanization, cities encounter considerable socioeconomic and environmental challenges embodied in the 17 Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda for Sustainable Development. Therefore, the crucial importance of urban planning cannot be underestimated in pursuing sustainable development. Among urban sustainability efforts, the smart city has emerged as a crucial paradigm for integrating innovation and sustainability to enhance urban living and achieve SDGs. The study aims to classify the Italian regional capital cities based on their progress in smart cities-related SDGs to understand the key implementation strategies, define the gaps between cities and identify priorities for action. For cluster analysis, 34 indicators related to SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities) were considered. The main results reveal significant variability in performance across Italian cities, suggesting that they are at different stages of development in achieving SDGs 9 and 11. Northern Italian cities outperform their southern counterparts in industry, innovation and infrastructure. Larger cities often suffer from more serious and structural problems in urban sustainability. This study guides policy by pinpointing effective strategies and gaps across Italian cities, enhancing collaborative efforts and best practice sharing. It also informs SDG progress assessments, directing investments and prioritizing development needs, thus advancing smart city policies and urban sustainability.

1. Introduction

The global population is increasingly concentrated in urban areas, with approximately 68 % of the world's population living in cities by 2050 (UN-SDSN, 2019). The high population density, intensity of human activities, and built environment inefficiency hinder the sustainable development of cities, making them disordered and unorganized (Johnson, 2008). As cities are major consumers of global resources and the largest producers of greenhouse gas emissions, they have to face very critical challenges (e.g., overcrowding, degradation, traffic congestion, pollution, waste management, energy shortage, land loss, inequalities, crime) (Kummitha and Crutzen, 2017).

The early efforts to promote urban sustainability date back to the late 1980s, when the World Commission on Environment and Development (WCED) of the United Nations published the Brundtland Report (WCED, 1987). According to the report's agenda, urban sustainability efforts aim to promote urbanization patterns and implement policies that prioritize the needs of inhabitants without compromising those of future generations. Subsequently, global interest has increasingly focused on cities for the success of the 2030 Agenda for Sustainable Development (McGranahan and Satterthwaite, 2014). Indeed, in 2015, the United Nations set 17 Sustainable Development Goals (SDGs) as reference targets for the global community by 2030 (UN-SDSN, 2015). Covering a broad range of issues, SDGs are an ambitious challenge for all countries to address the growing economic, social and environmental concerns, representing guiding principles toward sustainable development (Le Blanc, 2015; Sachs, 2012). The wider international approaches and methods have gradually modified the framework for sustainable development urban policies, as many countries lack a well-defined state and regional framework to address (Camerin et al., 2024; Zimmermann and Fedeli, 2021).

The increasing attention on urban areas has generated a large body of literature demonstrating that they are more inclined to initiate transformational actions, guiding the desired global changes (Masuda et al., 2022). Urban policies in many cities worldwide aim to drive activities in key sectors for sustainability, such as water, housing, land use,

* Corresponding author.
E-mail addresses: roberta.barbieri@unisalento.it (R. Barbieri), benedetta.coluccia@unipegaso.it (B. Coluccia), francesco.natale@unisalento.it (F. Natale).

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climate change, transport and economics (OECD, 2022). Furthermore, cities are believed to be more innovative than central governments and can develop strategies to finance various projects that may require less capital than central government initiatives (Caragliu and Del Bo, 2019). The potential for city governments to learn and share knowledge on how to shape solutions tailored to local challenges makes them the best candidates for achieving SDGs (Leavesley et al., 2022). Since almost one-third of the 232 SDG indicators may be measured locally, cities are crucial units for acting and tracking advancement toward sustainable development (Akuraju et al., 2020). They are not only executive actors but key players without whom most of the 2030 Agenda will not be fully realized (Satterthwaite, 2014).

Under this perspective, cities are required to enable better urban planning models to facilitate achieving sustainability goals at the city scale.

Among these models is the smart city, which has gained substantial attention in recent years thanks to widespread political support and marketing promotion (Masik et al., 2021). The smart city paradigm emerged in the early 1990s from the doctrine of technological change (Gibson et al., 1992). Although it was originally technology-centred, the role of non-technological factors (i.e., people, institutions, social innovation, knowledge economy) has been increasingly recognized (Giffinger et al., 2007). To date, the smart city represents a holistic approach to planning and managing city activities based on the simultaneous integration of technological, social, economic, environmental and institutional aspects, aiming to improve citizens' quality of life (Caragliu et al., 2011). The foundation of smart city initiatives lies in the strong connection between sustainability and innovation (Jain et al., 2023). Indeed, innovation is crucial for achieving sustainable development goals (Schraven et al., 2021) to overcome challenges and introduce new solutions (Bibri, 2022). Ignoring this connection in urban development can lead to risks, such as prioritizing short-term gains and commercial interests over environmental concerns and fostering marginalization, elitism, utilitarianism and materialism (Yigitcanlar et al., 2019).

The existing scientific literature on the relationship between smart cities and SDGs is fragmented and lacks critical exploration of the theoretical principles underlying this connection (Sharifi et al., 2024; Blasi et al., 2022). Research evaluating progress towards urban sustainability has not adequately investigated the role of the smart city (Berisha et al., 2022; Koch and Krellenberg, 2018). Moreover, the results of studies examining the contributions of smart cities in achieving sustainable urban outcomes are often nonlinear (Yigitcanlar and Kamruzzaman, 2018) and previously adopted measurement and evaluation tools have frequently been criticized (Sharifi, 2019, 2020; Ciacci et al., 2021). Finally, there is a lack of specific studies that deeply analyze the ability of Italian cities to pursue sustainability and innovation goals. Considering that Italian cities face various challenges, it is useful to examine how they align with the SDGs and how they react to global changes through sustainability and innovation strategies (Battarra et al., 2018). To fill these gaps, the present study introduces an innovative approach by using SDG indicators to measure the principles of smart cities. This represents a significant advancement in understanding how smart city policies are evolving. By classifying the 21 Italian regional capitals (including the autonomous provinces of Trento and Bolzano) according to their progress on smart cities-related SDG indicators, the study aims to define differences between city groups, understand the main challenges, and identify priorities for action or areas where further efforts and investments are needed. A cluster analysis based on Euclidean distance was performed using 34 indicators associated with two smart-cities SDG indicators, i.e., SDG 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities and Communities). Subsequently, a one-way Analysis of Variance (ANOVA) was carried out to evaluate the presence of a statistically significant difference between the separate clusters of each observed indicator. The remainder of the study is as follow. In the next section, the theoretical background of the research and the related literature are explained. In the Section 3, the two-step methodological strategy adopted is described. In Section 4, the empirical analysis results are shown and discussed. Finally, conclusions and implications are presented in Section 5.

2. Literature review

The previous scientific literature reveals a lack of agreement on the smart city idea and the best pathways to achieve urban smartness (Hollands, 2020). The various available definitions can considerably diverge due to the multiple entities involved and the many functions that smart cities perform (Mora et al., 2017). In its early stages, the evolution of the smart city notion was driven by a technocratic and efficiency-based perspective that recognized technology as the means to optimize the urban transformation process (Harrison and Donnelly, 2011; Ahad et al., 2020; Konbr and Abdelaal, 2022). Over time, there has been an evolution in the smart city notion to include soft elements (human and social capital), recognizing the central role of people (Komninos et al., 2019). The latter perspective involves a multidimensional city view (Giffinger and Gudrun, 2010), requiring more holistic objectives (Blasi et al., 2022). Nowadays, smart city goals openly address social, environmental and economic challenges as equally important as technological ones (Bouzguenda et al., 2019). Indeed, embracing and leveraging ICT, smart cities can catalyze significant changes by fostering connections between innovation and sustainability (Bibri, 2020).

In this context, the smart city has emerged as a paramount driver of sustainable development (Schraven et al., 2021), contributing in several and changing ways to the achievement of the SDGs (Blasi et al., 2022; Sharifi et al., 2024). The smart city's potential to address SDGs has recently been increasingly recognized. Several efforts have been undertaken to investigate the links between these two concepts, until introducing the concept of smart sustainable cities (Ahvenniemi et al., 2017; Bibri and Krogstie, 2017). In particular, it is demonstrated that implementing smart city initiatives is more or less connected to the targets and indicators of all SDGs, providing multiple benefits for sustainable urban development (Siragusa et al., 2020). For instance, smart city sensors ensure real-time feedback on various indicators, such as air quality (SDG 13), water pollution (SDG 14) and natural resources protection (SDG 15). Smart city solutions can optimize the use and management of resources, contributing to the goals of clean water and energy (SDGs 6 and 7). Advanced waste management systems in smart cities enhance recycling rates and reduce landfill disposal, promoting responsible consumption and production (SDG 12). Smart transportation systems, such as intelligent traffic management and alternative mobility solutions (e.g., e-mobility and sharing mobility), reduce emissions and pollution, supporting sustainable cities and communities (SDG 11). By leveraging digital platforms, smart cities enhance transparency and citizens' engagement in governance, giving them a voice and aligning with the goals of strong institutions (SDG 16) and partnerships (SDG 17). The integration of ICT in public services improves accessibility and quality, allowing for better medical care (SDG 3) and higher educational levels (SDG 4). Smart cities foster innovation and economic growth by creating an environment conducive to new business models and technological advancements (SDGs 8 and 9). Finally, smart city initiatives contribute to bridging social and territorial divides, reducing poverty and hunger (SDGs 1 and 2), gender diversity (SDG 5) and inequalities (SDG 10). These are just a few possible interconnections between the smart city paradigm and the SDGs, which need to be carefully considered in urban agendas. According to Sharifi et al. (2024), Table 1 summarizes each SDG's main direct and indirect benefits within a smart city context.

Among all the SDGs, the importance of developing innovative solutions to address urban sustainable development challenges is evident in SDG 11 (Sustainable Cities and Communities) (Jain et al., 2023; Tura and Ojanen, 2022; Visvizi and del Hoyo, 2021a). It aims to make cities

Table 1
Major direct and indirect benefits of smart city in relation to each SDGs.

