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Exploring the potential impact of smart urban technologies on urban sustainability using structural topic modelling: Evidence from Belgium

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ABSTRACT

This study explores the potential impact of smart urban technologies used in smart city projects on three dimensions of urban sustainability (economic, environmental and social). Although the literature notes that smart urban technologies and their capabilities are potential saviours when it comes to urban and sustainability challenges in cities, there is a lack of studies exploring the impact of smart urban technologies on urban sustainability. Thus, we address this literature gap by conducting structural topic modelling on smart city projects retrieved from the *Smart Territory* call for projects. In these projects, city managers' report extensively on how smart urban technologies can support urban sustainability. Our results show nine groups of smart urban technologies that will support at least two urban sustainability dimensions. Smart mobility systems can support all three dimensions of urban sustainability. Technology benefits will be realised by smart urban technology capabilities and through the involvement of the city's community in the use of technology.

1. Introduction

Due to population growth, two-thirds of the world's population will be living in urban areas by 2030 (UNWTO, 2017, 2020). The consequent challenges regarding air pollution, congestion, waste management and human health (OECD, 2012), in short, the challenges of urban sustainability, will be a key goal for cities (Ahvenniemi et al., 2017).

Urban sustainability is a multidimensional concept that comprises three intertwined dimensions, i.e. economic, environmental and social; achieving sustainability in each of these is the objective of the concept (Ahvenniemi et al., 2017).

Some studies observe that urban sustainability can be achieved by adopting smart urban technologies (SUTs) (Esposito et al., 2021; Yadav et al., 2019). SUTs refer to advanced digital information and communication technologies that are designed for and usable in cities (Angelidou et al., 2018; Bibri & Krogstie, 2017). Such technologies are also the core component of smart city (SC) projects, which adopt them to innovate in the management of cities (Joss et al., 2019; Yigitcanlar et al., 2019).

Although the study of SUTs and urban sustainability has drawn the attention of a number of scholars (Ahad et al., 2020; Angelidou et al., 2018; Yadav et al., 2019), there is a lack of studies exploring the impact of SUTs on urban sustainability (Bibri & Krogstie, 2017; Kramers et al., 2014). This research gap is motivated for two sets of reasons.

The first is that while one group of studies discusses how SUTs may be adopted in SC projects to achieve urban sustainability, the consequent urban sustainability impact is measured at city-level. In this regard, the literature argues that SC projects that follow a government-led approach may contribute to urban sustainability (Esposito et al., 2021). City managers can analyse the city context and select appropriate SUTs to address urban and sustainability challenges (Kummitha & Crutzen, 2017). In contrast, following the corporate-led approach, SC projects may fail to achieve urban sustainability because they are managed by high-tech companies that have selected and implemented their own digital technologies to increase their revenue and enhance the city's service efficiency (Kummitha, 2018, 2019).

A further group of studies illustrate SC support for urban sustainability without considering the impact of singular SUTs involved in the

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initiative (Escobar & Margherita, 2021; Margherita et al., 2020). Other studies illustrate potential indicators, taxonomies and evaluation frameworks that city managers can use to evaluate the SC contribution to urban sustainability (Huovila et al., 2019; Quijano et al., 2022).

Our second reason is that some studies discuss SUTs without presenting their impact on urban sustainability. This group includes studies devoted to presenting the technical characteristics and descriptions of potential applications of SUTs (Ahad et al., 2020; Yadav et al., 2019). Other researchers report the technological capabilities of SUTs that can be used to support urban sustainability, especially increasing digitalisation and smartness (Angelidou et al., 2018; Hilty et al., 2011; Stübinger & Schneider, 2020).

In this study we therefore expect to contribute to the literature by shedding light on the potential impact of SUTs on urban sustainability employed in government-led SC projects. We investigate the following research question: "*What is the potential impact of smart urban technologies used in smart city projects on the three dimensions of urban sustainability?*"

To answer this question, we use structural topic modelling analysis, employing data collected from the *Smart Territory* call for projects implemented by the Wallonia Region (Belgium) as part of the Walloon Smart Region strategy. Initiated in 2019, this call for projects was a funding opportunity for Walloon municipalities that hoped to solve urban sustainability issues by using SUTs in their urban areas. Therefore, by analysing these SC projects, we may discern the potential SUTs' impact on urban sustainability. Our contribution to the literature entails the presentation of the potential impact of SUTs on the three dimensions of urban sustainability.

The paper is structured as follows: Section 2 presents the theoretical framework. Section 3 reports the research design. In Section 4, we illustrate the findings, which are then discussed in Section 5. We conclude the article with Section 6.

2. Theoretical framework

In this section, we define the concepts of urban sustainability, SUTs, and SCs, and outline the state of the art and research gaps regarding the impact of SUTs on urban sustainability.

2.1. Urban sustainability

The concept of sustainability is rooted in the Brundtland Report, which conceptualises it as a form of economic development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43). Sustainability is conceptualised for urban areas by Hiremath et al. as an effort to "achieve a balance between the development of the urban areas and protecting the environment with an eye to equity in income, employment, shelter, basic services, social infrastructure and transportation in the urban areas" (Hiremath et al., 2013).

Various frameworks operationalise how urban sustainability might be achieved (Ahvenniemi et al., 2017; Bibri & Krogstie, 2017). For instance, Castells (2000) considers urban sustainability as being achieved if cities' production levels do not eliminate the opportunity for resource reproduction. Other authors consider urban sustainability as being achieved when the quality of life and services for citizens is enhanced in cities (Bibri & Krogstie, 2017).

