SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2024
ORGANIZATION AND MANAGEMENT SERIES NO. 193

DATA-DRIVEN APPROACH IN SUSTAINABLE CITY MANAGEMENT

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Purpose: This study aims to examine the relationships between the use of data-driven solutions in key areas of sustainable city management (urban planning, mobility and transportation management, and environment protection) and city's position in the global smart cities ranking (the IESE Cities in Motion Index).
Design/methodology/approach: A case study methodology is adopted to examine and compare the possibilities of implementing data-driven approaches in sustainable city management, in order to gain a better understanding of this new urban phenomenon. Data and information about data-driven smart city initiatives have been collected from secondary sources. The presented case studies were explored through desk research using online resources, such as the web pages of smart city initiatives. Smart Cities were selected based on their rankings in the IESE Cities in Motion Index 2022. In addition, multiple regressions were used to identify the relationship between the independent variables (environment protection, mobility and transportation management, urban planning) and dependent variable-value of city's ranking in the IESE Cities in Motion Index.
Findings: The results illustrate that the majority of cities use data-driven solutions in all categories to improve city management, efficiency and achieve sustainability goals. All research hypotheses have been accepted, therefore data-driven solutions implemented in all key areas of sustainable city management (urban planning, mobility and transportation management, and environment protection) positively influence performance of achieving sustainability goals.
Research limitations/implications: The selection of a limited number of case studies is a limitation of this research. It is therefore important to explore the potential of data-driven smart city solutions in urban development and city management in more detail by considering more cases. Future research should explore the impacts of other variables related to sustainability, which can determinate performance of sustainable city management. A future study should try to validate the result by using a wider sample.
Originality/value: The conducted research combines quantitative and quantitative analysis in order to identify the determinants of effective achievement of sustainable development goals in city management. This study provides a form of grounding for further discussion to debate over big data computing on forms of the operational functioning, planning, design, development, and governance of smart sustainable cities in the future.
Keywords: sustainability, data-driven cities, data driven technologies, sustainable city management, sustainable smart cities.
Category of the paper: research paper.

1. Introduction

As predicated by the United Nations, more than half of the world's population live currently in urban areas, and around 70% will be concentrated in the cities by the year 2050. This anticipated urbanization of the world pose significant challenges related to environmental, economic, and social sustainability (Bibri, Krogstie, Kärrholm, 2020). Nevertheless, modern cities have a defining role in sustainable development and a central position in applying advanced technologies to support progress towards sustainability in the face of urbanization. Sustainable smart cities, the leading paradigm of urbanism today, are seen as the most important arena for sustainability transitions in an increasingly urbanized world (Su, Fan, 2023).

Contemporary cities have a key role in strategic sustainable development. This is clearly reflected in the Sustainable Development Goal 11 (SGD 11) of the United Nations' 2030 Agenda, which entails making cities more sustainable, resilient, inclusive, and safe (United Nations, 2015). In this regard, the UN's 2030 Agenda regards information and communication technology (ICT) as a means to promote socio-economic development and protect the environment, increase resource efficiency, achieve human progress and knowledge in societies, upgrade legacy infrastructure, and retrofit industries based on sustainable design principles (United Nations, 2015). In particular, there is an urgent need for developing and applying data-driven innovative solutions and sophisticated approaches to overcome the challenges of sustainability and urbanization (Khan, 2022).

In recent years, there has been a marked intensification of datafication. This is manifested in a radical expansion in the volume, range, variety, and granularity of the data being generated about urban environments and citizens.

As a consequence of datafication, a new era is presently unfolding wherein smart sustainable urbanism is increasingly becoming data-driven. At the heart of such urbanism is a computational understanding of city systems and processes that reduces urban life to logical and algorithmic rules and procedures, while also harnessing urban big data to provide a more holistic and integrated view of the city. This is increasingly being directed towards improving, advancing, and maintaining the contribution of both sustainable cities and smart cities to the goals of sustainable development (Zhang et al., 2022).

Modern cities have a defining role in sustainable development and a central position in applying advanced technologies to support progress towards sustainability in the face of urbanization.