SDGs	Direct benefits	Indirect benefits	Key references
1 NO POVERTY	- Provide means to identify better urban poor and understand their needs	- Enabling economic growth - Efficiency improvement and operational optimization	Ismagilova et al. (2019), Joia and Kuhl (2019), Vinuesa et al. (2020)
2 ZERO HUNGER	- Offer solutions to identify groups that lack access to food during times of crisis	- Promotes sustainable behaviors that lead to better food access - Reduced food waste through enhanced supply chain management - Offers more efficient ways of food production and conservation	Baena et al. (2020), Ryan et al. (2020), Varghese et al. (2021), Vinuesa et al. (2020)
3 GOOD HEALTH AND WELL-BEING	- Improved health monitoring and surveillance	- Enhanced indoor and outdoor air quality - Reduced traffic congestion and increased share of active transportation - Improved access to healthcare services for vulnerable groups	De Las Heras et al. (2020), Hannan et al. (2020), Ismagilova et al. (2019), Liaqat et al. (2021), Liu et al. (2021)
4 QUALITY EDUCATION	- Enhanced accessibility during crisis times such as the pandemics and syndemics	- Improved methods for evaluation of educational programs	Nikitin et al. (2016)
5 GENDER EQUALITY	- Not mentioned in the reviewed papers	- Provision of alternative means of financing to secure support for empowering women - Enable better participation of women in the society	Sagaris and Tiznado-Aitken (2020), Vinuesa et al. (2020)
6 CLEAN WATER AND SANITATION	- Real-time monitoring of water and wastewater resources - Early warning systems and predictive models for water management	- Efficient management of water distribution and wastewater systems - Enhanced accessibility to safe drinking water in water-stressed areas - Improved fundraising for water management projects	Blasi et al. (2022), Mora et al. (2021), Parmentola et al. (2022), Vinuesa et al. (2020)
7 AFFORDABLE AND CLEAN ENERGY	- Promotion of decentralized energy systems - Integration of renewables and electric vehicles	- Energy saving - Identification of cases of illegal wiretapping - Demand optimization and energy resilience - Better awareness of and control over energy consumption - P2P energy trading at the community scale	Blasi et al. (2022), Lazaroiu and Roscia (2018), Liaqat et al. (2021), Ryan et al. (2020)
8 DECENT WORK AND ECONOMIC GROWTH	- Simplified and safer access to banking and finance for small- and medium-sized enterprises	- Improvements in innovation and productivity - Promotion of green economy - Creating more decent and dignified working conditions	Ismagilova et al. (2019), Savchenko and Borodina (2020), Truby (2020)
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	- Accelerate innovation	- Strengthen the innovation capacity of developing economies - Promotion of green industries	Ismagilova et al. (2022), Mora et al. (2021), Parmentola et al. (2022)
10 REDUCED INEQUALITIES	- Reduce transaction costs that can facilitate remittance to residents in developing country cities	- Improved mobility and access to services - Promotion of participatory mechanisms and democratic processes - Help identify sources of inequality - Improved service accessibility - Can overcome urban-rural disparities	Blasi et al. (2022), Kourtit et al. (2020), Mhlanga (2022), Vinuesa et al. (2020)
11 SUSTAINABLE CITIES AND COMMUNITIES	- Optimization of urban management	- Mainstream citizen engagement in urban management - Potential to reduce travel demand	Alagirisamy and Ramesh (2022), Grossi and Trunova (2021), Tura and Ojanen (2022), Visvizi and del Hoyo (2021a), (2021b)
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	- Contribute to better waste and wastewater management	- Optimization and enhanced awareness of natural resource management	Ismagilova et al. (2019), Liu et al. (2021), Vinuesa et al. (2020)
13 CLIMATE ACTION	- Improved modeling of climate change and its impacts	- Facilitate integration of renewable energy into energy systems	Hannan et al. (2020), Parmentola et al. (2022), Vinuesa et al. (2020)

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Table 1 (*continued*)

SDGs	Direct benefits	Indirect benefits	Key references
14 LIFE BELOW WATER	- Monitoring of water pollution	- Reducing marine pollution through automatic identification features	Parmentola et al. (2022), Vinuesa et al. (2020)
15 LIFE ON LAND	- Not mentioned in the reviewed papers	- Contribute to the protection of natural resources	Ghadami et al. (2021), Lovich and Ennen (2021), Tian et al. (2021)
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	- Improved opportunities for citizen participation	- Enhanced transparency - Better crime control	Allam (2018), Artusio et al. (2017), Ismagilova et al. (2022), Moura and Gomes (2017)
17 PARTNERSHIPS FOR THE GOALS	- Enhanced platforms for facilitating communication and collaboration among stakeholders	- Enhanced capacity to monitor the progress toward achieving SDGs - Enhanced trust among stakeholders	Ismagilova et al. (2019), Nelson et al. (2019), Sethi and Sarangi (2017), Sharifi and Allam (2021)

Source: Sharifi et al., (2024).

and human settlements inclusive, safe, resilient, and sustainable, addressing several factors that can significantly impact the quality of life in cities (e.g., housing conditions, public transportation, waste management, air pollution, water supply, land consumption and public green spaces) (UN-Habitat, 2016). The smart city, through integrated urban planning and the strategic use of ICT, enables greater access to public services, the improvement of environmental conditions, the optimization of resource usage, the advancement of infrastructure, the promotion of human knowledge and socioeconomic development (Grossi and Trunova, 2021), all contributing to SDG 11 (Visvizi and del Hoyo, 2021a).

In addition to the specific urban-based SDG 11, among the smart cities-related SDGs that have received more attention in the literature, a primary role is taken by SDG 9 (Industry, Innovation and Infrastructure) (Clement et al., 2023; Parra-Domínguez et al., 2022). It aims to build resilient infrastructure, promote innovation and foster equitable, responsible and sustainable industrialization. In this sense, by providing several solutions that allow diverse innovations to emerge, the smart city offers a great opportunity for advanced manufacturing, infrastructure, research and development (Kummitha, 2019). These innovations strengthen the urban economy's productivity and competitiveness, creating a favorable environment for start-ups and technology companies and contributing to SDG 9 (Nam and Pardo, 2011).

Although smart cities are often promoted as advanced solutions to numerous problems to improve urban life, they also present some disadvantages that have been analyzed in the academic literature. Ziosi et al. (2023) refer to ethical concerns of smart cities in four dimensions: (i) network infrastructure, with its associated issues of control, surveillance and data privacy and ownership; (ii) post-political governance, including conflicts between public and private decision-making; (iii) social inclusion, referring to citizens participation, inequalities and discriminations; (iv) sustainability, especially considering the environmental issues that technologies might cause, such as energy consumption. Similarly, Sharifi et al. (2024) argue for addressing trade-offs regarding privacy and cybersecurity, infrastructure upgrade costs, biased decision-making, reproduction of social biases, the digital divide and lack of skills, and limited legal frameworks. Moreover, technological development within smart cities can foster e-gentrification processes, expelling low-income residents with limited digital skills from more technologically advanced areas (Middha and McShane, 2022; Mykhnenko, 2023). Government interventions and multi-level governance mechanisms are key to overcoming these problems and ensuring equitable urban development (Sharifi et al., 2024).

3. Methodology

The study area includes a sample of 21 cities to support the analysis of sustainability and innovation in Italian municipalities. Specifically, Italian regional capitals (including the autonomous provinces of Trento and Bolzano) were selected due to the availability and goodness of the necessary data. Defining this city's sample guarantees that valid and comparable information is obtained. The geolocation of the 21 analyzed cities is shown in Fig. 1.

3.1. Data collection

The adoption of the SDGs by all United Nations member states, fostered by the United Nations Sustainable Development Solutions Network (UN-SDSN, 2015), offers an adequate framework to track the impacts of smart cities-related measures in the context of Italy. Therefore, two specific goals were chosen from the 17 SDGs for which the smart city is crucial, i.e., (i) SDG 9 (Industry, innovation, and infrastructure) and (ii) SDG 11 (Sustainable cities and communities). As illustrated in Table 2, the degree of achievement of both selected targets was measured employing a total of 34 indicators, of which 11 for SDG 9 and 23 for SDG 11. A database was created with all indicators data for the year 2022. Since the analysis is based on data collected in a single year, it may not capture long-term trends or seasonal variations crucial for understanding cities' progress toward sustainability goals. The information was extracted from various institutional sources, including mainly ISTAT (Istituto Nazionale di Statistica), but also ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) and CRESME (Centro Ricerche Economiche Sociologiche e di Mercato per l'Edilizia). Some indicators are defined at the city level (NUTS 3), while others are derived from data at the regional or provincial level (NUTS 2). Although they may not accurately capture local dynamics, the latter are a reliable proxy for urban data when unavailable and provide additional information concerning the external endowment of cities.

Because of the high number of heterogeneous indicators included in the analysis and their low degree of dependency, cluster analysis was selected as the most suitable research method to group and identify similarities among the observed cities (Scott and Knott, 1974). Cluster analysis is designed to classify single observation units according to their similarity, aiming to form a series of very homogeneous groups. The clustering of observation units relies on different characteristics (indicators) measured for each observation unit (cities). The initial step is to select an adequate distance measure, as it is required to establish how "similar" or "different" they are from each other (Fraley and Raftery, 1998). Various distance measures are available in the literature and the widely employed are Euclidean distance, squared Euclidean distance, Mahalanobis distance, Minkowski distance and Manhattan distance (Hair et al., 2010). In the present study, the Euclidean distance measure was used, calculated by the expression (1):

$$d_{ij}^2 = \sum_{k=1}^{p} (X_{ik} - \quad X_{jk}) \tag{1}$$

where p is the number of indicators, x_{ik} is the value of the observation unit x_i for the indicator X_k, and x_{jk} is the value of the observation unit x_j for the indicator X_k. Utilizing this distance measure and the starting data matrix (n x p) (n objects classified according to p indicators), a distance matrix (n x n) is constructed, which expresses the level of similarity or

Fig. 1. Italian cities sample.

difference between all pairs of grouped objects (Elmore and Richman, 2001).

The current study developed three agglomerative hierarchical clustering analyses: one for each of the two targets expressed in Table 2 and the last one that simultaneously considered both targets with their overall associated 34 indicators. Ward's method was applied for each analysis. In addition, the R package NbClust was employed to determine the relevant number of clusters in each analysis. It provides 30 indices that establish the number of clusters in a dataset and proposes the best clustering scheme among different obtained results by changing all combinations of number of clusters, distance measures and clustering methods (Charrad et al., 2014). After determining the best number of clusters, agglomerative hierarchical clustering based on Ward's method was carried out and displayed in dendrogram form (Murtagh and Legendre, 2014).

Finally, one-way ANOVA was applied to determine whether a statistically significant difference existed between the separate clusters of each observed indicator (Ward, 1963).). The ANOVA was computed for just one of the three cluster analyses, namely the one that takes into account all smart city-related goals and their corresponding indicators simultaneously. R software was used to analyze the collected data and all needed statistical computations. Table 3 shows the descriptive statistical measures, i.e., selected indicators' minimum, maximum, average and standard deviation values.

4. Results and discussion

Cluster analysis was applied to standardized values of each indicator by using Ward's approach and the squared Euclidean distance as distance measurements between observation units (i.e., observed cities). Fig. 2 presents a dendrogram that visually interprets the procedure and results of the hierarchical agglomeration for the observed cities. It shows the analysis of SDG 9 and SDG 11 individually and the combined analysis of both SDGs 9 and 11.