Our study defines urban sustainability using the comprehensive framework of the triple bottom line, which involves three dimensions to support (Ahvenniemi et al., 2017; Giddings et al., 2002):

- The *economic dimension* refers to developing a city context capable of ensuring viable organisations and long-term economic growth that fairly distributes socio-economic benefits among a city's stakeholders (Michael et al., 2014).
- The *environmental dimension* refers to developing a city context that makes optimal use of environmental resources, protects essential ecological processes, and helps to conserve natural heritage and biodiversity (Michael et al., 2014).
- The *social dimension* deals with city community well-being and how people's needs can be addressed to improve quality of life. It embraces the notions of equal opportunity for people's development, respect for the community's socio-cultural authenticity, and conservation of cultural heritage. It also includes the notion of community empowerment, whereby citizens increase control over their lives by accessing public information and facilities (OECD, 2004).

2.2. Smart urban technologies and smart city

SUTs are defined as "a set of urban infrastructures, architectures, applications, systems, and data analytics capabilities – i.e. constellations of hardware and software instruments across several scales connected through wireless, mobile, and ad hoc networks which provide continuous data regarding the physical, spatiotemporal, infrastructural, operational, functional, and socio–economic forms of the city" (Bibri & Krogstie, 2017. p. 190). There is no list of SUTs, and in several studies such technologies are presented with their capabilities (Angelidou et al., 2018).

Research into SUTs has recently gained attention due to the emergence of the SC paradigm, as these two concepts are closely related. The SC concept was first introduced in 2008 by International Business Machines (IBM) corporation as part of its Smarter Planet strategy, which aims to exploit the capacity of ICTs outside the corporate realm to implement policy solutions in cities (Chu et al., 2021).

Even though there are several definitions of SCs in the literature, Yigitcanlar et al. show that the various SC definitions converge in the adoption of SUTs to make a city "smart". Thus, we define an SC as "an innovative city that uses ICTs and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects" (International Telecommunications Union, 2015).

To conclude, the literature shows various SC deployments where city managers often see the transition towards an SC as fuzzy, nebulous and complex, blaming the varying definitions for pushing them to use a variety of SUTs in cities (Angelidou, 2014; Esposito et al., 2021; Mora et al., 2019). In these studies, SCs are developed with SC projects defined as the means where SUTs are selected, adopted, rolled out and managed in cities (Joss et al., 2019).

2.3. The contribution of smart urban technologies towards urban sustainability

The literature observes that SUTs and their capabilities are potential saviours when it comes to urban and sustainability challenges in cities (Bibri & Krogstie, 2017; Yigitcanlar et al., 2019). However, some authors report a lack of studies exploring the impact of SUTs on urban sustainability (Bibri & Krogstie, 2017; Kramers et al., 2014). We can explain this research gap with two sets of reasons.

The first is that one group of studies discusses how to adopt SUTs in SC projects to achieve urban sustainability, but measures the consequent impact on urban sustainability at SC-level. In this regard, some studies show that SC projects may contribute to urban sustainability by following the government-led approach (Esposito et al., 2021; Jiang et al., 2022). This approach frames city managers as being capable of analysing the needs of their local context, attracting government funds for SC projects, and managing them (Jiang et al., 2022). Thus, city managers can understand the city context and finance the purchase of SUTs designed and implemented to address a predefined set of urban sustainability challenges in the local context (Desdemoustier et al., 2019; Mora et al., 2019). In contrast, SC projects may not contribute to urban sustainability following the corporate-led approach (Kummitha, 2018, 2019). High-tech companies, in this case, manage SC projects and implement proprietary SUTs to increase their revenues and improve city service efficiency, and are thus not oriented primarily towards urban sustainability goals (Grossi & Pianezzi, 2017).

A further group of studies gives indicators and frameworks for measuring SC impact on urban sustainability without considering the impact of individual SUTs. Ahvenniemi et al. conduct a review in this regard showing indicators for assessing SC impact on the three dimensions of urban sustainability. In line with this, Huovila et al. review urban sustainability indicators at city- level, and propose a more articulated taxonomy that helps city managers to measure an SC's level of smartness and its contribution to urban sustainability. Quijano et al. propose an evaluation framework to measure SC progress towards urban sustainability, taking various SC dimensions into account (such as energy, mobility, governance and the economy).

The second reason is that studies focus on SUTs without illustrating their impact on urban sustainability. Bibri and Krogstie (2017) give a detailed account of the dominant visions of SUTs in terms of their definitions, characteristics, differences, and overlaps. Ahad et al. conduct a literature review, providing a technology description of the potential SUTs usable in SC projects. Yadav et al. report the potential SUTs in SCs for achieving urban sustainability. This list of SUTs was used to conduct a best-worst method, with various experts showing that SUTs for a city's infrastructure constitute a key enabler for achieving urban sustainability, though the consequent impact on urban sustainability was not presented. A further group of studies concentrate on SUT capabilities for supporting urban sustainability. Hilty et al. show that SUTs may support urban sustainability by decoupling resource consumption and environmental impact from economic growth. Angelidou et al. add that SUT capabilities of digitalisation, system integration and automatic data collection may support urban sustainability. Stübinger & Schneider further include the smartness feature, i.e. the technological capability of being aware of current circumstances and reacting intelligently to changes in the environment. Further detailed studies illustrate how SUT capabilities can help to detect urban challenges, especially those related to air pollution: internet of things applications can monitor pollution status, and data analytics can be used to provide real-time information on such issues (Kaginalkar et al., 2021; Zhang et al., 2022).

In the next section, we analyse the *Smart Territory* call for projects implemented by the Wallonia Region (Belgium) as part of the Walloon Smart Region strategy. Initiated in 2019, this call for projects was a funding opportunity for Walloon municipalities that aimed to solve sustainability problems at the local level by using SUTs within their urban areas. The projects submitted by municipalities address a variety of sustainability issues and aim to achieve different objectives. Our findings allow us to classify these objectives along with the three dimensions of urban sustainability (economic, environmental and social), thus providing empirical evidence of the potential impact of SUTs on the urban sustainability of government-led projects of SC projects.