Among the numerous concepts addressing urban development, the smart city concept offers the most comprehensive and multidimensional approach to sustainable city management. A smart city is one of the latest concepts in the development of modern cities. The dynamic development of innovative technologies provides new opportunities in managing urban development. Nowadays, the transformations of metropolises into smart cities is a crucial factor in improving the living conditions of the inhabitants. The goal of the smart city concept is modern urban management using technical tools (Wang, Zhou , 2022).

A lot of publications try to conceptualize and define the elements and application domains that constitute smart cities, mostly through case studies or comparative case study analysis. However, it is argued that there is a need for research on effective strategies for cities to become smarter.

The literature does not pay much attention to the organizational and managerial solutions during the transition from a classic city to a sustainable smart city, therefore the paper try to explore the potential of the data-driven applications in sustainable city management and urban development.

The motivation for this study is to identify the core dimensions of the sustainable data-driven city management and their influence on a city's position in the global smart cities ranking.

This study aims to examine the relationships between the use of data-driven solutions in key areas of sustainable city management (urban planning, mobility and transportation management, and environment protection) and city's position in the global smart cities ranking (the IESE Cities in Motion Index).

The paper is structured as follows: After this introduction the next section presents the literature review with discussions of the research model and hypotheses development. Then research methodology is presented in detail. Finally, research findings are outlined and discussed, implications are explored, limitation and futures research are described.

2. Literature review and hypotheses development

The sustainable smart city concept has become extremely popular in scientific literature and contemporary management of urban development. Cities and urban areas comprise about half of the total world's population (Bakıcı, Almirall, Wareham, 2013). The transformations of contemporary metropolises into smart cities is a crucial factor in improving the quality of life and sustainable development. The urban population growth has been adversely affecting quantity and quality of services provided to the citizens. Smart cities aim at providing effective solutions. Various smart city initiatives by both government and private sector organizations have resulted in deployment of Information and Communication Technologies (ICT) to find sustainable efficient and effective solutions to the growing list of challenges facing cities (Caragliu, Del Bo, Nijkamp, 2011). Knowing the identified challenges and the expected increase in the number of urban residents around the world, there is an increasing need for new and innovative ways to manage the complexity of urban life.

The importance of smart cities derives from the future projections of a growing urban population (Pašalić, Ćukušić, Jadrić, 2021). According to the general accepted definition, smart cities should contribute to increased quality of life and better governance (Dameri, 2013).

A smart city approach was recognized as contributing to boosting the sustainability of cities environmentally and economically, and improving the delivery of services to their inhabitants In addition, smart city development is perceived as a process of building the capacity of the city's economic, social, and institutional infrastructures to enhance and conserve quality of life, socio- economic development, and natural resources (Shahat, Hyun, Yeom, 2021).

Smart cities initiatives try to improve urban performance by using data, information and information technologies to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration among different economic actors, and to encourage innovative business models in both the private and public sectors (Marsal-Llacuna, Colomer-Llinàs, Meléndez-Frigola, 2015).

The sustainable smart city concept assumes that a city should be a creative, sustainable area that improves the quality of life, creates a friendlier environment and the prospects of economic development are stronger (Lee et al., 2014). Although there is no formal and widely accepted definition of a smart city, the ultimate goal is a better use of public resources, the improvement of the quality of services offered to citizens, while reducing operational costs of public administration (Zanella et al., 2014).

Peng, Nunes and Zheng (2017) defined a smart city as a city using a set of advanced technologies, such as wireless sensors, smart meters, intelligent vehicles, smartphones, mobile networks or data storage technologies. Other researchers (Guo et al., 2017; Herath, Mittal, 2022) claimed that a smart city is urban development based on the integration of many information and communication technology solutions to manage the city's resources. These definitions of a smart city emphasize the role of technology. However, a city can hardly become smart because of technology alone (Nam, Pardo, 2014). Other authors (Ortiz-Fournier et al., 2010) included citizens of smart cities in the definition of a smart city. The authors described a smart city in the context of its intelligent inhabitants, the quality of social interactions, and integration with public life. In the current perception of the smart city concept, there is a return to the needs and preferences of the inhabitants, which are the focus. Huang, Zhang and Wang (2017) also emphasised aspects of city management. They defined a city as smart if it was managed in intelligently, efficiently and sustainably. According to the assumptions of Allam and Dhunny (2019), a smart city is a city where public issues are solved using ICT, with the involvement of various types of stakeholders working in partnership with the city authorities. Tura and Ojanen, (2022) stress the importance of the integration of a city's various systems in creating a smart city.