4.1. Clustering based on SDG 9

The first clustering of Italian regional capital cities was conducted using 11 indicators related to SDG 9. This analysis identified three distinct clusters, each reflecting different performance levels and characteristics regarding the development of manufacturing, research, innovation and digital infrastructure: (1) Venezia, Ancona, Milano, Torino, Bologna, Trento and Trieste; (2) Potenza, Perugia, L'Aquila, Aosta and Bolzano; (3) Bari, Catanzaro, Napoli, Palermo, Cagliari, Roma, Campobasso, Genova and Firenze (Fig. 2a). Looking at the results in Table 4, it can be observed that cities in Cluster 1 ranked first in most of the SDG 9 indicators, showing a robust manufacturing sector, a strong presence of technology industries and excellent universities and research facilities that attract large investments in R&D. These cities are leaders about SDG 9, with a strong technological base and a favorable environment for industrial development. Their economies are diversified, with a mix of industrial and service sectors that contribute to their economic resilience (The cities in Cluster 1 are all located in northern Italy, except Ancona, located in central Italy. Indeed, northern Italian cities are generally characterized by advanced infrastructure and well-developed industries (Crescenzi and Rodríguez-Pose, 2011; Camagni and Capello, 2004). Therefore, to maintain their leadership, northern Italian cities should invest in centres of excellence for research and innovation. Industrial automation and the adoption of artificial intelligence are essential to maintain their leading position in the advanced manufacturing sector. It is also advisable to promote the development of integrated technological districts that combine housing, industry and services, thus creating fully sustainable urban ecosystems (Konbr et al., 2023).

Cluster 2 includes cities that, while not major industrial hubs, possess a moderate economic profile with significant potential for development (Fig. 2b). These cities show good performance in some areas, but have room for improvement in others. In particular, the industrial presence is significant, but not at the same level as Cluster 1 cities. It is more focused

Table 2
Targets and related indicators included in the study.

Target	Target description		Indicators	Sources	Territorial level
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Building resilient infrastructure and promoting innovation and equitable, responsible and sustainable industrialization	1	Value-added of manufacturing industry (euro per capita)	Istat	NUTS 2
		2	Value-added of manufacturing industry to total economy (%)	Istat	NUTS 2
		3	Employment in manufacturing industry to total economy (%)	Istat	NUTS 2
		4	Research intensity (%)	Istat	NUTS 2
		5	Researchers in full-time equivalent (per 10,000 inhabitants)	Istat	NUTS 2
		6	Knowledge workers (per 100 employed)	Istat	NUTS 2
		7	Firms with product and/or process innovative activities per 100 firms (%)	Istat	NUTS 2
		8	Productive specialization in high-tech sectors (%)	Istat	NUTS 3
		9	Fixed network coverage of ultra-fast internet access (%)	Istat	NUTS 3
		10	Firms with at least 10 employees in web sales to end customers (%)	Istat	NUTS 2
		11	Firms with at least 10 employees in web sales to firms and public institutions (%)	Istat	NUTS 2
11 SUSTAINABLE CITIES AND COMMUNITIES	Making cities and human settlements inclusive, safe, resilient, and sustainable	1	People living in housing with structural or moisture problems (%)	Istat	NUTS 2
		2	People living in overcrowded housing (%)	Istat	NUTS 2
		3	People living in housing with noise from neighbors or street (%)	Istat	NUTS 2
		4	Illegal building rate (per 100 constructions)	CRESME	NUTS 2
		5	Households reporting difficulties with public transport connections (%)	Istat	NUTS 2
		6	Students who habitually travel to the place of study only by public means (%)	Istat	NUTS 2
		7	Employed people who habitually travel to the workplace only by private means (%)	Istat	NUTS 2
		8	Seat-km offered by the local public transportation system (per inhabitant)	Istat	NUTS 3
		9	Regular users of public transportation (%)	Istat	NUTS 2
		10	Waterproofing and land use (m^2 per inhabitant)	ISPRA	NUTS 2
		11	Population at risk of flooding (%)	ISPRA	NUTS 3
		12	Population at risk of landslides (%)	ISPRA	NUTS 3
		13	Landfilling of municipal waste (%)	ISPRA	NUTS 2
		14	Municipal waste generated (kg per inhabitant)	Istat	NUTS 3
		15	Air pollution (%)	Istat	NUTS 2
		16	Annual average concentration of PM10 (micrograms per m^3)	Istat	NUTS 3
		17	Annual average concentration of PM2.5 (micrograms per m^3)	Istat	NUTS 3
		18	Annual average concentration of NO2 (micrograms per m^3)	Istat	NUTS 3
		19	Predicted daily limit value exceedances for PM10 (number of days)	Istat	NUTS 3
		20	Predicted daily limit value exceedances for O3 (number of days)	Istat	NUTS 3
		21	Anomalies from climatological values 1981–2010 (number of summer days)	Istat	NUTS 3
		22	Anomalies from climatological values 1981–2010 (number of tropical nights)	Istat	NUTS 3
		23	Incidence of urban green areas on urbanized area (m^2 per 100 m^2)	Istat	NUTS 3

on services and small businesses, with a strong emphasis on digitalization, which is essential to promoting economic growth in medium-sized cities (Audretsch and Thurik, 2001). On the other hand, cities in Cluster 2 show a variable level of investment in research and development. For instance, Bolzano is known for its advanced research hubs that can provide a competitive advantage (Cooke and Leydesdorff, 2006), while other cities such as Potenza and L′Aquila may have more limited investments. In general, there is a commitment to R&D to promote economic growth, but with uneven results (Capello et al., 2011). Cities in this cluster should benefit from specialized research hubs that exploit regional specificities, such as technological agriculture and sustainable tourism. Supporting the digitalization of small and medium-sized enterprises and improving access to the internet and digital technologies are key steps to stimulate economic growth and increase competitiveness.

Cluster 3 is the most numerous, including 9 cities (Fig. 2c). They register the lowest average values for many of the indicators considered. This result indicates the need for these cities to make significant improvement in industry, innovation and infrastructure, especially in terms of manufacturing and digitalization. Cluster 3 comprises predominantly southern Italian cities. Indeed, there is evidence that the digital transformation of manufacturing firms in southern Italy is still in

Table 3
Descriptive statistical measures of selected indicators.

Target	Variables	Min.	Max.	Mean	Std. Dev.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Value-added of manufacturing industry (euro per capita)	502.65	7207.65	3334.88	2076.24
	Value-added of manufacturing industry to total economy (%)	3.60	25.40	13.75	6.96
	Employment in manufacturing industry to total economy (%)	5.1	24.1	14.12	6.08
	Research intensity (%)	0.58	2.33	1.27	0.5
	Researchers in full-time equivalent (per 10,000 inhabitants)	9.5	46.3	24.43	10.6
	Knowledge workers (per 100 employed)	13.5	23.2	17.11	1.99
	Firms with product and/or process innovative activities per 100 firms (%)	34.1	59	47.68	6.6
	Productive specialization in high-tech sectors (%)	2.84	11.05	6.34	2.15
	Fixed network coverage of ultra-fast internet access (%)	22.20	81	60.79	15.62
	Firms with at least 10 employees in web sales to end customers (%)	6.2	24.8	14.18	4.3
	Firms with at least 10 employees in web sales to firms and public institutions (%)	4.3	16.6	10.15	3.57
11 SUSTAINABLE CITIES AND COMMUNITIES	People living in housing with structural or moisture problems (%)	8.3	26.4	16.73	4.6
	People living in overcrowded housing (%)	14.5	38.5	24.73	6.26
	People living in housing with noise from neighbors or street (%)	3.2	28.6	11.48	6.38
	Illegal building rate (per 100 constructions)	3.3	54.1	19.6	18.75
	Households reporting difficulties with public transport connections (%)	13.5	52.7	29.61	7.79
	Students who habitually travel to the place of study only by public means (%)	17.7	43.6	27.08	5.7
	Employed people who habitually travel to the workplace only by private means (%)	53.8	53.8	75.66	7.19
	Seat-km offered by the local public transportation system (per inhabitant)	315	16,827	4589.38	3712.73
	Regular users of public transportation (%)	6.5	22.6	11.63	4.36
	Waterproofing and land use (m^2 per inhabitant)	244	592	418.95	104.2
	Population at risk of flooding (%)	0.3	51.1	9.95	14.32
	Population at risk of landslides (%)	0	5.5	1.72	1.97
	Landfilling of municipal waste (%)	0	90.4	27.21	21.47
	Municipal waste generated (kg per inhabitant)	408	605	504.67	56.00
	Air pollution (%)	6.1	100	69.15	26.42
	Annual average concentration of PM10 (micrograms per m^3)	16	37	24.24	6
	Annual average concentration of PM2.5 (micrograms per m^3)	9	24	14.95	4.81
	Annual average concentration of NO2 (micrograms per m^3)	6	51	30.86	13.54
	Predicted daily limit value exceedances for PM10 (number of days)	4	75	23.48	21.18
	Predicted daily limit value exceedances for O3 (number of days)	0	72	22.76	18.99
	Anomalies from climatological values 1981–2010 (number of summer days)	0	29	13.24	9.03
	Anomalies from climatological values 1981–2010 (number of tropical nights)	0	37	17.19	9.78
	Incidence of urban green areas on urbanized area (m^2 per 100 m^2)	4	16.9	9.28	3.82

its early stages and many firms have yet to develop the necessary capabilities to fully embrace technological innovation (Abid et al., 2022). Despite the difficulties, Cluster 3 cities have great potential for development, with opportunities for expansion and modernization of infrastructure and industries, also supported by national and European funds. The development of training initiatives to enhance digital and technological skills is essential to stimulate innovation and improve local employability. Significant interventions are required to improve their performance and create an enabling environment for sustainable development, approaching the levels of cities in Clusters 1 and 2.