3. Research design

In this study, we investigate the potential impact of SUTs on urban sustainability. We tackle this research issue by conducting structural topic modelling (Roberts et al., 2014, 2019), employing the Walloon *Smart Territory* call for projects from 2019.

3.1. Data sample

We chose Belgium for our analysis because it is one of the highest performing European Union countries in the field of SC development (European Commission, 2018). Specifically, we chose to study municipalities in the Wallonia region. Since 2015 the Walloon government has adopted Digital Wallonia, which consists of 23 actions in the following four areas of activity: (a) empowering digital enterprises; (b) reforming public administration; (c) strengthening the connectivity and smartness of the territory through better ICT infrastructures; and (d) training the Walloon human capital to increase its digital literacy. In 2018, the impact of the regional strategy was apparent, with 288 SC projects initiated across the Walloon cities. In 2019, to further boost this positive trend, the regional government launched the *Smart Territory* call for projects, inviting city managers to propose SC projects within three domains, i.e. energy and environment, governance and citizenship, and mobility and logistics.

The sample of SC projects we analyse in this paper is the total number of project proposals sent by Walloon municipalities to the Wallonia region as part of the 2019 *Smart Territory* call for projects. This call aimed to fund SC projects developed by municipalities to support urban sustainability goals with SUTs. Our sample includes all 88 projects submitted to the call (27 % with applications in the field of Energy and Environment, 44 % in Governance and Citizenship, and 29 % in Mobility and Logistics). Geographically, the projects are distributed between the different Walloon Provinces as follows: 10 % in Namur, 13 % in Walloon Brabant, 21 % in Luxembourg, 26 % in Hainaut and 30 % in Liège. In each project, city managers illustrate their SC projects, including the desired SUTs, their implementation plan, a feasibility study and the expected contribution to urban sustainability.

Our analysis concentrates on the textual data included in the answers to open-ended question 46, where the call's form asks for a description of the SC project and the expected impact of SUTs on the three dimensions of urban sustainability.

This call for projects has been selected as a suitable sample for analysis for three reasons:

- All these SC projects follow the government-led approach because city managers and municipalities are those developing the projects. Thus, according to the literature, under this condition, SUTs can support urban sustainability (Kummitha, 2018).
- The call for projects funds SC projects to purchase SUTs for urban sustainability. Thus, city managers present in detail the SUTs and their functionalities to improve their likelihood of getting funded. Accordingly, we can discern SUTs and their details extensively.
- The call for projects does not restrict city managers from developing a SC project to support one urban sustainability dimension, but leaves space to these actors to develop SC projects based on SUTs to support the various urban sustainability dimensions. Thus, we can discern the potential impact of SUTs on the three dimensions of urban sustainability.

3.2. Data analysis

We analysed the data sample using Structural Topic Modelling (STM). STM is an advanced method for conducting topic modelling that builds on the tradition of probabilistic topic models, such as Latent Dirichlet Allocation (LDA) (Blei et al., 2003). It is an unsupervised statistical model for extracting probabilistic topic models that occur in a collection of documents (Roberts et al., 2019). A probabilistic topic model describes the discussed topics in a given group of documents. Thus, STM uncovers how different documents might discuss the same underlying topic using different word choices (Braccini et al., 2018). Within this framework, a topic is defined as a mixture of words where each word has a probability of being part of a certain topic, and a document is a mixture of topics, meaning that a single document can consist of multiple topics. As such, the sum of the topic proportions across all topics for a document is equal to one, and the sum of word probabilities for a certain topic is equal to one (Roberts et al., 2019).

We selected this method for three reasons. From a methodological point of view, compared to previous topic modelling methods (like LDA), STM provides tools to facilitate the workflow associated with analysing textual data and the selection of topics to extract (Roberts et al., 2019). STM is also useful for analysing a large amount of data that cannot be used in qualitative studies (i.e. multiple case studies).

Secondly, STM is designed for social science research, especially for comparative studies (Roberts et al., 2014, 2019), and it is recommended for analysing open-ended questions (Roberts et al., 2014; Tvinnereim & Fløttum, 2015). Thus, since we analyse an open-ended question, STM fits our research.

Thirdly, we found state-of-the-art studies that successfully used STM with similar investigations. The authors recommended its usage in future studies because it is less prone to subjective misinterpretation than other topic modelling methods (Guenduez & Mettler, 2023).

Our data analysis protocol was composed of three steps (see Fig. 1): (1) data collection, (2) automatic topic extraction by STM, and (3) manual topic analysis and summary topics definition.

In the data collection step, we prepared a data corpus where we reported all the answers related to question 46 of the 88 projects – considered as the documents of the analysis. We had to drop three SC projects because the answer to question 46 was blank.

Then, one researcher conducted the STM via R using the stm package (Roberts et al., 2019):

- A pre-processing phase was conducted to remove stop-words, punctuations and stemming (Roberts et al., 2019).
- Topic estimation was conducted. To do so, the researcher followed the recommendation made by Roberts et al. (2019), who argue that the preferred topic number is that which maximises the two scores of semantic coherence and exclusivity. In our study, this preferred topic number was four (Fig. 2), and this is what we selected.

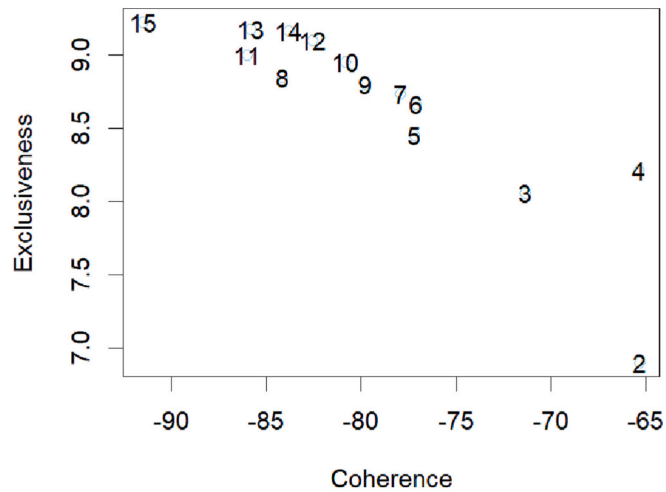

Fig. 2. Coherence and exclusiveness table for topic number selection.

