BIG DATA MANAGEMENT OF SMART SUSTAINABLE CITIES: NETWORKED DIGITAL TECHNOLOGIES AND AUTOMATED ALGORITHMIC DECISION-MAKING PROCESSES

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Abstract
Empirical evidence on big data management of smart sustainable cities has been scarcely documented in the literature. Using and replicating data from Black & Veatch, ESI ThoughtLab, KPMG, McKinsey, Osborne Clarke, Phillips, and SmartCitiesWorld, we performed analyses and made estimates regarding how smart city technologies can make daily commutes faster and less frustrating (%), key actions to accelerate education development in smart cities (%), potential improvement through current generation of smart city applications, from time of implementation (%), the components of a smart city which are most likely to improve citizen well-being (%), actions needed to improve transportation and mobility in smart cities (%), the components of a smart city which are most likely to reduce energy consumption (%), key actions to improve smart cities' management of energy and resources (%), and the components of a smart city which are most likely to increase economic growth (%). Data were analyzed using structural equation modeling.
Keywords: big data management, smart sustainable city, networked digital technology.

1. INTRODUCTION

The digital-driven smart city will take over the archetypal networked urban space of the industrial epoch. (Picon, 2015). Smart cities invest in cutting-edge technologies to network the urban places and improve its performance (Androniceanu & Popescu, 2017; Hollowell et al., 2019; Kubík & Zůvala, 2018; Nica et al., 2019a, b; Šandal & Křupka, 2018), develop the big data sphere as a mechanism of growth and property advancement, and stimulate first-rate professionals by offering them a high standard of living. (McLaren and Agyeman, 2015) Innovations related to smart city technologies are shifting in the direction of automation by the inclusion of expert systems, big data analytics, and artificial intelligence to monitor and enable switching commands supervised by sophisticated software. The architecture of smart cities will be environmentally sustainable, developed on more coherent kinds of use, networking, and renewable energy. (Pelton and Singh, 2019) Big data analytics and context-aware computing are decisive for smart sustainable cities. (Bibri, 2018)

2. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Having attained materialization, the smart city will be typified by enhanced supervision of essential core features, e.g. the operation of its configuration, and by a rise in the innovative capacity of its citizens. (Picon,

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2015) Big data and artificially intelligent systems are harnessed in the configuration and performance of smart cities (Pelton and Singh, 2019; Dobrin et al., 2015) The increase of sharing enabled by smart technologies and Internet-based operations massively amplifies the extent of apprehensions regarding breaches of privacy. (McLaren and Agyeman, 2015) The social and political requirements of the energy disruption, bounded on the promising prospects of an interconnected but dispersed realm within the Internet of Things configuration (Clarke & Sulsky, 2019; Kearney et al., 2019; Lyakina et al., 2019; Pera, 2014a, b; Tuyls & Pera, 2019), are intensifying the shift of urban clusters toward eventually being smart cities. (Gassmann et al., 2019) Smart sustainable cities are intrinsically elaborate and robustly changing by the agency of the cutting-edge technologies (Eysenck et al., 2019; Kliestik et al., 2018; Kohlhoffer-Mizser, 2019; Pera, 2015; Valaskova et al., 2018) harnessed to supervise, grasp, and inspect the core physical architecture, spatial and temporal scales, public-sector services and operations associated with administration, coordination, and advancement to enhance their significant addition to sustainability and consequently maximize their capacity to address citification via algorithmically groundbreaking decision-support systems. A prominent determinant for urban design and organization adopting the stream of smartness (Fielden et al., 2019; Kovacova & Kliestik, 2017; Meyers et al., 2019; Pera, 2019; Westbrook et al., 2019; Zhulega et al., 2019) resides in the tremendous prospects brought about by the harnessing of the groundbreaking ways out and intricate procedures progressively facilitated by big data and context-aware technologies – fashioned and employed for reinforcing the objectives of sustainable development. (Bibri, 2018)

3. METHODOLOGY AND EMPIRICAL ANALYSIS

Using and replicating data from Black & Veatch, ESI ThoughtLab, KPMG, McKinsey, Osborne Clarke, Phillips, and SmartCitiesWorld, we performed analyses and made estimates regarding how smart city technologies can make daily commutes faster and less frustrating (%), key actions to accelerate education development in smart cities (%), potential improvement through current generation of smart city applications, from time of implementation (%), the components of a smart city which are most likely to improve citizen well-being (%), actions needed to improve transportation and mobility in smart cities (%), the components of a smart city which are most likely to reduce energy consumption (%), key actions to improve smart cities' management of energy and resources (%), and the components of a smart city which are most likely to increase economic growth (%). Data were analyzed using structural equation modeling.