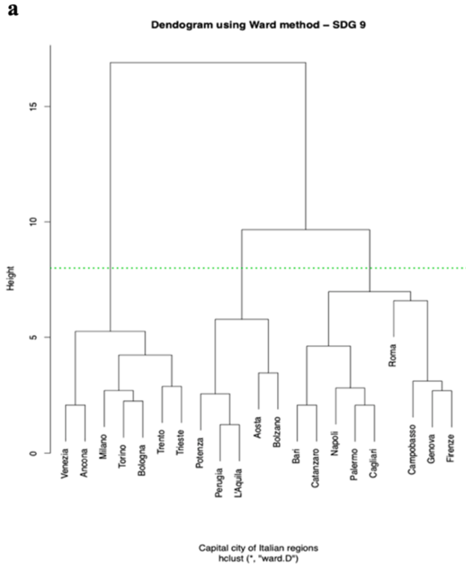
4.2. Clustering based on SDG 11

The second clustering of Italian regional capital cities is based on 23 indicators of SDG 11 (Sustainable Cities and Communities). This analysis provides valuable insights into each urban group's specific needs and priorities on their path to sustainability. The indicators cover various aspects of urban sustainability, including housing conditions, urban transportation, waste management, land consumption, air pollution and environmental risks. The analysis identifies three distinct clusters: (1) Potenza, Campobasso, Catanzaro, Bari, Palermo, Ancona, Cagliari, Trieste, Perugia and L'Aquila; (2) Aosta, Trento, Bologna, Firenze, Bolzano, Genova and Roma; (3) Napoli, Torino, Milano and Venezia. Cluster 1 is the largest, demonstrating diversified urban sustainability performance. As shown in Table 5, cities in Cluster 1 have the lowest average percentage of people living with overcrowding and noise issues but the highest for people living in dwellings with structural or damp problems and illegal building. The difficulties related to urban mobility are due to poor public transportation offers, high connection difficulties and low attitudes of citizens to use public transport regularly. Although these cities produce, on average, smaller quantities of urban waste, they have the highest incidence of urban waste in landfills, indicating serious deficiencies in the waste collection and management system. Cluster 1 also has the highest average levels of land consumption and the lowest incidence of urban green areas, denoting heavy urbanization with possible negative impacts on biodiversity and quality of life. These factors could also cause the dangerous climatological anomalies recorded in these cities, especially onsummer days. The landslide risk is also considerable, compared to a lower flood risk level.

On the other hand, the environmental performance is better, revealing the lowest average levels of air pollution in these cities. It should be noted that Cluster 1 cities are located in different geographical areas of Italy between the south, the islands and the centre (with the exception of Trieste). Geographical diversity implies variousclimatic and environmental conditions that may influence sustainability priorities (Gao et al., 2021). These cities also vary in size and population, influencing their ability to implement sustainable policies (Vandecandelaere et al., 2021). For example, Bari and Palermo are large urban areas, while Potenza and Campobasso are smaller. Although considerable differences characterize them, they face common challenges. The need to improve housing conditions, public transport, waste management and sustainable land use represent key development goals for all cities in Cluster 1.

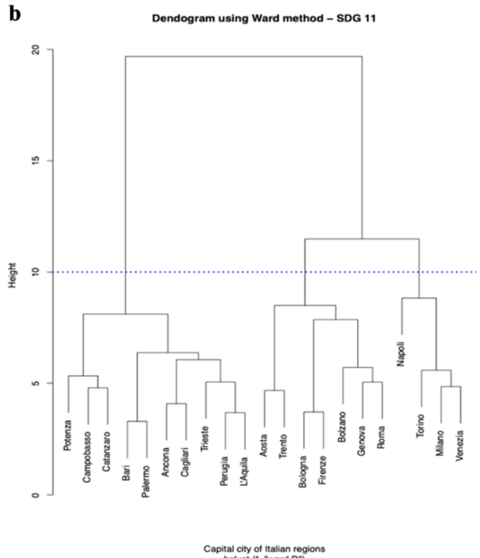
Cluster 2 includes various cities in northern and central Italy.

a



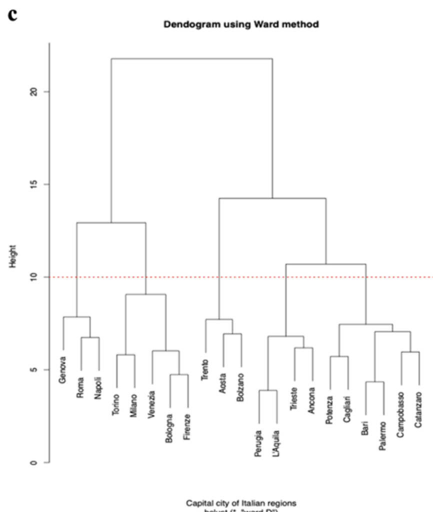
SDG 9		
Cluster 1	**Cluster 2**	**Cluster 3**
Venezia Ancona Milano Torino Bologna Trento Trieste	Potenza Perugia L'Aquila Aosta Bolzano	Bari Catanzaro Napoli Palermo Cagliari Roma Campobasso Genova Firenze

b



SDG 11		
Cluster 1	**Cluster 2**	**Cluster 3**
Potenza Campobasso Catanzaro Bari Palermo Ancona Cagliari Trieste Perugia L'Aquila	Aosta Trento Bologna Firenze Bolzano Genova Roma	Napoli Torino Milano Venezia

c



SDG 9 and SDG 11				
Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Genova Roma Napoli	Torino Milano Venezia Bologna Firenze	Trento Aosta Bolzano	Perugia L'Aquila Trieste Ancona	Potenza Cagliari Bari Palermo Campobasso Catanzaro

Fig. 2. Results of cluster analyses based on SDG 9, SDG 11, and both SDGs 9 and 11.

Table 4
Average variables per cluster based on SDG 9.

		Cluster 1		Cluster 2		Cluster 3	
		Average	Rank	Average	Rank	Average	Rank
SDG9	Value-added of manufacturing industry (euro per capita)	5630.21	1	3127.55	2	1664.81	3
	Value-added of manufacturing industry to total economy (%)	20.99	1	12.94	2	8.58	3
	Employment in manufacturing industry to total economy (%)	20.36	1	13.48	2	9.62	3
	Research intensity (%)	1.65	1	0.85	3	1.21	2
	Researchers in full-time equivalent (per 10,000 inhabitants)	32.4	1	18.48	3	21.54	2
	Knowledge workers (per 100 employed)	16.64	2	15.7	3	18.27	1
	Firms with product and/or process innovative activities per 100 firms (%)	53.87	1	45.8	2	43.91	3
	Productive specialization in high-tech sectors (%)	7.8	1	4.68	3	6.14	2
	Fixed network coverage of ultra-fast internet access (%)	67.09	2	38.9	3	68.06	1
	Firms with at least 10 employees in web sales to end customers (%)	11.94	3	17.6	1	14.02	2
	Firms with at least 10 employees in web sales to firms and public institutions (%)	10.01	2	13.4	1	8.46	3

Table 5
Average variables per cluster based on SDG 11.

		Cluster 1		Cluster 2		Cluster 3	
		Average	Rank	Average	Rank	Average	Rank
SDG11	People living in housing with structural or moisture problems (%)	19.21	3	13.71	1	15.8	2
	People living in overcrowded housing (%)	21.56	1	27.61	2	27.63	3
	People living in housing with noise from neighbors or street (%)	8.25	1	13.21	2	16.53	3
	Illegal building rate (per 100 constructions)	29.88	3	6.89	1	16.15	2
	Households reporting difficulties with public transport connections (%)	31.21	2	24.97	1	33.73	3
	Students who habitually travel to the place of study only by public means (%)	26.22	2	29.5	1	25	3
	Employed people who habitually travel to the workplace only by private means (%)	79.81	3	69.83	1	75.48	2
	Seat-km offered by the local public transportation system (per inhabitant)	3039	3	4569.29	2	8500.5	1
	Regular users of public transportation (%)	8.66	3	15.66	1	12	2
	Waterproofing and land use (m^2 per inhabitant)	473.4	3	382.14	2	347.25	1
	Population at risk of flooding (%)	3.02	1	20.9	3	8.1	2
	Population at risk of landslides (%)	2.08	3	1.5	2	1.23	1
	Landfilling of municipal waste (%)	38.59	3	21.96	2	7.98	1
	Municipal waste generated (kg per inhabitant)	488.7	1	518.86	2	519.75	3
	Air pollution (%)	52.98	1	79.77	2	91	3
	Annual average concentration of PM10 (micrograms per m^3)	21	1	23	2	34.5	3
	Annual average concentration of PM2.5 (micrograms per m^3)	12.8	1	13.43	2	23	3
	Annual average concentration of NO2 (micrograms per m^3)	19.4	1	40.29	2	43	3
	Predicted daily limit value exceedances for PM10 (number of days)	12.3	1	17.71	2	61.5	3
	Predicted daily limit value exceedances for O3 (number of days)	10.3	1	30.29	2	40.75	3
	Anomalies from climatological values 1981–2010 (number of summer days)	16.8	3	9.43	1	9.5	2
	Anomalies from climatological values 1981–2010 (number of tropical nights)	16.4	2	13.43	1	25.75	3
	Incidence of urban green areas on urbanized area (m^2 per 100 m^2)	7.76	3	8.84	2	13.83	1

According to Table 5, the housing condition indicators show good performance in this cluster, but there is potential room for improvement regarding overcrowding and noise. The transport system is well functioning. Indeed, although the offer could be improved by increasing seat-km per inhabitant, citizens do not report any particular difficulties with public transport connections. In addition, the results show that the cities in this cluster generally have a greater tendency to use public transportation regularly. This cluster presents intermediate values for municipal waste management, indicating possible margins to reduce the amount of waste produced per inhabitant and simultaneously reduce waste to landfills. With reference to environmental performance, intermediate values are also observed for air pollution, urban greening, land use and risk of landslides. Instead, the risk of flooding appears substantial and current in these cities. In general terms, the Cluster 2 cities are well developed, but each of them has peculiarities that influence their performance with respect to SDG 11 indicators. For example, while the Alpine cities (Trento, Aosta and Bolzano) benefit from better air quality due to altitude and climate (Bertoldi and Tesser, 2018), the other cities might be more developed from an infrastructural point of view. Moreover, especially Roma and Firenze are cities with a vast cultural heritage and a strong tourist attraction (Formica and Uysal, 1996). Therefore, to enhance the quality of life for their residents by leveraging their potential, cities should focus not only on improving conditions related to overcrowding and noise, optimizing waste management and implementing flood risk reduction strategies, but also on enhancing their significant cultural heritage. In short, these cities need targeted policies to improve their quality of life further and contribute to the achievement of SDG 11.

Cluster 3 includes cities that have serious housing problems, such as overcrowding and noise from neighbours or the street. In addition, the average values for structural housing problems and illegal buildings are suboptimal. Urban mobility also shows performances that need significant improvement. Although these cities have the largest public transportation offer per inhabitant, citizens report the highest levels of connection difficulties, often favoring the use of private vehicles for their journeys. This demonstrates that urban mobility has many inefficiencies. These cities are also the largest producers of municipal waste per inhabitant, highlighting the need for better management of the collection and disposal service. In addition, despite being the cities with, on average, the most urban green areas and the least land consumption, Cluster 3 has the worst environmental values. In particular, these cities demonstrate the lowest air quality, recording the highest annual average concentration levels of PM10, PM2.5 and NO2, as well as the highest number of days of predicted daily limit value exceedances for PM10 and O3. Accordingly, relevant are the anomalies from climatological values. In comparison, the risks of landslides and floods are more contained. It should be noted that Cluster 3 cities are some of the largest and most densely populated in Italy. For these cities, which are struggling with pollution, overcrowding and inefficient public transport, a cohesive policy approach is needed. Key strategies include improving public transit to reduce reliance on private vehicles, enhancing recycling and introducing waste-to-energy initiatives to manage municipal waste more effectively, and enforcing stricter emissions standards to improve air quality. Additionally, strengthening building regulations and offering renovation subsidies can address housing inadequacies. Implementing flood mitigation and landslide risk assessment measures will protect these densely populated areas, enhancing their sustainability and livability in a culturally and economically significant context. Indeed, the bigger the cities, the more pronounced the economic, social and environmental inequalities may be (Sarkar, 2019).