- For each of the four topics, the researcher retrieved the probabilistic allocation of the topics.

Finally, the topics were automatically extracted, and the corpus annotated with the probabilistic allocation of the topics. We proceeded by

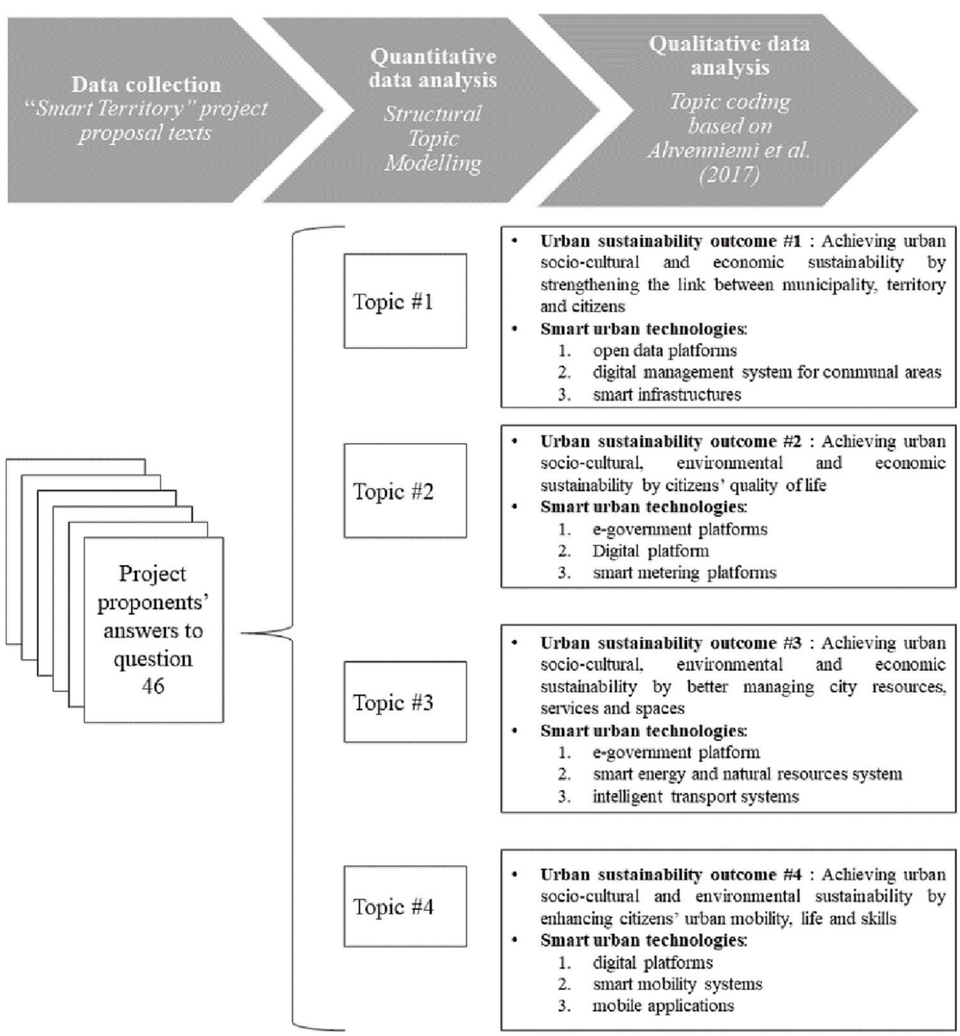

Fig. 1. Data analysis protocol.

qualitatively analysing (step 3) all topics and the associated documents. We examined the four topics using the three dimensions of urban sustainability (economic, environmental, and social) (Ahvenniemi et al., 2017) as a sensitising device (Margherita & Braccini, 2020). Thus, we were able to discern the associated impact of SUTs on urban sustainability (Margherita & Braccini, 2020). When further information was needed to understand the SUT impact on urban sustainability, we read the entire SC project beyond the answer to question 46.

4. Results

STM automatically extracted four topics with their probabilistic allocation (see Table 1).

In this section, we illustrate the impact of SUTs on the three dimensions of urban sustainability for each topic.

4.1. Topic 1 - achieving social and economic sustainability by strengthening the link between municipality, territory and citizens through a smart city

This topic includes 18 SC projects that adopt SUTs to support *social* and *economic urban sustainability* by strengthening the link between municipality, territory and citizens (see Fig. 3). We identified three main groups of SUTs: open data platforms (found in 3 SC projects), digital management systems for communal areas (found in 8 SC projects), and smart infrastructure (found in 7 SC projects).

Among the SC projects aiming to develop open data platforms, city managers stress that information about cities in terms of cultural activities and territorial data is currently highly fragmented. This is an obstacle for citizens willing to acquire more information about cultural events and shops available in the urban territory. Open data platforms are advocated to tackle both issues. These platforms can integrate all this information and allow citizens to share information about shops and cultural events and be actively engaged in gathering and visualising such territorial data. Due to the complexity of such platforms, a municipality also stresses the importance of developing workshops and training and creating an instruction book to educate a city's community about technology usage. In this way, adopting such technologies can support *economic sustainability* because open data are a catalyst for the development of potential new business ventures and events in cities. *Social sustainability* will be supported because citizens acquire digital skills thanks to the training.

Among SC projects aiming to adopt smart infrastructure, we identified municipalities that want to increase the promotion of cultural events to citizens in their territory. To this end, these municipalities aim to install multimedia columns located on strategic crossroads and in pedestrian areas that will show information on events and cultural activities in the city in different languages. Citizens can see and check real-time information on events and cultural activities in the city in different languages. Thus, adopting these technologies will support *social sustainability* because citizens can find and participate in social events and enjoy a better social life.