The concept of Smart City seeks to make maximum use of modern technologies, mainly information technologies with the aim of achieving sustainable development goals. Social and environmental sustainability is a major strategic component of smart cities (Lee et al., 2023).

The importance of the environment protection in modern cities can be justified by the fact that the latter occupy 2% of the world's surface, have more than 50% of the world population, consume 70% of global energy supply, and generate 75% of GHG emissions (Guo, Wang, Dong, 2022). It is clear that we can have a major positive impact on the environment by making cities more sustainable and greener thanks to the evolving digitally and computationally augmented urban environments that could change our relationship with nature by, for example, consuming less natural resources and protecting the environment (Razmjoo et al., 2022).

Improving environmental sustainability through anti-pollution plans, support for green buildings and alternative energies, efficient water and waste management, and policies that help counteract the effects of climate change are essential to ensure the sustainability of cities over time (Su, Hu, Yu, 2023). Therefore, the first hypothesis of this study is thus as follows:

H1: Data-driven solutions in area of environmental protection positively influence performance of city management.

Transport and traffic management is generally the most popular area of using data-driven solutions within smart cities and sustainable smart cities (Savastano et al., 2023).

Cities of the future face two major challenges in the area of mobility and transportation: facilitating travel (often over large territories) and access to public services. Mobility and transportation (in terms of road and route infrastructure, the vehicle fleet, public transit and air transport) affect the quality of life of a city's inhabitants and can be key to its sustainability over time (da Silva, Santos, Setti, 2022).

AI is now playing a key role in improving the development of cities. Among other benefits, it is helping local authorities collect information about city inhabitants, thereby facilitating efficient management of resources. For example, a city that uses AI to reduce traffic problems is in a good position to solve its mobility problems. AI tools make it possible to collect traffic information in real time, predict traffic jams, improve mobility, and decongest key areas (Singh et al., 2022; Cruz, Paulino, 2022). Therefore, the second hypothesis of this study is thus as follows:

H2: Data-driven solutions in area of mobility and transportation management positively influence performance of city management.

Urban planning in cities has always been considered a driver of sustainable development. Urban planning, in turn, is closely related to sustainability. To improve the liveability of any territory, it is important to take into account local master plans and the design of green areas and spaces for public use while also focusing on smart growth. New urban planning methods should focus on creating compact, well-connected cities with accessible public services (Son et al., 2023). Urban infrastructure management constitutes one of the key applications of the IoT and big data analytics in terms of monitoring, control, automation, and optimization. This involves the operations of roads, railway tracks, bridges, and tunnels (Sanchez et al., 2023). This relates to the events and changes associated with the structural conditions of urban infrastructure that can increase risk and cost and compromise safety and service quality.

In this regard, the IoT devices can be used to improve incident management, enhance emergency response coordination and service quality, and reduce operational costs in all infrastructure related areas (Wang and Yin, 2023). Therefore, the third hypothesis of this study is thus as follows:

H3: Data-driven solutions in area of urban planning positively influence performance of city management.

Cities have the potential to generate vast amounts of data. Data usage, data management, and operation are key processes associated with data. Finding the opportunities to innovatively use this data helps governments to forecast, respond to, and plan for the future. Additionally, access to real-time data and information can improve city management, resulting in environmental, social, and economic benefits (Xia et al., 2022).

The wave of the datafication of cities, as mainly enabled by the IoT technology, is giving rise to a new phenomenon–known as the data–driven city. Already, the number of objects connected to the Internet (e.g., computers, smartphones, WiFi-enabled sensors, mobile devices, household appliances, and many more) has exceeded the number of human beings in the world (Olaniyi, Okunleye, Olabanji, 2023). The continuously increasing number of networked devices deployed across urban environments will in turn result in the explosive growth in the amount of the data generated. Therefore, big data technologies have become essential to the functioning of smart cities, particularly in their endeavour to improve their sustainability performance.