4.3. Combined clustering of SDGs 9 and 11

The final cluster analysis simultaneously considered smart cities-related SDGs 9 and 11, using 34 indicators. Five clusters emerge, which offers a targeted analysis of the specific challenges and

Table 6
Average variables per cluster based on both SDGs 9 and 11.

		Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5	
		Average	Rank	Average	Rank	Average	Rank	Average	Rank	Average	Rank
	Value-added of manufacturing industry (euro per capita)	1864.81	4	5888.53	1	3400.32	3	4375.53	2	1215.39	5
SDG9	Value-added of manufacturing industry to total economy (%)	8.83	3	21.72	1	8.43	4	19.53	2	7.5	5
	Employment in manufacturing industry to total economy (%)	8.8	5	20.6	1	11.27	3	19.45	2	9.25	4
	Research intensity (%)	1.63	2	1.77	1	1.02	4	1.22	3	0.83	5
	Researchers in full-time equivalent (per 10,000 inhabitants)	28.97	3	32.76	1	29.4	2	22.63	4	13.95	5
	Knowledge workers (per 100 employed)	20.27	1	16.96	3	14.57	5	16.73	4	17.2	2
	Firms with product and/or process innovative activities per 100 firms (%)	47.13	3	52.2	2	43.07	4	53.68	1	42.5	5
	Productive specialization in high-tech sectors (%)	7.53	2	7.73	1	5.93	3	5.56	4	5.33	5
	Fixed network coverage of ultra-fast internet access (%)	73.83	1	65.12	2	42.87	5	59.78	4	60.3	3
	Firms with at least 10 employees in web sales to end customers (%)	18.83	3	11.7	5	19.83	1	12.88	4	14.47	2
	Firms with at least 10 employees in web sales to firms and public institutions (%)	9.37	4	7.48	5	15.1	1	11.38	2	9.48	3
SDG 11	People living in housing with structural or moisture problems (%)	18.23	3	14.12	2	11.3	1	20.58	5	18.3	4
	People living in overcrowded housing (%)	25.77	4	34.13	5	22.9	2	24.82	3	20.67	1
	People living in housing with noise from neighbors or street (%)	18.37	5	14.56	4	6.9	1	10.23	3	9.15	2
	Illegal building rate (per 100 constructions)	25.6	4	5.04	2	3.6	1	13.78	3	40.62	5
	Households reporting difficulties with public transport connections (%)	36.27	5	26.5	2	22.8	1	28.33	3	33.13	4
	Students who habitually travel to the place of study only by public means (%)	28.75	2	26.04	3	34.43	1	24.33	5	24.53	4
	Employed people who habitually travel to the workplace only by private means (%)	68.53	2	77.22	3	66.33	1	82.4	5	78.08	4
	Seat-km offered by the local public transportation system (per inhabitant)	5174.67	2	8344.6	1	2913.33	4	3979.5	3	2412	5
	Regular users of public transportation (%)	16.3	2	11.58	3	16.93	1	9.3	4	8.23	5
	Waterproofing and land use (m^2 per inhabitant)	252.33	1	394	2	445.67	3	474.25	5	472.83	4
	Population at risk of flooding (%)	5.93	3	25.16	5	11.7	4	1.25	1	4.2	2
	Population at risk of landslides (%)	3.33	5	0.12	1	1.6	3	1.55	2	2.43	4
	Landfilling of municipal waste (%)	17.77	2	14.92	1	19.23	3	29.1	4	44.92	5
	Municipal waste generated (kg per inhabitant)	545	5	532.6	4	471	1	508.25	3	475.67	2
	Air pollution (%)	89.06	4	91.67	5	67.37	2	70.05	3	41.6	1
	Annual average concentration of PM10 (micrograms per m^3)	28.67	4	30.2	5	20.67	2	22	3	19.5	1
	Annual average concentration of PM2.5 (micrograms per m^3)	16	4	20	5	12.67	2	13.5	3	11.75	1
	Annual average concentration of NO2 (micrograms per m^3)	49	5	42.2	4	32	3	20.75	2	18.1	1
	Predicted daily limit value exceedances for PM10 (number of days)	28.67	4	48.4	5	14	3	12.5	2	12.17	1
	Predicted daily limit value exceedances for O3 (number of days)	22	3	46	5	26.33	4	13.5	2	8.17	1
	Anomalies from climatological values 1981–2010 (number of summer days)	11.33	2	7.2	1	11.33	2	14.83	4	21.25	5
	Anomalies from climatological values 1981–2010 (number of tropical nights)	28	5	20.4	4	3.67	2	13.5	2	18.33	3
	Incidence of urban green areas on urbanized area (m^2 per 100 m^2)	7.27	4	14.02	1	8.43	3	9.5	2	6.6	5

opportunities for each urban group towards higher levels of innovation and sustainability (Table 6). These clusters illustrate how Italian regional capital cities vary regarding their progress and characteristics related to sustainable development indicators for smart cities. The city groups are composed as follows: (1) Genova, Roma and Napoli; (2) Torino, Milano, Venezia, Bologna and Firenze; (3) Trento, Aosta, and Bolzano; (4) Perugia, L'Aquila, Trieste and Ancona; (5) Potenza, Cagliari, Bari, Palermo, Campobasso, Catanzaro.

Cities in Cluster 1 rank last in manufacturing employment and second to last in the value-added of the manufacturing industry, indicating that the manufacturing industry in this cluster is less developed compared to other clusters. However, they perform better in research intensity, knowledge sector employment, and high-tech industry specialization. Additionally, they have the largest fixed network coverage for ultra-fast internet access. Findings also show poor housing conditions, characterized by overcrowding, noise and squatting. Although these cities have a good seat-km ratio and the citizens are, for the most part, frequent public transportation users due to traffic conditions, they also report the greatest difficulties with urban mobility connections. Finally, Cluster 1 cities are, on average, the largest producers of urban waste and demonstrate worrying environmental conditions regarding the annual average concentration of pollutants in the air (especially NO_2 produced by emissions from motor vehicles, power plants and other industrial processes) and climatological anomalies. Therefore, these cities are characterized by significant urban complexities. High population density and urban traffic pose challenges with negative implications for public health and the urban environment (Wubneh, 2023). They also need infrastructure modernization to improve urban resilience, which is essential to address the shocks caused by climate change and unforeseen events (Bruzzone et al., 2021). Moreover, Genova and Napoli are also important port cities that need to manage port activities in a sustainable way (Musso et al., 2000). Improvement in public transportation, waste management and housing conditions is essential to increase the quality of life in these cities. In particular, it would be useful to encourage policies for the implementation of an integrated public transport plan to improve connectivity and reduce traffic congestion, using intelligent traffic management systems to streamline urban flows.

Cluster 2 includes mainly Northern cities. They rank first in almost all SDG 9 indicators, indicating the presence of a well-developed manufacturing industry, excellent research hubs and robust digital infrastructure. Instead, performance in SDG 11 is variable. Although the dwellings are noisy and overcrowded, they do not present significant structural or irregularity problems. In addition, these cities are characterized by the highest public transportation offers and households do not report great difficulties with urban mobility connections. Despite this, the use of public means instead of private ones should be further encouraged to reduce traffic and pollution problems. Indeed, the environmental conditions in this cluster are the worst, recording the lowest air quality, the highest annual average concentration levels of PM10, PM2.5, and NO2, as well as the highest number of days of predicted daily limit value exceedances for PM10 and O3. In contrast, good results are recorded for urban waste management, land use and the incidence of urban green areas. Thus, Cluster 2 cities are among the leading economic and industrial centres in Italy, with a strong orientation towards innovation. In particular, Torino, Milano and Bologna are leaders in innovation and industry and Milano is also an international financial and technological hub (Bertamino et al., 2017). Venezia and Firenze are focal points for world tourism (Formica and Uysal, 1996). In the face of very good infrastructural and industrial development, these cities show that housing conditions in general should be improved and huge efforts are needed to improve environmental conditions towards sustainability. To this end, green zones and low-emission areas need to be established, along with incentives for businesses and residences to reduce emissions and adopt sustainable practices.

Cluster 3 comprises mountain cities. These cities present medium levels of development in manufacturing industry and research. Although digital infrastructure is the weakest compared to the other clusters, companies seem to be committed to digitization and web services. Housing conditions are good, recording the lowest average percentage of people living in housing with structural or moisture problems, noise from neighbors or street and illegal building. Overcrowding levels are also quite low. Although public transportation provision in terms of seat-km could be increased, the results show a well-functioning and effective urban mobility service. In fact, cities in this cluster rank first in almost all indicators on urban transportation, showing the lowest level of connection difficulties declared by citizens and the greatest attitude towards regular use of public transport (including worker and student travel). Cluster 3 also has the lowest average amount of municipal waste generated per inhabitant, but with a large room for improvement in the collection and disposal service to reduce waste to landfills. With reference to environmental conditions, there are relatively low levels of pollution and climatic anomalies, although these could certainly be further improved. Indeed, these cities should commit to reducing pollutant exposures and effectively managing landslide and flood risks, while ensuring better management of urban land and green areas. It should be observed that Cluster 3 cities are small urban centres located in the Italian Alps. The results obtained related to SDG 9 could be explained by the profound changes that mountain regions have been experiencing over the years (Wilson et al., 2018). The difficult physical integration with lowland areas and the clash between the traditional economy and the market economy have produced growing weaknesses in these territories, including low competitiveness of small businesses, geographical isolation, depopulation, etc. Current conditions require the use of appropriate analytical and operational tools to manage change and address economic weaknesses by leveraging local know-how and sustainability (Zanon, 2007). Indeed, surrounded by natural landscapes, these cities are strongly committed to sustainable development. This is confirmed by the results that demonstrate successful public transport, waste management policies and good quality of living standards in general. Further efforts should be directed towards improving digital connectivity and services to support remote working and digital businesses, leveraging the smaller scale of the region to pilot innovative technological solutions.