Similarly, municipalities aim to revitalise and reinvigorate the social fabric of the city in cases where elderly inhabitants are isolated at home.

Table 1
Structural topic model results.

Topic	Probabilistic allocation score of the topic[a]	Number of projects included in the topic
1	0.2093	18
2	0.2705	23
3	0.3411	29
4	0.1764	15

[a] The sum of the probabilistic allocation score of the topics is 0.9973 and not 1 (Roberts et al., 2019), since probabilistic allocation scores are rounded to the fourth decimal place.

To this end, they want to install a smart infrastructure composed of free Wi-Fi and a cloud service that hosts a digital audio guide and web radio. They want to create a digital audio guide narrating the city's cultural and natural heritage, where citizens are invited to participate actively in the process as content creators. They would also like a participative web radio with which to develop cross-generational connections among citizens. Adopting such technologies can support *social sustainability* as it promotes social cohesion in the city and help citizens to connect to the internet thanks to freely available Wi-Fi.

As regards SC projects aimed at the adoption of digital management systems for communal areas, municipalities stress city-dwellers' difficulties in using certain kinds of communal physical infrastructure, such as indoor stadiums or municipal spaces. These spaces are difficult to book due to complex administrative procedures, resulting in a reduced number of events in the city. These management systems can address these issues because they help citizens, associations and organisations to create events by booking communal infrastructure with a digital, easy-to-use and guided procedure. At the same time, these systems can be used by potential clients with web-based applications to visualise events in the city, find alternative transport options to enter the city, and book tickets with protected payment systems. Such technologies can support *economic sustainability* because they help to increase the number of potential customers for local shops. Also, *social sustainability* can be supported because with the help of these technologies citizens can enjoy a wider offer of events and activities in the city.

4.2. Topic 2 - achieving urban sustainability by improving social life for citizens with a smart city

This topic includes 23 SC projects that aim to adopt SUTs to support the three dimensions of urban sustainability by improving citizens' lifestyles (see Fig. 4). Three types of SUTs are included: e-government platforms for the centralisation of administrative procedures (found in 5 SC projects), a digital platform for the city's social life (found in 5 SC projects), and smart metering systems (found in 13 SC projects).

As regards SC projects that aim to implement digital platforms, municipalities consulted with citizens who demonstrated their lack of knowledge about available cultural and natural sites and local shops in which to enjoy city life. Accordingly, municipalities want to adopt digital platforms, i.e. online city mapping tools. These allow citizens to discover local places, share their knowledge and experience with pictures and reviews, and propose additional attractions and itineraries. The adoption of these technologies will support *social sustainability* because citizens are involved in the co-creation process of itineraries to enjoy city life better, and, consequently, *economic sustainability* is supported because local businesses close to these sites can have more clients.

With regard to SC projects willing to implement e-government platforms, municipalities report the need to reduce the time spent on administrative procedures and their complexity. These procedures are currently handled in physical offices or by obsolete websites with a static interface that impedes interaction between the public sector and citizens. Accordingly, municipalities want to implement e-government platforms that can be accessed through easy-to-use digital graphic interfaces that give citizens easy access to municipal information and guide them to fill municipality administrative procedures and even pay taxes within a secure environment. Adoption of these technologies will support *social sustainability* because citizens are more informed about administrative procedures and able to complete them more quickly and without any time constraints related to physical office opening hours. *Environmental sustainability* is also supported because municipalities will use less paper for their procedures.

In SC projects that aim to implement a smart metering system, municipalities report the need to raise awareness among citizens about their impact on the city environment. The adoption of smart metering systems can address this issue. These systems can be installed in public

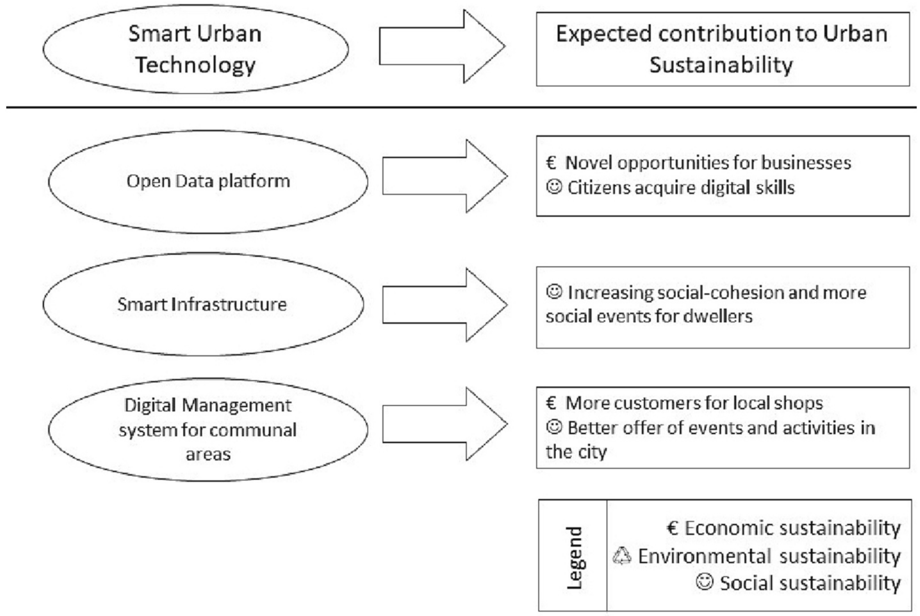

Fig. 3. The expected contribution of STUs to urban sustainability in Topic 1.