3. Materials and methods

The presented study was conducted in September and October 2023. Its purpose was to determine the relationship between datafication and a city's position in the global smart cities ranking (IESE Cities in Motion Index 2022).

The IESE Cities in Motion Index is a study published annually by the business school of the University of Navarra (IESE) that aims to evaluate the development of the world's cities. It assesses several socioeconomic aspects of development, including human capital, social cohesion (which includes employment, female participation in the work force, etc.), governance, sustainable development, mobility and transportation, urban planning, international outreach, and technology. IESE Cities in Motion Index offers a platform for a comprehensive initial diagnosis of the cities and, through comparative analysis, aims to serve as the first point of reference. The index compares 183 cities globally, looking at 114 criteria grouped into nine dimensions: human capital, social cohesion, economy, governance, environment, mobility and transportation, urban planning, international profile, and technology (Lai, Cole, 2023).

A case study methodology is adopted to examine and compare the possibilities of implementing data-driven approaches in sustainable city management, in order to gain a better understanding of this new urban phenomenon. Data and information about data-driven smart city initiatives have been collected from secondary sources. The presented case studies were explored through desk research using online resources, such as the web pages of smart city initiatives. Smart Cities were selected based on their rankings in the IESE Cities in Motion Index 2022.

In addition, multiple regressions were used to identify the relationship between the independent variables (environment protection, mobility and transportation management, urban planning) and dependent variable - value of city's ranking in the IESE Cities in Motion Index.

The table below (Table 1) presents the values of dimensions related to sustainability according to IESE Cities in Motion Index 2022.

Table 1.
The results from the IESE Cities in Motion Index 2022- the value of dependent and independent variables

City	Value of IESE Cities in Motion Index (dependent variable)	Value of independent variables according to IESE Cities in Motion Index indicators		
		Environment protection	Mobility and transportation management	Urban planning
Amsterdam- Netherlands	73.03	14	20	13
Barcelona - Spain	65.13	67	10	15
Beijing - China	63.20	173	2	32
Berlin - Germany	76.42	21	7	5
Bilbao - Spain	47.31	57	73	88
Brussels - Belgium	58.67	60	15	61
Chicago - USA	70.22	118	56	25
Copenhagen - Denmark	71.47	3	31	23
London - United Kingdom	100.00	17	4	1
Moscow - Russia	49.75	146	60	91
New York - USA	98.25	105	1	2
Paris - France	84.99	49	3	34
Quebec City - Canada	55.90	36	110	45
San- Francisco - USA	69.03	132	14	121
Santiago - Chile	56.23	75	47	55
São Paulo - Brazil	36.43	126	177	133
Seattle - USA	67.69	102	81	17
Seoul - South Korea	71.22	76	41	22
Singapore - Singapore	73.33	78	58	26
Stockholm - Sweden	66.84	6	19	80
Sydney - Australia	63.41	52	128	119
Tokyo - Japan	80.30	25	62	112
Toronto - Canada	67.88	65	113	3
Turin - Italy	49.78	85	38	78
Vancouver - Canada	60.48	35	94	12
Vienna - Austria	69.20	11	8	11
Washington - USA	74.27	131	37	9

Source: The IESE Cities in Motion Index 2022.

The IESE Index were selected on the basis of temporal and thematic relevance, as it reflects the current results in several indicators, which are the priority indicators of city's technological development and sustainability.

4. Results and discussion

This section presents data obtained through secondary analysis of best practice strategies from selected sustainable smart cities. A case-study approach was used to explore the role of data-driven solutions in sustainable city management

A sample of 27 case studies that use data-driven applications deployed in real-world settings were identified from secondary sources and evaluated based on sustainable city indicators and related data-driven applications. All analyzed cities are included in the IESE Cities in Motion Index 2022 and they have been also included in the regression analysis. The results are presented in Table 2.