4. RESULTS AND DISCUSSION

The smart city is driven heterogeneously, with the assistance of information and communications technology. (Picon, 2015) Smart cities are typically steadily directed by value creation capacities, chiefly facilitated by innovative technologies. (Gassmann et al., 2019) Context sensing, handling data, and Internet of Things communication frameworks are being largely utilized in urban service settings (Graessley et al., 2019; Kovacova et al., 2019a, b; Milward et al., 2019; Popescu et al., 2018a, b), and the massive volumes of information produced by various sensors will be harnessed to more thoroughly deal with the demands of distinct classes of customers, separate and collective participants active in the urban environment. (Bibri, 2018) (Tables 1–4)

TABLE 1 - PLEASE RANK THE FOLLOWING CITY AGENCIES IN TERMS OF WHICH BENEFIT MOST FROM A "SMART CITY" INITIATIVE (%)

	First	Second	Third	Fourth	Fifth	Sixth
Transportation (streets, parking, mass transit, etc.)	26	24	17	15	14	4
Electric utility	26	22	17	15	11	9
Public works (maintenance)	17	21	16	18	18	10
Water/Sewer utility	17	21	17	18	15	12
Law enforcement	14	13	19	16	18	20
City administration	15	11	15	12	19	28

Sources: Black & Veatch; our survey among 4,200 individuals conducted October 2019.

TABLE 2 - HOW SMART CITY TECHNOLOGIES CAN MAKE DAILY COMMUTES FASTER AND LESS FRUSTRATING (%)

Commute time ***% decrease in average commute time by application***	
Real-time public transit information	4.3
Predictive maintenance of transit system	2.2
Intelligent traffic signals	4.5
Smart parking	2.3
Real-time road navigation	2.1
Demand-based microtransit	2.6
Bike sharing	0.5
Congestion pricing	1.6
Digital payment in public transit	2.3
Smart parcel lockers	0.3
Parcel load pooling	0.3
Integrated multimodal information	0.2
Car sharing	-0.3
E-hailing (private and pooled)	-1.3
Time spent interacting with government and healthcare system % reduction in time spent by application	
Digital administrative citizen services	44
Telemedicine	12
Online care search and scheduling	4
Integrated patient flow management systems	6

Sources: McKinsey; our survey among 4,200 individuals conducted October 2019.

TABLE 3 - HOW RELIABLE ARE THE FOLLOWING AREAS OF INFRASTRUCTURE IN YOUR CITY? (%)

Airports and control towers	59
Mobile connectivity	65
Electricity supply (lack of interruptions and fluctuations)	67
Postal offices and mail delivery	55
Water supply (lack of interruptions and flow fluctuations)	64
Roads, tunnels, and bridges	59
Fixed broadband (lack of interruptions and speed fluctuations)	57
Sewer system, and waste management facilities	58

Sources: ESI ThoughtLab; our survey among 4,200 individuals conducted October 2019.

TABLE 4 - KEY ACTIONS TO ACCELERATE EDUCATION DEVELOPMENT IN SMART CITIES (%)

Encouraging continuous education/lifelong learning	64
Developing education programs that encourage creativity and risk-taking	66
More funding for education and research in science, technology, engineering, and mathematics (STEM) disciplines	70
More smart city and innovation technology training for professionals at different levels	72
Developing education programs/courses/training in artificial intelligence, data analytics and machine learning	70
Providing mandatory coding/programming training starting from primary school	67
Attracting top scholars and professors to do research/teach in your city	60

Sources: KPMG; our survey among 4,200 individuals conducted October 2019.

The intelligence of smart cities is intensely spatial, being spread out, acting in accordance with the landscape of the networks of roads and buildings and with the activity of vehicles and of citizens, and generating a topographical depiction of urban activity instantaneously. (Picon, 2015) Groundbreaking technologies, process automation, and artificial intelligence-controlled management systems in smart cities are being progressively adopted by the urban planners. (Pelton and Singh, 2019) Smart city approaches assimilate the perpetuation of preliminary urban planning operations. (Gassmann et al., 2019) Big data analytics can deploy a set of advanced and unique software applications and database systems operated by computers having high processing capacity that can turn a vast quantity of urban information into convenient knowledge for rational decision making and improved experiences. The huge expansion of data sensing, information handling, pervasive computing, and Internet of Things networking technologies throughout urban systems (Gray-Hawkins et al., 2019; Kowo & Akinbola, 2019; Nica, 2018; Popescu & Ciurlău, 2019; Zhuravleva et al., 2019a, b) configures smart sustainable cities that have to capitalize on their analytical setting in manners that assist them in integrating and perpetuating their significant addition to environmental sustainability (Bibri, 2018) (Tables 5–8).

TABLE 5 - THE IMPORTANCE OF DIFFERENT TRANSPORT MODES (%)

Public transportation	89
Personal vehicles	74
Taxis	62
Biking	59
Walking	62
Car-sharing apps	58
Ride-sharing apps	46
Autonomous vehicles	28

Sources: ESI ThoughtLab; our survey among 4,200 individuals conducted October 2019.