Cluster 4 demonstrates good levels of manufacturing industry development and product/process innovation but seems weaker in research, specialization in high-tech sectors and digital infrastructure. Although dwellings are not very crowded and noisy, they are the ones with the most structural or moisture problems. While it does not show extremely negative values, public transportation should be improved, both in terms of seat-km and connection. In addition, citizens appear little inclined to use public transport regularly, especially workers and students who very often prefer to use private means. Despite a good incidence of urban green areas, Cluster 4 cities have the worst value concerning land use. They also perform poorly on urban waste management, with a high percentage of landfilling. On the other hand, environmental conditions appear much better in these cities, reporting generally low levels of pollution and little risk of landslides or flooding. Instead, worrying are the climatological anomalies in terms of number of summer days. These results can be attributed to an established industrial tradition in Cluster 4 cities, but more collaboration with research hubs and better digital connectivity could further increase their competitiveness (Mazzola and Bruni, 2000). Moreover, these findings point to the need for building maintenance and infrastructural improvements to ensure safe and healthy housing (Femenias, Geromel, 2020). In particular, L'Aquila faced significant challenges related to post-earthquake reconstruction, highlighting the importance of resilient infrastructure (Alexander, 2013). Encouraging the use of public transportation, urban planning practices, and waste management strategies are also essential to achieving sustainability goals in these cities.

Cluster 5 includes some southern cities. These cities are on average the worst in SDG 9, ranking last in many of the indicators analyzed. In particular, they obtain the lowest score for manufacturing industry value added, research intensity, number of researchers, firms with product and/or process innovative activities and specialization in high-tech sectors. The situation is not much better in reference to SDG 11. Although the dwellings are not overcrowded or too noisy, they have serious structural or moisture problems. These cities also have the highest percentage of illegal building. Building codes should be strictly enforced to address illegal construction and ensure safety and environmental compliance, as well as provide financial support for the renovation of older buildings to address structural problems.

Urban mobility appears to be severely compromised. In fact, Cluster 5 cities have the poorest local public transportation supply and the lowest propensity of citizens to use public means, who also report high connection difficulties. Politics could intervene by introducing financial incentives that could be useful to encourage public transit use, such as reduced fares and integrated ticket systems.

Land-use planning is inefficient, with the highest average levels of land consumption and the lowest average incidence of urban green areas. These cities also have the most municipal waste in landfills, reporting great difficulties in waste collection, storage and disposal systems. In contrast, environmental conditions are better, showing a more comforting performance than the other clusters. Despite Cluster 5 cities being the best in terms of air quality, numerous climatological anomalies continue to occur. It should be noted that these cities are all located in southern and island Italy, with different socioeconomic and environmental conditions. The results indicate that they have a number of significant challenges in relation to SDG 9, attributable to a variety of reasons (e.g., lack of investment, inadequate infrastructure, unfavorable socioeconomic environment, low presence of academic and research institutions, limited government and private support for research, lack of skills and resources for innovation, poor business environment) (Caragliu and Del Bo, 2012; Bonaccorsi, 2008). In addition, the findings highlight the urgent need for interventions in the building sector, urban mobility, waste management and land use planning, while continuing to enhance the existing good environmental conditions in these cities.

In summary, Clusters 2 and 4 tend to show better performance in industrial and infrastructure development but need to improve urban sustainability. In particular, Cluster 2 differs in its leadership in innovation, but demonstrates an urgent need to improve environmental conditions and air quality. Cluster 3 shows mixed results, with some specific excellences such as firm digitization, aptitude for public transportation use and low air pollution. On the other hand, it needs to address specific challenges related to the profound changes that mountain regions have been experiencing over the years. Clusters 1 and 5 suffer the most from an infrastructural point of view, showing poor housing conditions, complex urban mobility and inefficient waste management. It can be seen that Cluster 1, while demonstrating good research intensity and technological specialization, is characterized by a compromised urban environmental situation. Cluster 5, on the other hand, demonstrates significant problems in industry, research and innovation but boasts good environmental conditions, especially with reference to air pollution.

Table 7 shows the results of the one-way ANOVA, which was used to determine whether there are statistically significant differences between the clusters based on the 34 sustainable development indicators. The results show that the clusters of cities differ in most indicators. In particular, they are statistically significant for 26 of the 34 indicators. Thus, it can be concluded that the clusters differ strongly in achieving the sustainable development goals related to smart cities. Overall, indicators related to manufacturing, innovation, mobility, land management and environmental conditions are the ones that lead to the greatest differences in the clustering of Italian regional capital cities in relation to SDGs 9 and 11.

Table 7
Results of the ANOVA.

	Indicators	F-value	Significance
SDG 9	Value-added of manufacturing industry (euro per capita)	17.79	0.00***
	Value-added of manufacturing industry to total economy (%)	19.31	0.00***
	Employment in manufacturing industry to total economy (%)	13.98	0.00***
	Research intensity (%)	5.98	0.00***
	Researchers in full-time equivalent (per 10,000 inhabitants)	4.22	0.02**
	Knowledge workers (per 100 employed)	6.86	0.00***
	Firms with product and/or process innovative activities per 100 firms (%)	4.72	0.01***
	Productive specialization in high-tech sectors (%)	1.34	0.3
	Fixed network coverage of ultra-fast internet access (%)	1.9	0.16
	Firms with at least 10 employees in web sales to end customers (%)	2.29	0.11
	Firms with at least 10 employees in web sales to firms and public institutions (%)	3.53	0.03**
SDG11	People living in housing with structural or moisture problems (%)	3.69	0.03**
	People living in overcrowded housing (%)	3.77	0.02**
	People living in housing with noise from neighbors or street (%)	2.47	0.09*
	Illegal building rate (per 100 constructions)	8.19	0.00***
	Households reporting difficulties with public transport connections (%)	1.97	0.15
	Students who habitually travel to the place of study only by public means (%)	2.35	0.01***
	Employed people who habitually travel to the workplace only by private means (%)	6.58	0.00***
	Seat-km offered by the local public transportation system (per inhabitant)	2.65	0.07*
	Regular users of public transportation (%)	6.95	0.00***
	Waterproofing and land use (m^2 per inhabitant)	4.78	0.01***
	Population at risk of flooding (%)	2.87	0.06*
	Population at risk of landslides (%)	1.78	0.18
	Landfilling of municipal waste (%)	2.03	0.14
	Municipal waste generated (kg per inhabitant)	1.52	0.24
	Air pollution (%)	5.48	0.01***
	Annual average concentration of PM10 (micrograms per m^3)	4.86	0.01***
	Annual average concentration of PM2.5 (micrograms per m^3)	3.04	0.05**
	Annual average concentration of NO2 (micrograms per m^3)	16.74	0.00***
	Predicted daily limit value exceedances for PM10 (number of days)	4.41	0.01***
	Predicted daily limit value exceedances for O3 (number of days)	6.12	0.00***
	Anomalies from climatological values 1981–2010 (number of summer days)	1.65	0.21
	Anomalies from climatological values 1981–2010 (number of tropical nights)	4.51	0.01***
	Incidence of urban green areas on urbanized area (m^2 per 100 m^2)	5.55	0.00***

* Significant on 90 % level.
** Significant on 95 % level.
*** Significant on 99 % level.

5. Conclusions

Italian cities, like their global counterparts, face significant challenges due to urbanization's effects, which pose risks to public health, resource management, and inhabitants' quality of life (Grimm et al., 2008; Legambiente.. 2023). In response to these challenges, smart city initiatives have increasingly been implemented, aimed at meeting the immediate and future demands of the tight deadlines of the United Nations 2030 Agenda for Sustainable Development (Caragliu et al., 2011; Komninos et al., 2019).

Using cluster analysis, this study categorizes Italian regional capital cities based on their progress towards SDGs 9 (Industry, Innovation and Infrastructure) and 11 (Sustainable Cities and Communities), which serve as indicators of city smartness levels. It highlighted significant variance in results, with a marked disparity between northern and southern cities. Northern cities generally perform better in terms of industrial development, innovation and infrastructure thanks to stronger economic and infrastructural fabrics supporting smart technology integration. However, despite excellent infrastructural and industrial development, these cities demonstrate that housing conditions should be improved, and huge efforts are needed to improve environmental conditions towards sustainability. In contrast, Southern cities face substantial barriers, including inadequate infrastructure and limited access to technological innovations, which require targeted policy interventions to elevate their capacities to achieve the SDGs (Accetturo et al., 2022; Ziosi et al., 2023). This analysis highlights the dual nature of smart city initiatives: while they offer a promising path toward achieving the SDGs, they also risk exacerbating urban disparities, as seen in the stark contrasts between Northern and Southern Italian cities (Sharifi et al., 2024). Larger cities grappling with structural complexities may face additional challenges in implementing equitable smart solutions, potentially widening disparities and deepening inequalities among citizens (Middha and McShane, 2022; Mykhnenko, 2023). Furthermore, the technological advances that underpin smart city initiatives carry their risks, potentially introducing new social and economic divisions (Ziosi et al., 2023). Addressing these issues requires a strategic and coordinated approach at the national and local levels, which is often lacking, thus limiting the effectiveness of these initiatives. Smart cities need to be developed with a holistic strategy that considers risks and benefits, ensuring that government interventions and multi-level governance mechanisms prevent the rise of inequalities and maintain public trust. This implementation should be envisaged in a broader urban policy linked to the city scale (from metropolitan to medium-sized cities) and embedded in an integrated planning approach (Camerin et al., 2024).

The contribution of this study is twofold: first, it provides a nuanced understanding of how the SDGs of smart cities are being achieved in different Italian regions, identifying specific areas where progress is lagging and where targeted policy interventions are most needed. Second, it offers practical insights for policy makers by highlighting the need for policies that are inclusive and adaptable to local specificities. In this sense, land use policies play a strategic role: the implementation of urban plans that promote green infrastructure and sustainable land use can improve the quality of urban life and reduce regional inequalities. These policies should be integrated into a national strategy that recognizes and addresses local and regional specificities, supporting cities to become technologically smarter but also more sustainable.

In conclusion, although this study provides in-depth insights into the development of smart cities in Italy with respect to the Sustainable Development Goals, it has limitations that may affect the interpretation of the data. The analysis is based on data collected in a single year, which may not capture the long-term trends or seasonal variations that are crucial for a complete understanding of progress towards sustainability. Furthermore, the robust methodology employed may not fully account for all local dynamics or policy specificities that may influence the implementation and success of smart city initiatives. Further studies could extend the analysis to other SDGs related to smart cities, applying these insights to other geographical contexts.

CRediT authorship contribution statement

Francesco Natale: Supervision, Investigation, Conceptualization. **Roberta Barbieri:** Writing – original draft, Investigation, Data curation, Conceptualization, Writing – review & editing. **Benedetta Coluccia:** Writing – original draft, Software, Methodology, Conceptualization, Data curation, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

References

Abid, N., Marchesani, F., Ceci, F., Masciarelli, F., 2022. Assessing capabilities to embrace digital transformation: the case of southern Italy. In: Sustainable Digital Transformation: Paving the Way Towards Smart Organizations and Societies. Springer International Publishing, Cham, pp. 169–182.