Table 2.
Data-driven smart city solutions related to sustainability – results of case study analysis

City	Examples of data-driven solutions related to sustainability
Amsterdam - Netherlands	smart lighting controls for energy efficiency and saving, traffic reduction
Barcelona - Spain	communication and green technologies, smart water efficiency, smart public transportation, smart noise control solutions
Beijing - China	intelligent urban infrastructure
Berlin - Germany	smart metering, smart transport systems,
Bilbao - Spain	smart parking systems
Brussels - Belgium	energy efficiency through smart sensors, smart mobility systems, real-time transportation information, waste management, environmental monitoring.
Chicago - USA	smart grid
Copenhagen - Denmark	smart energy incubators and energy labs, smart transport systems smart noise control solutions
London - United Kingdom	green and smart technology application in transport and parking, pollution and congestion control, smart noise control solutions
Moscow - Russia	intelligent transport systems
New York - USA	online transportation control system
Paris - France	smart applications for lighting, road circulation, waste management, and environment monitoring, online transportation control system
Quebec City - Canada	infrastructure management system, online transportation control system
San- Francisco - USA	interconnected smart streetlights system

Cont. table 2.

Santiago - Chile	smart meters, smart mobility and traffic management,
São Paulo - Brazil	innovation in mobility
Seattle - USA	smart grid
Seoul - South Korea	smart energy efficiency, intelligent transport systems
Singapore - Singapore	smart energy efficiency, intelligent transportation system, environment monitoring system,
Stockholm - Sweden	fiber optic communication network smart noise control solutions
Sydney - Australia	smart lighting system that utilizes sensors, smart waste management system that uses data analytics, intelligent transportation system
Tokyo - Japan	smart energy efficiency, digital connectedness, smart waste management, fully automated buildings, smart street lighting and meters, intelligent urban infrastructure, smart mobility management
Toronto - Canada	integrated mobility, minimized energy consumption, waste and emissions wit data-driven solutions, garbage robots that transport waste in underground tunnels
Turin - Italy	smart meters
Vancouver - Canada	integrated mobility, energy saving options with data-driven solutions
Vienna - Austria	energy efficiency via smart sensors, smart mobility systems
Washington - USA	smart grid

Source: own study.

The results illustrate that the majority of smart cities use data-driven applications in all categories to improve city management, efficiency and achieve sustainability goals. The most common data-driven solutions identified include: transport and traffic, mobility, energy, power grid, environment, buildings, infrastructures and urban planning.

Smart mobility and transport concepts have been implemented in cities for some time and cover a wide range of criteria. A variety of data-driven traffic control systems have been implemented for the efficient performance of city services and include interactive notifications of parking availability and distribution, bike and car sharing, digital public transit payment, predictive maintenance of transportation infrastructure, real-time public transit information, and road navigation. These applications support agent-based simulations of transport systems and many encounters they can face so that complex systems that incorporate and respond to a multitude of entities, including the shortest routes, minimal waiting times, and diversions aware from traffic congestions, can provide the optimum traffic solutions.

Cities apply the data-driven technology for transport and traffic management. The application of such technology pertains to the management of transport services on the basis of the received data, as well as the automatic control of traffic signals on the basis of the data collected on traffic congestion using sensors embedded in the traffic lights.

Advanced technologies allow, thanks to the city's Wi-Fi-network, real-time tracking of the quality of the air in terms of the presence of various substances as well as applying preventive measures in a timely manner, in addition to monitoring the condition and composition of green space in urban areas. The real-time data collected about the air quality in the city are analyzed to determine the impact of the solutions that have been adopted in terms of improving environmental conditions, as well as to identify the areas where further actions are needed.

Implemented in cities low-cost sensors detect noise levels and pollution, aiding in identifying and countering violations of the city policy in this regard. The smart noise control solutions used in cities enable to optimize and centralize the collection, integration, processing, analysis, and dissemination of information by the noise sensors of different suppliers and sound level meters distributed throughout the city.

The use of the data-driven approach to urban planning, the analysis of the data related to the population, allows to consider the emerging demand for shaping various venues. In other words, the application of the data-driven technology in planning is associated with the planning of districts, streets, as well as urban infrastructure based on the collection of information on the movement of residents and their activities.

In addition, multiple regressions were used to identify the relationship between the independent variables (environment protection, mobility and transportation management, urban planning) and dependent variable - value of the IESE Cities in Motion Index 2022. The results of regression analysis have been shown in the table 3.