TABLE 6 - TO WHAT EXTENT DO YOU AGREE WITH THE FOLLOWING STATEMENTS ABOUT SMART CITIES IN FRANCE? (%)

	Strongly agree	**Agree**	**Disagree**	**Strongly disagree**
The expansion of renewable energy on the grid is the main driver for much-needed investment in energy storage and smart grids	28	55	15	2
There is insufficient regulation/ government incentive to encourage investment in smart grid technologies	18	63	17	2
Energy consumers generally understand and are convinced by the benefits of installing smart meters	10	53	33	4
The roll-out of intelligent transport systems (for example, the connected car, autonomous/driverless cars, next-generation smart ticketing, improved urban mobility schemes) is a priority for France's transport authorities	8	44	44	4
France will achieve its target to install 35 million smart meters (95% penetration rate) by 2020	11	41	42	6

Sources: Osborne Clarke; our survey among 4,200 individuals conducted October 2019.

TABLE 7 - POTENTIAL IMPROVEMENT THROUGH CURRENT GENERATION OF SMART CITY APPLICATIONS, FROM TIME OF IMPLEMENTATION (%, YES)

Safety	Fatalities averted (homicides, road deaths, fire deaths)	14
Safety	Crime incidents prevented (assaults, robberies, burglaries, auto thefts)	38
Safety	Emergency response time reduced	39
Time and convenience	Commute time saved	28
Time and convenience	Time saved in interactions with government and the healthcare system	64
Health	Disease burden reduced (disability-adjusted life years averted)	26
Environmental quality	GHG emissions averted	24
Environmental Quality	Unrecycled waste reduced	28
Environmental quality	Water consumption reduced	36
Social connectedness and civic participation	Share of residents who feel connected to the local community	21
Social connectedness and civic participation	Share of residents who feel connected to the local government	32
Jobs	Formal employment increased	3
Cost of living	Average annual expenditures reduced	3

Sources: McKinsey; our survey among 4,200 individuals conducted October 2019.

TABLE 8 - THE COMPONENTS OF A SMART CITY WHICH ARE MOST LIKELY TO IMPROVE CITIZEN WELL-BEING (%)

Intelligent transport systems	52
Building efficiency/control systems	30
Smart grids (including smart meters)	13
Energy storage	5

Sources: Osborne Clarke; our survey among 4,200 individuals conducted October 2019.

Smart city planning involves the participation of the individuals in adequate and responsive manners to make their urban places a more desirable area to live. (Pelton and Singh, 2019) The advancement of data platforms constitutes a key component of the smart city service initiatives. (Gassmann et al., 2019) The exploration of resultant massive datasets is pivotal in deriving computationally intricate operations, activities, processes, and environmental patterns to determine and obtain predictive experiences into cutting-edge configurations, networks, systems, and mechanisms concerning how smart sustainable cities may boost their significant addition to sustainability via improving urban intelligence capacities for regulation. The increasing depth, magnitude, and intricacy of urban networks demand advancing and designing such interconnections and improving their digital capabilities in manner that further and bolster the role of smart sustainable cities in attaining the objectives of sustainable development. (Bibri, 2018) (Tables 9–12)

TABLE 9 - ACTIONS NEEDED TO IMPROVE TRANSPORTATION AND MOBILITY IN SMART CITIES (%)

Improved walkability and safety for pedestrians	78
Constructing more rail and underground transport links	74
Building infrastructure for electric vehicles and providing incentives to electric vehicle owners	81
Tighter regulation of private cars and vehicles	74
Constructing more bicycle lanes/bicycle paths	77
Installing cameras/sensors to record traffic violations	76
Smart tolls and smart parking	72
Studying feasibility of driverless transportation models	71

Sources: KPMG; our survey among 4,200 individuals conducted October 2019.

TABLE 10 - WHAT IS THE MOST EFFECTIVE FINANCING SOURCE AVAILABLE FOR INVESTMENT IN THE ROLL-OUT OF HUNDREDS OF THOUSANDS OF SMALL SMART CITY COMPONENTS (SMART METERS, BUILDING CONTROL SYSTEMS, VEHICLE TO INFRASTRUCTURE SENSORS)? (%)

Public-sector financing (e.g. grants, tax breaks, European investment, national investment)	74
Private-sector resources (e.g. cash, corporate bonds, banking)	53
EU structural funds	54
Public/Private JVs	49
Project finance	41
Municipal bonds	12
Project bonds	10

Sources: Osborne Clarke; our survey among 4,200 individuals conducted October 2019.