Accetturo, A., Albanese, G., Ballatore, R.M., Ropele, T., Sestito, P., 2022. I divari territoriali in Italia tra crisi economiche, ripresa ed emergenza sanitaria. Banca d'Italia.

Ahad, M.A., Paiva, S., Tripathi, G., Feroz, N., 2020. Enabling technologies and sustainable smart cities. Sustain. Cities Soc. 61, 102301.

Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., Airaksinen, M., 2017. What are the differences between sustainable and smart cities? Cities 60, 234–245.

Akuraju, V., Pradhan, P., Haase, D., Kropp, J.P., Rybski, D., 2020. Relating SDG11 indicators and urban scaling – an exploratory study. Sustain. Cities Soc. 52, 101853.

Alagirisamy, B., Ramesh, P., 2022. Smart sustainable cities: principles and future trends. In: Sustainable cities and resilience: Select proceedings of VCDRR 2021. Springer, Singapore, pp. 301–316.

Alexander, D., 2013. An evaluation of medium-term recovery processes after the 6 April 2009 earthquake in L'Aquila, Central Italy. Environ. Hazards 12 (1), 60–73.

Allam, Z., 2018. On smart contracts and organisational performance: a review of smart contracts throught the blockchain technology. Rev. Econ. Bus. Stud. (22), 137–156.

Artusio, M., Axelrod, Z., Davis, B., Dong, D., Elzey, C., Joye, J., ... , Roman, A. S., 2017. Comparative gentrification policy: displacement, housing instability, and homelessness (Retrieved from Pennsylvania).

Audretsch, D.B., Thurik, A.R., 2001. What's new about the new economy? Sources of growth in the managed and entrepreneurial economies. Ind. Corp. Change 10 (1), 267–315.

Baena, B., Cobian, C., Larios, V.M., Orizaga, J.A., Maciel, R., Cisneros, M.P., Beltran-Ramirez, J.R., 2020, September. Adapting food supply chains in Smart Cities to address the impacts of COVID19 a case study from Guadalajara metropolitan area. In: *2020 IEEE international smart cities conference (ISC2)*. IEEE, pp. 1–8.

Battarra, R., Pinto, F., Tremiterra, M.R., 2018. Indicators and actions for the smart and sustainable city: a study on Italian metropolitan cities. Smart Plan.: Sustain. Mobil. Age Change 83–107.

Berisha, E., Caprioli, C., Cotella, G., 2022. Unpacking SDG target 11. a: what is it about and how to measure its progress? City Environ. Interact. 14, 100080.

Bertamino, F., Bronzini, R., De Maggio, M., Revelli, D., 2017. Regional policies for innovation: the case of technology districts in Italy. Reg. Stud. 51 (12), 1826–1839.

Bertoldi, P., Tesser, S., 2018. Air quality and climate in alpine urban areas: a review of trends and data. Environ. Sci. Policy 88, 18–29.

Bibri, S.E., 2020. Compact urbanism and the synergic potential of its integration with data-driven smart urbanism: an extensive interdisciplinary literature review. Land Use Policy 97, 104703.

Bibri, S.E., 2022. Eco-districts and data-driven smart eco-cities: emerging approaches to strategic planning by design and spatial scaling and evaluation by technology. Land Use Policy 113, 105830.

Bibri, S.E., Krogstie, J., 2017. Smart sustainable cities of the future: an extensive interdisciplinary literature review. Sustain. Cities Soc. 31, 183–212.

Blasi, S., Ganzaroli, A., De Noni, I., 2022. Smartening sustainable development in cities: strengthening the theoretical linkage between smart cities and SDGs. Sustain. Cities Soc. 80, 103793.

Bonaccorsi, A., 2008. Search regimes and the industrial dynamics of science. Minerva 46 (3), 285–315.

Bouzguenda, I., Alalouch, C., Fava, N., 2019. Towards smart sustainable cities: a review of the role digital citizen participation could play in advancing social sustainability. Sustain. Cities Soc. 50, 101627.

Bruzzone, M., Dameri, R.P., Demartini, P., 2021. Resilience reporting for sustainable development in cities. Sustainability 13 (14), 7824.

Camagni, R., Capello, R., 2004. The city network paradigm: theory and empirical evidence. Contrib. Econ. Anal. 266, 495–529.

Camerin, F., Álvarez-Del-Valle, L., Díez-Bermejo, A., Rodríguez-Suárez, I., 2024. Towards the Spanish local urban Agenda. The evolution of urban regeneration in Spain (2014–2022). TeMA-J. Land Use Mobil. Environ. 17 (1), 51–70.

Capello, R., Caragliu, A., Nijkamp, P., 2011. Territorial capital and regional growth: increasing returns in knowledge use. Tijdschr. voor Econ. en. Soc. Geogr. 102 (4), 385–405.

Caragliu, A., Del Bo, C., 2012. Smartness and European urban performance: assessing the local impacts of smart urban attributes. Innov.: Eur. J. Soc. Sci. Res. 25 (2), 97–113.

Caragliu, A., Del Bo, C.F., 2019. Smart innovative cities: the impact of Smart City policies on urban innovation. Technol. Forecast. Soc. Change 142, 373–383.

Caragliu, A., Del Bo, C., Nijkamp, P., 2011. Smart cities in Europe. J. Urban Technol. 18 (2), 65–82.

Charrad, M., Ghazzali, N., Boiteau, V., Niknafs, A., 2014. NbClust: an R package for determining the relevant number of clusters in a data set. J. Stat. Softw. 61, 1–36.

Ciacci, A., Ivaldi, E., González-Relaño, R., 2021. A partially non-compensatory method to measure the smart and sustainable level of Italian municipalities. Sustainability 13, 435.

Clement, J., Ruysschaert, B., Crutzen, N., 2023. Smart city strategies–a driver for the localization of the sustainable development goals? Ecol. Econ. 213, 107941.

Cooke, P., Leydesdorff, L., 2006. Regional development in the knowledge-based economy: the construction of advantage. J. Technol. Transf. 31, 5–15.

Crescenzi, R., Rodríguez-Pose, A., 2011. Innovation and Regional Growth in the European Union. Springer Science & Business Media.

De Las Heras, A., Luque-Sendra, A., Zamora-Polo, F., 2020. Machine learning technologies for sustainability in smart cities in the post-covid era. Sustainability 12 (22), 9320.

Elmore, K.L., Richman, M.B., 2001. Euclidean distance as a similarity metric for principal component analysis. Mon. Weather Rev. 129 (3), 540–549.

Femenias, P., Geromel, F., 2020. Adaptable housing? A quantitative study of contemporary apartment layouts that have been rearranged by end-users. J. Hous. Built Environ. 35, 481–505.

Formica, S., Uysal, M., 1996. The revitalization of Italy as a tourist destination. Tour. Manag. 17 (5), 323–331.

Fraley, C., Raftery, A.E., 1998. How many clusters? Which clustering method? Answers via model-based cluster analysis. Comput. J. 41 (8), 578–588.

Gao, S., Ren, Y., Masabni, J., Zou, F., Xiong, H., Zhu, J., 2021. Influence of geographical and climatic factors on Quercus variabilis blume fruit phenotypic diversity. Diversity 13 (7), 329.

Ghadami, N., Gheibi, M., Kian, Z., Faramarz, M.G., Naghedi, R., Eftekhari, M., Tian, G., 2021. Implementation of solar energy in smart cities using an integration of artificial neural network, photovoltaic system and classical Delphi methods. Sustain. Cities Soc. 74, 103149.

Gibson, D.V., Kozmetsky, G., Smilor, R.W., 1992. The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Networks. Rowman & Littlefield.

Giffinger, R., Gudrun, H., 2010. Smart cities ranking: an effective instrument for the positioning of the cities? ACE: Archit. City Environ. 4 (12), 7–26.

Giffinger, R., Fertner, C., Kramar, H., Meijers, E., 2007. City-ranking of European medium-sized cities. Cent. Reg. Sci. Vienna UT 9 (1), 1–12.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., Briggs, J.M., 2008. Global change and the ecology of cities. Science 319 (5864), 756–760.

Grossi, G., Trunova, O., 2021. Are UN SDGs useful for capturing multiple values of smart city? Cities 114, 103193.

Hair, J., Black, W.C., Babin, B.J., Anderson, R.E., Tatham, R.L., 2010. Multivariate data analysis, 6th ed. Prentice-Hall, Upper Saddle River NJ.

Hannan, M.A., Begum, R.A., Al-Shetwi, A.Q., Ker, P.J., Al Mamun, Hussain, A., Hussain, A., Mahlia, T.M.I., 2020. Waste collection route optimisation model for linking cost saving and emission reduction to achieve sustainable development goal. Sustainable Cities and Society 62, 102393.

Harrison, C., Donnelly, I.A., 2011. A theory of smart cities. In: Proceedings of the 55th Annual Meeting of the ISSS-2011. Hull, UK.

Hollands, R.G., 2020. Will the real smart city please stand up?: Intelligent, progressive or entrepreneurial?. In: The Routledge Companion to Smart Cities. Routledge, pp. 179–199.

Ismagilova, E., Hughes, L., Dwivedi, Y.K., Raman, K.R., 2019. Smart cities: Advances in research. An information systems perspective. Int. J. Inf. Manag. 47, 88–100.

Ismagilova, E., Hughes, L., Rana, N.P., Dwivedi, Y.K., 2022. Security, privacy and risks within smart cities: literature review and development of a smart city interaction framework. Inf. Syst. Front. 1–22.

Jain, A., Gue, I.H., Jain, P., 2023. Research trends, themes, and insights on artificial neural networks for smart cities towards SDG-11. J. Clean. Prod. 412, 137300.

Johnson, B., 2008. Cities, systems of innovation and economic development. Innovation 10 (2–3), 146–155.

Joia, L.A., Kuhl, A., 2019, April. Smart city for development: A conceptual model for developing countries. In: *International conference on social implications of computers in developing countries*. Springer International Publishing, Cham, pp. 203–214.

Koch, F., Krellenberg, K., 2018. How to contextualize SDG 11? Looking at indicators for sustainable urban development in Germany. ISPRS Int. J. Geo-Inf. 7 (12), 464.

Komninos, N., Kakderi, C., Panori, A., Tsarchopoulos, P., 2019. Smart city planning from an evolutionary perspective. J. Urban Technol. 26 (2), 3–20.

Konbr, U., Abdelaal, M., 2022. Utilizing smart systems to enhance the sustainability of Egyptian administrative buildings. Civ. Eng. Archit. 10 (7), 2779–2808.

Konbr, U., Elsayed, M., Elboshy, B., 2023. A framework for assessing the sustainability of Egyptian university campuses. Civ. Eng. Archit. 11 (4), 1909–1939.