Table 3.
The results of regression analysis

Independent variables	**Standardized coefficients**	**t**	**Significance level**
	Beta		
Environment protection	0,391	4,371	0,000
Mobility and transportation management	0,374	3,832	0,000
Urban planning	0,398	4,693	0,000
Dependent variable: value of the IESE Cities in Motion Index. R^2 = 0,813, F = 28,956, significance level = 0,01.			

Source: own study.

The result shows that R-square was 0,813, which demonstrates that independent variables explain 81,3% of the variance in value of the IESE Cities in Motion Index. The linear relationship between independent variables (environment protection, mobility and transport management and urban planning) with value of the IESE Cities in Motion Index is significant with an F-value of 28,956 at the 0,01 significance level. Therefore, the model fits this study.

The significance level of environment protection with value of IESE Cities in Motion Index was 0,000, which is less than 0,05. Therefore Hypothesis 1 is accepted. Environment protection was the second highest coefficient (beta = 0,391), hence, higher level of data-driven solutions related to sustainability positively influences the value of the IESE Cities in Motion Index and a city's position in the global smart cities ranking.

The significance level of mobility and transportation management with in value of IESE Cities in Motion Index was 0,000, hence, Hypothesis 2 is accepted. The beta value for this variable was 0,374. Therefore, higher level of level of data-driven solutions related to mobility and transportation management has a significant positive effect on the value of the IESE Cities in Motion Index and a city's position in the global smart cities ranking.

The significance level of urban planning with the value of the IESE Cities in Motion Index was 0,000, therefore, Hypothesis 3 is accepted. The test also showed that urban planning had the highest coefficient (beta = 0,398) compared to others independent variablen. In other words, sustainable urban planning has the highest positive impact on city's position in IESE Cities in Motion Index.

This study shows that the cities have a high level of the development of the applied data-driven technologies, but they slightly differ in the level of the implementation of such technologies in different city systems and domains with respect to sustainability areas. They also moderately differ in the degree of their readiness as to the availability and development level of the competences and infrastructure needed to generate, transmit, process, and analyze large masses of data to extract useful knowledge for enhanced decision making and deep insights pertaining to urban operational functioning, management, and planning in relation to sustainability.

5. Conclusion

The potential of big data technology lies in enabling smart sustainable cities and leverage their informational landscape in effectively understanding, monitoring, probing, and planning their systems and environments in ways that enable them to reach the optimal level of sustainability.

Big data technologies are certainly enriching experiences of how cities function. And they are offering many new opportunities for more informed decision-making with respect to knowledge of how to monitor, understand and plan cities development more effectively. Many smart cities across the globe have embarked on exploring and unlocking the potential of big data technologies for addressing and overcoming many of the pressing issues and complex challenges related to sustainability and urbanization.

Concerning the value of this work, the outcome will help strategic city stakeholders understand what they can do and invest in more to advance smart sustainable urbanism on the basis of data-driven solutions and approaches, and also give policymakers an opportunity to identify areas for further improvement while leveraging areas of strength with regard to the future form of such urbanism. In addition, it will enable researchers and scholars to direct their future work to the emerging paradigm of data-driven smart sustainable urbanism, and practitioners and experts to identify common problems and potential ways to solve them, all as part of future research and practical endeavours, respectively.

Lastly, this paper provides a form of grounding for further discussion to debate over big data computing on forms of the operational functioning, planning, design, development, and governance of smart sustainable cities in the future. Also, it presents a sort of basis for stimulating more in-depth research in the form of both qualitative analyses and quantitative investigations focused on the relevance of big data technology and its advancements as to accelerating sustainable development.

The conducted research combines quantitative and quantitative analysis in order to identify the determinants of effective achievement of sustainable development goals in city management.

However, it is clear that the selection of a limited number of case studies is a limitation of this research. It is therefore important to explore the potential of data-driven smart city solutions in urban development and city management in more detail by considering more cases. Nonetheless, the analysis of best practices in selected case studies the smart city model for the city can provide useful insights and practical guidelines.

Future research should explore the impacts of other variables related to sustainability, which can determinate performance of sustainable city management. A future study should try to validate the result by using a wider sample.

Moreover, as this study has demonstrated that applied technological solutions already exist across the selected cities, it would be extremely useful to conduct a wider and more varied comparison involving more other cities with a view to revealing more general trends in data-driven sustainable city management.

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