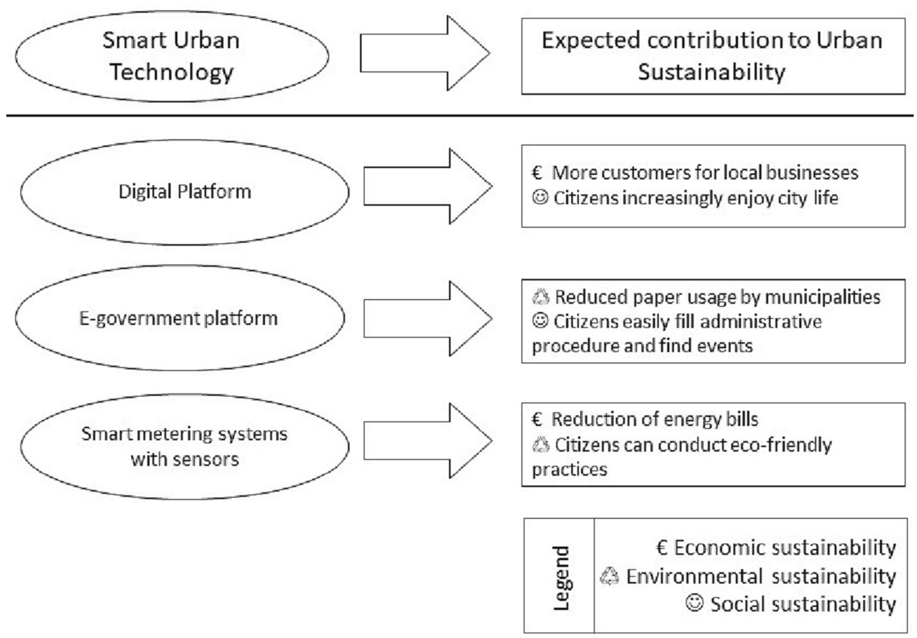

Fig. 4. The expected contribution of STUs to urban sustainability in Topic 2.

spaces (near parking areas, crossroads) and private residences, providing real-time information about consumption levels of natural resources and air pollution, and advice on how to reduce such consumption. As a result, these technologies will support *environmental sustainability* because citizens can understand their daily consumption and undertake eco-friendly practices (reduction of car usage and consumption of energy and natural resources), with a consequent reduction of energy bills (*economic sustainability*).

4.3. Topic 3 - achieving urban sustainability by better managing city resources, services and spaces with a smart city

This topic includes 29 SC projects that have the common purpose of adopting SUTs to support the three dimensions of urban sustainability by improving the management of city resource services and spaces (see Fig. 5). Three types of technologies are included: an e-government platform (found in 29 SC projects), a smart energy and natural resources system (found in 8 SC projects), and smart mobility systems (found in 7 SC projects).

In SC projects involving smart mobility systems, municipalities report that the part of the population that uses cars as a preferred means of transport is increasing – in one municipality this has grown by 16 % in the last 15 years. This leads to issues related to lack of parking and mobility congestion in city centres. In addition, the limited mobility infrastructure pushes organisations and entrepreneurs to develop financial districts outside the city. Thus, municipalities want to adopt a smart mobility system in the form of intelligent transport systems based on IoT sensors in the city centre. Such sensors are placed along roads and

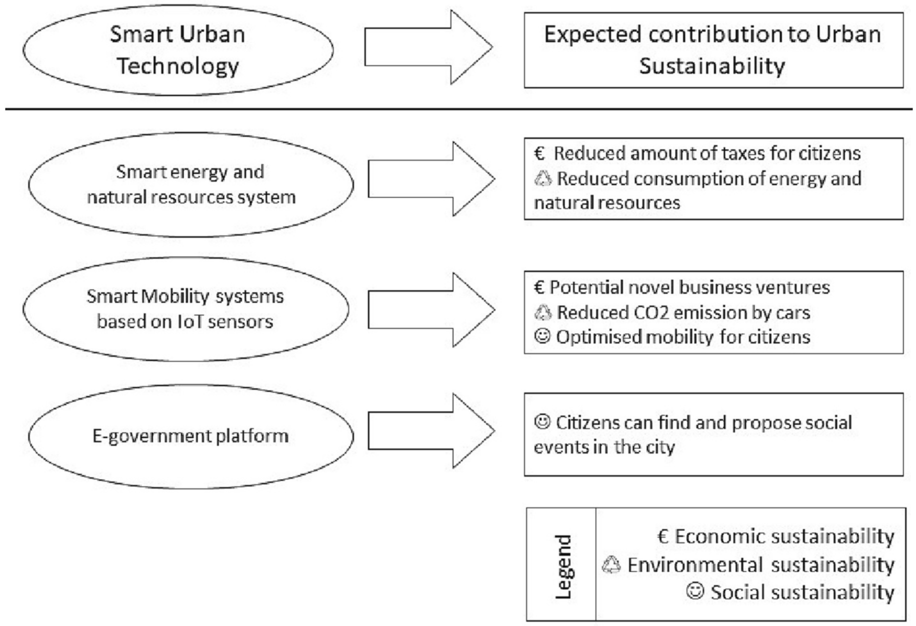

Fig. 5. The expected contribution of STUs to urban sustainability in Topic 3.

parking to gather real-time information related to road conditions and congestion as well as available parking around city centres. Such information is acquired by an intelligent transport system that citizens can use through mobile or web-based applications to receive daily notifications about the state of mobility in the city. Therefore, the adoption of intelligent transport systems will support *economic sustainability*. These systems provide optimised mobility in the city centre that will help potential clients to reach local businesses, find nearby parking, and encourage new business ventures to open in the city centre. Such technologies can also support environmental sustainability, as optimisation of mobility congestion in the city helps reduce CO_2 emissions levels and enhance air quality.