Kourtit, K., Elmlund, P., Nijkamp, P., 2020. The urban data deluge: challenges for smart urban planning in the third data revolution. Int. J. Urban Sci. 24 (4), 445–461.

Kummitha, R.K.R., 2019. Smart cities and entrepreneurship: an agenda for future research. Technol. Forecast. Soc. Change 149, 119763.

Kummitha, R.K.R., Crutzen, N., 2017. How do we understand smart cities? An evolutionary perspective. Cities 67, 43–52.

Lazaroiu, C., Roscia, M., 2018. October). Smart resilient city and IoT towards sustainability of Africa. IEEE, pp. 1292–1298.

Le Blanc, D., 2015. Towards integration at last? The sustainable development goals as a network of targets. Sustain. Dev. 23 (3), 176–187.

Leavesley, A., Trundle, A., Oke, C., 2022. Cities and the SDGs: realities and possibilities of local engagement in global frameworks. Ambio 51 (6), 1416–1432.

Legambiente, 2023. Ecosistema urbano 2023. Rapporto sulle performance ambientali delle città. Roma.

Liaqat, R., Sajjad, I.A., Waseem, M., Alhelou, H.H., 2021. Appliance level energy characterization of residential electricity demand: prospects, challenges and recommendations. IEEE Access 9, 148676–148697.

Liu, Z., Yang, Z., Osmani, M., 2021. The relationship between sustainable built environment, art therapy and therapeutic design in promoting health and well-being. Int. J. Environ. Res. Public Health 18 (20), 10906.

Lovich, J.E., Ennen, J.R., 2021. Wildlife conservation and solar energy development in the desert southwest, United States. BioScience 61 (12), 982–992.

Masik, G., Sagan, I., Scott, J.W., 2021. Smart city strategies and new urban development policies in the Polish context. Cities 108, 102970.

Masuda, H., Kawakubo, S., Okitasari, M., Morita, K., 2022. Exploring the role of local governments as intermediaries to facilitate partnerships for the sustainable development goals. Sustain. Cities Soc. 82, 103883.

Mazzola, F., Bruni, S., 2000. The role of linkages in firm performance: evidence from southern Italy. J. Econ. Behav. Organ. 43 (2), 199–221.

McGranahan, G., Satterthwaite, D., 2014. Urbanization Concepts and Trends, 220. International Institute for Environment and Development.

Mhlanga, D., 2022. Human-centered artificial intelligence: the superlative approach to achieve sustainable development goals in the fourth industrial revolution. Sustainability 14 (13), 7804.

Middha, B., McShane, I., 2022. E-gentrification: digital community engagement, urban change and digital rights to the city. In: Citizen Participation in the Information Society: Comparing Participatory Channels in Urban Development. Springer International Publishing, Cham, pp. 141–165.

Mora, L., Bolici, R., Deakin, M., 2017. The first two decades of smart-city research: a bibliometric analysis. J. Urban Technol. 24 (1), 3–27.

Mora, H., Mendoza-Tello, J.C., Varela-Gazmán, E.G., Szymanski, J., 2021. Blockchain technologies to address smart city and society challenges. Comput. Hum. Behav. 122, 106854.

Moura, T., Gomes, A., 2017, June. Blockchain voting and its effects on election transparency and voter confidence. In Proceedings of the 18th annual international conference on digital government research, pp. 574-575.

Murtagh, F., Legendre, P., 2014. Ward's hierarchical agglomerative clustering method: which algorithms implement Ward's criterion? J. Classif. 31, 274–295.

Musso, E., Benacchio, M., Ferrari, C., 2000. Ports and employment in port cities. Int. J. Marit. Econ. 2, 283–311.

Mykhnenko, V., 2023. Smart shrinkage solutions? The future of present-day urban regeneration on the inner peripheries of Europe. Appl. Geogr. 157, 103018.

Nam, T., Pardo, T.A., 2011. Conceptualizing smart city with dimensions of technology, people, and institutions. In: Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times, pp. 282–91.

Nelson, A., Toth, G., Linders, C., Nguyen, C., Rhee, S., 2019. Replication of smart-city Internet of Things assets in a municipal deployment. IEEE Internet Things J. 6 (4), 6715–6724.

Nikitin, K., Lantsev, N., Nugaev, A., Yakovleva, A., 2016. Data-driven cities: from concept to applied solutions. Pricewater-houseCoopers (PwC).

OECD, 2022. OECD Regions and Cities at a Glance 2022. OECD Publishing.

Parmentola, A., Petrillo, A., Tutore, I., De Felice, F., 2022. Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs). Bus. Strategy Environ. 31 (1), 194–217.

Parra-Domínguez, J., Gil-Egido, A., Rodríguez-González, S., 2022. SDGs as one of the drivers of smart city development: the indicator selection process. Smart Cities 5 (3), 1025–1038.

Ryan, M., Antoniou, J., Brooks, L., Jiya, T., Macnish, K., Stahl, B., 2020. The ethical balance of using smart information systems for promoting the United Nations' Sustainable Development Goals. Sustainability 12 (12), 4826.

Sachs, J.D., 2012. From millennium development goals to sustainable development goals. Lancet 379 (9832), 2206–2211.

Sagaris, L., Tiznado-Aitken, I., 2020. Sustainable transport and gender equity: insights from Santiago, Chile. In: Urban mobility and social equity in Latin America: evidence, concepts, methods, Vol. 12. Emerald Publishing Limited, pp. 103–134.

Sarkar, S., 2019. Urban scaling and the geographic concentration of inequalities by city size. Environ. Plan. B: Urban Anal. City Sci. 46 (9), 1627–1644.

Satterthwaite, D., 2014. Guiding the goals: empowering local actors. SAIS Rev. Int. Aff. 34 (2), 51–61.

Savchenko, A.B., Borodina, T.L., 2020. Green and digital economy for sustainable development of urban areas, 10. Regional Research of Russia, pp. 583–592.

Schraven, D., Joss, S., De Jong, M., 2021. Past, present, future: engagement with sustainable urban development through 35 city labels in the scientific literature 1990–2019. J. Clean. Prod. 292, 125924.

Scott, A.J., Knott, M., 1974. A cluster analysis method for grouping means in the analysis of variance. Biometrics 507–512.

Sethi, P., Sarangi, S.R., 2017. Internet of Things: architectures, protocols, and applications. J. Electical Comput. Eng. (1), 9324035.

Sharifi, A., 2019. A critical review of selected smart city assessment tools and indicator sets. J. Clean. Prod. 233, 1269–1283.

Sharifi, A., 2020. A typology of smart city assessment tools and indicator sets. Sustain. Cities Soc. 53, 101936.

Sharifi, A., Allam, Z., 2021. On the taxonomy of smart city indicators and their alignment with sustainability and resilience. Enrivonmental Plan. B: Urban Anal. City Sci. 49 (5), 1536–1555.
Sharifi, A., Allam, Z., Bibri, S.E., Khavarian-Garmsir, A.R., 2024. Smart cities and sustainable development goals (SDGs): a systematic literature review of co-benefits and trade-offs. Cities 146, 104659.
Siragusa, A., Vizcaino, M.P., Proietti, P., Lavalle, C., 2020. European Handbook for SDG Voluntary Local Reviews, EUR 30067 EN. Publications Office of the European Union, Luxembourg, 2 ISBN 978-92-76-15402-0.
Tian, A., Zünd, D., Bettencourt, L.M., 2021. Etimating rooftop solar potential in urban environents: a generalized approach and assessment of the Galápagos Islands. Front. Sustain. Cities 3, 632109.
Truby, J., 2020. Governing artificial intelligence to benefit the UN sustainable development goals. Sustain. Dev. 28 (4), 946–959.
Tura, N., Ojanen, V., 2022. Sustainability-oriented innovations in smart cities: a systematic review and emerging themes. Cities 126, 103716.
UN-Habitat, 2016. World Cities Report 2016: Urbanization and Development – Emerging Futures. United Nations Human Settlements Programme.
UN-SDSN, 2015. Indicators and a monitoring framework for Sustainable Development Goals – launching a data revolution for the SDGs. Available at: 〈https://sdgs.un.org/sites/default/files/publications/2013150612-FINAL-SDSN-Indicator-Report1.pdf〉.
UN-SDSN, 2019. Transformations to achieve the Sustainable Development Goals – includes the SDG Index and Dashboards Available at: 〈https://s3.amazonaws.com/sustainabledevelopment.report/2019/2019_sustainable_development_report.pdf〉.
Vandecandelaere, E., Samper, L.F., Rey, A., Daza, A., Mejía, P., Tartanac, F., Vittori, M., 2021. The geographical indication pathway to sustainability: a framework to assess and monitor the contributions of geographical indications to sustainability through a participatory process. Sustainability 13 (14), 7535.
Varghese, C., Pathak, D., Varde, A.S., 2021. January). SeVa: a food donation app for smart living. IEEE, pp. 0408–0413.
Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., Fuso Nerini, F., 2020. The role of artificial intelligence in achieving the Sustainable Development Goals. Nat. Commun. 11 (1), 1–10.
Visvizi, A., del Hoyo, R.P., 2021a. Sustainable development goals (SDGs) in the smart city: a tool or an approach? (An introduction). In: Smart Cities and the Un SDGs. Elsevier, pp. 1–11.
Visvizi, A., del Hoyo, R. P., 2021b. In: *Smart cities and the UN SDGs*. Elsevier.
Ward Jr, J.H., 1963. Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. 58 (301), 236–244.
WCED, 1987. Report of the World Commission on Environment and Development: Our Common Future. Available at: 〈https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf〉.
Wilson, G.A., Schermer, M., Stotten, R., 2018. The resilience and vulnerability of remote mountain communities: the case of Vent, Austrian Alps. Land Use Policy 71, 372–383.
Wubneh, M., 2023. Planning, urban resilience, and sustainability. In: Planning for Cities in Crisis: Lessons from Gondar, Ethiopia. Springer International Publishing, Cham, pp. 3–29.
Yigitcanlar, T., Kamruzzaman, M., 2018. Does smart city policy lead to sustainability of cities? Land Use Policy 73, 49–58.
Yigitcanlar, T., Kamruzzaman, M., Foth, M., Sabatini-Marques, J., Da Costa, E., Ioppolo, G., 2019. Can cities become smart without being sustainable? A systematic review of the literature. Sustain. Cities Soc. 45, 348–365.
Zimmermann, K., Fedeli, V., 2021. A Modern Guide to National Urban Policies in Europe. Edward Elgar Publishing, Cheltenham, UK, Northampton, MA.
Ziosi, M., Hewitt, B., Juneja, P., Taddeo, M., Floridi, L., 2023. Smart cities: reviewing the debate about their ethical implications. In: The 2022 Yearbook of the Digital Governance Research Group. Springer Nature Switzerland, Cham, pp. 11–38.