TABLE 11 - THE COMPONENTS OF A SMART CITY WHICH ARE MOST LIKELY TO REDUCE ENERGY CONSUMPTION (%)

Intelligent transport systems	9
Building efficiency/control systems	54
Smart grids (including smart meters)	27
Energy storage	10

Sources: Osborne Clarke; our survey among 4,200 individuals conducted October 2019.

TABLE 12 - KEY ACTIONS TO IMPROVE SMART CITIES' MANAGEMENT OF ENERGY AND RESOURCES (%)

Making renewable energy sources a greater percentage of overall power supplied to the city	74
Incentives for citizens to use water-saving and energy-saving home appliances	72
Promote construction of energy-efficient buildings	67
Utilize technology to better manage the city's power grid	74
Incentives for citizens to install solar power devices in their homes	77
Adjust the charging schemes for electricity, water and gas use to discourage waste	78
Utilize technology to better manage the city's water resources	76

Sources: KPMG; our survey among 4,200 individuals conducted October 2019.

Suitable and accurately designed employment of digital technology and software is essential to setting up smart cities. (Pelton and Singh, 2019) Individuals, organizations, and entrepreneurs need free, straightforward, and equitable access to urban information. (Gassmann et al., 2019) Big data analytics uses elaborate and customized approaches and algorithms that can carry out intricate computational handling of data for prompt and precise decision making. Urban big data require swift processing capacity and top-level performance to accomplish operable outcomes required to improve decision making (Hecht et al., 2019; Kral et al., 2019; Nica, 2019; Popescu Ljungholm, 2019) connected with the urban practical, serviceable, and developing strategies of smart sustainable cities. The performance of context awareness technology driven for improved decision making and service provision operations are vital to smart sustainable cities as regards urban analytics related to environmental sustainability (Bibri, 2018) (Tables 13–16).

TABLE 13 - EXPECTED BENEFITS FROM A SMART CITY (%)

Less traffic congestion	79
Economic growth	74
Improved delivery and management of public services	73
Less wasted resources	67
Cleaner air and water	64
Improved public safety	56
More job opportunities	54
Reduced carbon footprint	65
Reduced noise pollution	64

Sources: KPMG; our survey among 4,200 individuals conducted October 2019.

TABLE 14 - TO WHAT EXTENT DO YOU AGREE WITH THE FOLLOWING STATEMENTS ABOUT SMART CITIES IN BELGIUM? (%)

	Strongly agree	Agree	Disagree	Strongly disagree
The expansion of renewable energy on the grid is the main driver for much-needed investment in energy storage and smart grids.	28	67	3	2
There is insufficient regulation/ government incentive to encourage investment in smart grid technologies.	30	54	14	2
The €400 million smart and sustainable finance scheme launched by the EIB and Belfius Bank will be vital in creating smart cities in Belgium.	29	53	15	3
The roll-out of intelligent transport systems (for example, the connected car, autonomous/driverless cars, next-generation smart ticketing, improved urban mobility schemes) is a priority for Belgium's transport authorities.	36	24	29	11
Energy consumers generally understand and are convinced by the benefits of installing smart meters.	19	31	38	12

Sources: Osborne Clarke; our survey among 4,200 individuals conducted October 2019.

TABLE 15 - WHAT DO YOU THINK ARE THE KEY COMPONENTS OF A SMART CITY? (%)

Inner-operability of systems	74
Sustainability – energy and water efficiency	65
City-wide connectivity	62
Security	59
Effective transportation	54
Development of private/public partnerships	43

Sources: SmartCitiesWorld; Phillips; our survey among 4,200 individuals conducted October 2019.

TABLE 16 - THE COMPONENTS OF A SMART CITY WHICH ARE MOST LIKELY TO INCREASE ECONOMIC GROWTH (%)

Intelligent transport systems	38
Building efficiency/control systems	31
Smart grids (including smart meters)	21
Energy storage	10

Sources: Osborne Clarke; our survey among 4,200 individuals conducted October 2019.

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5. CONCLUSIONS AND IMPLICATIONS

The smart city has specific features, being associated with the physical setting within which its citizens live. (Picon, 2015) Smart cities give attention to handling resources and infrastructures cautiously, adequately, and sustainably. Smart sustainable cities may assist in disconnecting urban welfare, health, and the standard of living of individuals from the energy use and environmental risks related to urban activities. (Bibri, 2018) Blockchain systems may be instrumental in offering secured databases and protected data distribution in the smart urban architecture. Groundbreaking capabilities related to smart data, causal patterns, and heuristic algorithms are operational in supplying instantaneous information to urban monitoring. (Pelton and Singh, 2019)

Note

The interviews were conducted online and data were weighted by five variables (age, race/ethnicity, gender, education, and geographic region) so that each country's sample composition reliably and accurately reflects the demographic profile of the adult population according to the country's most recent census data. The precision of the online polls was measured using a Bayesian credibility interval. An Internet-based survey software program was utilized for the delivery and collection of responses.

Author Contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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