Among the SC projects that adopt a smart energy and natural resources system, municipalities report the need to efficiently manage the energy, water and gas consumption of public and private buildings. These buildings are not constantly controlled, and municipalities do not have accurate information about the real consumption of these resources. These issues derive from obsolete metering systems that are not centralised. Therefore, it is difficult to check the daily state of water and energy infrastructure, which hinders the chance of preventing leakages. In consequence, municipalities want to adopt an energy and natural resources system with IoT sensors that collect energy and natural resources consumption data on such buildings and show consumption statistics to citizens via web platforms. Municipalities can use these data to analyse consumption trends and plan preventive maintenance to maintain constant use and prevent potential leakages.

Adopting smart energy and natural resources systems will support *environmental sustainability* because such systems help reduce energy and natural resource consumption and result in more timely technical maintenance. Adopting these technologies will also support *economic sustainability* by reducing the amount of taxes related to energy and natural resources paid by citizens to municipalities.

Among SC projects willing to adopt e-government platforms, municipalities report that citizen consultations have indicated a need to clearly illustrate and involve citizens in municipal decisions and social events. Social events are promoted through various communication channels, making access to such information fragmented for citizens. Accordingly, municipalities want to address this issue by adopting an e-government platform that manages communication between municipalities and citizens by integrating all such information. Citizens can access such a platform in various ways – mobile application or web-based interface – and visualise this information. Moreover, citizens can use the platform to answer surveys and provide feedback regarding municipalities' activities. Citizens can also propose new activities or ideas for the development of municipalities' activities. Therefore, adopting these technologies will support *social sustainability*, as they will allow citizens to find social events and include them when planning new activities in the city.

4.4. Topic 4 - achieving social and environmental sustainability by enhancing citizens' urban mobility, life and skills with a smart city

This topic comprises 15 SC projects that aim to support *social* and *environmental urban sustainability* by enhancing citizens' mobility around the city and enhancing their skills (see Fig. 6). We found three groups of SUTs: digital platforms (found in 5 SC projects), smart mobility systems (found in 5 SC projects), and mobile applications (found in 5 SC projects).

In SC projects involving smart mobility systems, municipalities want to encourage alternative forms of transport to cars. For instance, one municipality estimates that 80 % of its citizens use a car to go to work or drive children to school for trips shorter than 5 km. In consequence, four SC projects want to encourage bicycle use by implementing a soft mobility system. Citizens can use this system to visualise urban maps of areas dedicated to walking and cycling, find soft mobility services such as bike sharing, and find a way to move around the city on alternative forms of transport, minimising distances.

Similarly, the remaining SC projects that involve smart mobility systems want to improve city mobility by integrating the city's various shuttle and bus services or the already adopted smart mobility systems into a novel "global smart mobility system". In this way, citizens can use various means of transport to reach a destination in less time and avoid potential traffic circulation issues.

Therefore, by adopting such technologies, municipalities expect to support *social sustainability* with a better quality of life because citizens can move more efficiently around the city using public transport or alternative forms of mobility, reducing car usage. This implies more available parking, greater street safety, and the possibility of creating zones and streets reserved for bicycles and pedestrians. Consequently, the *environmental dimension* is supported because CO_2 produced by cars

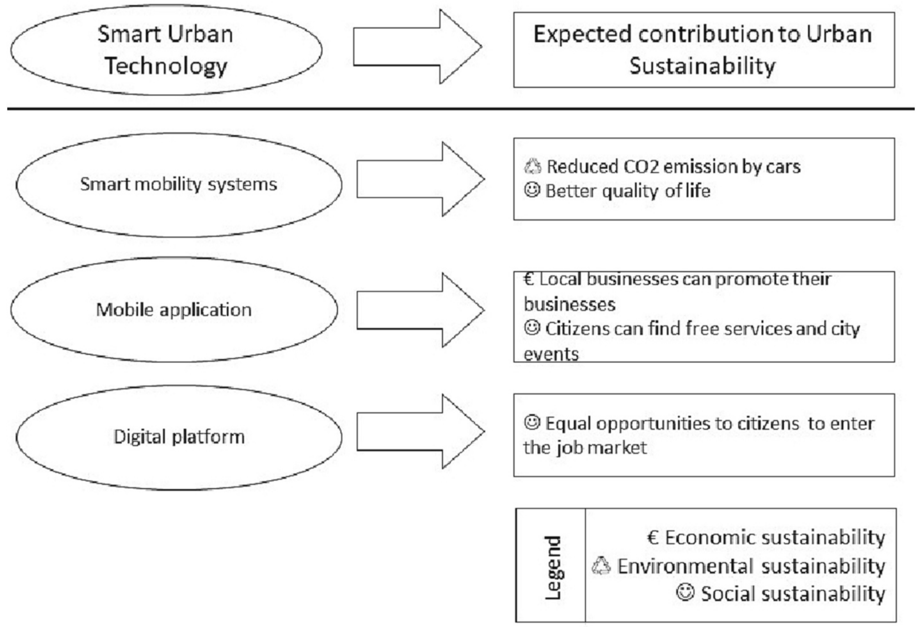

Fig. 6. The expected contribution of STUs to urban sustainability in Topic 4.

is reduced, and the quality of air in the city is improved.

In SC projects involving mobile applications, municipalities underline citizens' limited awareness about free services in the city – such as toilets, picnic areas, sport fields – and city events, fairs and local shops. Since 55 % of Walloons use a smartphone, municipalities want to address these issues by adopting an easy-to-use mobile application that lists and continuously updates all this information. Adopting such technologies will thus support *social sustainability* by helping citizens to find city events and use free services. Consequently, the *economic dimension* is supported, because local shoppers can use such technologies to promote their businesses.

Finally, in SC projects involving digital platforms, municipalities stress the need to create a link between municipalities and unemployed people, especially those foreigners that are unaware of municipal services, to help them find a job. To this end, municipalities want to implement two types of digital platforms. The first is a digital platform that retrieves job offers from regional and national systems. This platform is coupled with a free Wi-Fi service installed in various points of public gathering, such as libraries, schools, and municipality buildings, to help citizens that do not have internet access. Moreover, the second digital platform focuses on developing citizens' new skills. By using this technology, citizens can find training activities organised by the municipality, and organisations and associations in the cities that can be booked to reinforce specific skills. Citizens can thus develop a better profile to apply for a job. Therefore, such technology adoptions can support *social sustainability* because they contribute to citizen empowerment and community well-being by providing equal opportunities for citizens to undertake development and find job positions.

5. Discussion

Our findings show the potential impact of SUTs on the three dimensions of urban sustainability (see 2) under government-led SC projects. Thus, we contribute to the literature by addressing the research gap related to the impact of SUTs on urban sustainability (Bibri & Krogstie, 2017; Kramers et al., 2014). The findings show nine groups of SUTs that can support urban sustainability in different ways. All these SUTs will support at least two dimensions of urban sustainability.

More specifically, SUTs will support economic sustainability by helping to increase the number of local businesses, encouraging new ones, and reducing taxes.

SUTs will support environmental sustainability by reducing CO2 emissions thanks to improved viability, integrated service of public means of transport, and soft mobility. Such technologies can also optimise the usage of energy and natural resources and encourage citizens' eco-friendly actions.

SUTs will support social sustainability by helping citizens to participate in a larger number of social events and activities and planning novel city activities. Citizens will also enjoy easy digital procedures for filling administrative documents, better mobility, safer streets, and technology capable of improving their skills to help them find a job.

Moreover, smart mobility systems can support urban sustainability in all three dimensions. Since the literature reports that city managers see the transition towards a sustainable SC as complex, fuzzy and nebulous (Angelidou, 2014; Esposito et al., 2021; Mora et al., 2019), our study contributes to the literature by showing precisely how city managers can leverage smart mobility systems to initiate SC projects, because such technologies may support the three dimensions of urban sustainability.

Our study extends the literature reporting that SUTs realise benefits by leveraging their technological capabilities, especially the smartness feature (Angelidou et al., 2018; Bibri & Krogstie, 2017; Stübinger & Schneider, 2020). Indeed, the findings show that SUT benefits will also be realised through socio-technical interplay between SUTs and citizens, i.e. when citizens effectively use the SUT.

Therefore, SUT adoption, and the consequent SC project, should not be considered as a mere technical process where SUT capabilities are fine-tuned for the city's needs (Kummitha, 2018, 2019); rather, they should be seen as a social-technical process where city managers develop activities both to fine-tune SUTs for the city and activities to communicate and prepare people to use SUTs.

Moreover, the literature devoted to exploring the relationship between STUs and urban sustainability takes a city-level stance, using the SC as unit of analysis, rather than SUTs (Ahvenniemi et al., 2017; Grossi & Pianezzi, 2017). Such studies measure the impact of SCs on urban sustainability with evaluation frameworks that pinpoint sustainability indicators (Ahvenniemi et al., 2017; Huovila et al., 2019; Quijano et al., 2022). Our study contributes to this literature by providing ways to extend the list of sustainability indicators following a more context-specific approach based on real-life SC projects. This approach may capture a large variety of urban sustainability outcomes delivered by SUTs that may escape with a *one-size-fits-all* set of sustainability indicators. In this regard, the impact of SUTs on urban sustainability, shown in Table 2, may inspire the development of urban sustainability indicators. For instance, a smart mobility system may be implemented to achieve economic, social and environmental urban sustainability outcomes which can be measured through performance indicators that capture, respectively, the number of novel businesses created in the city, the reduction of accidents in the city, as well as the increase in urban spaces reserved for pedestrians and bicycles, and the reduction of CO2 emission by cars.

Indicators such as this would be more precise and city managers would contribute to their construction by identifying the most important urban sustainability goals and metrics, and tailor their assessments accordingly.

Finally, our study contributes to the literature on the government-led SC approach that has city managers initiating SC projects because they understand urban challenges and therefore select appropriate SUTs (Jiang et al., 2022). In contrast, our study illustrates that the city's community – especially citizens – can help municipalities to understand urban challenges. Accordingly, citizens should not simply be considered as actors using SUTs (Angelidou et al., 2018), but collaborative partners in the development of a SC project. The involvement of them as stakeholders may also help SC project evaluation because it helps to build trust and engagement among SC actors and fosters a sense of ownership and accountability for the success of SC projects.

Table 2
The expected contribution of smart urban technologies to urban sustainability.

Smart urban technologies	The expected contribution to urban sustainability		
	Economic sustainability	Environmental sustainability	Social sustainability
Open Data platforms	- Potential novel businesses, activities, and events		- Citizens acquired digital skills
Smart Infrastructure			- Increased participation of city-dwellers in social events - Increased social cohesion
Management systems for communal areas	- An increasing number of potential customers for local shops		- Increased offer of events and activities in the city
Digital Platforms	- More customers for local businesses		- More itineraries in the city - Citizens can easily find a job - Citizens can increase their skills
E-government platforms		- Reduced paper usage by municipalities	- Improved ease of completing administrative procedures for citizens - Improved ease of finding social events for citizens - Citizens are included in the planning of novel activities in the city
Smart metering systems	- Reduction of energy bills	- Citizens can conduct eco-friendly practices	
Smart energy and natural resources system	- Reduced amount of taxes for citizens	- Reduced consumption of energy and natural resources	
Smart Mobility systems	- Potential novel business ventures	- Reduced CO2 emission by cars	- Optimised mobility for citizens - Improved safety in the streets - More reserved streets for bicycles and pedestrians
Mobile apps	- Increasing promotional actions for local shops		- More events and services for citizens

5.1. Implications for practitioners

Our study provides some implications for practitioners. The study contains rich examples of SC projects that illustrate how to link SUTs to sustainability outcomes. Thus, city managers can use this study as a guideline when selecting SUTs that are appropriate to a city's needs, and include them in the SC strategy to achieve urban sustainability.

City managers who want to develop sustainable SCs should initiate the transition by adopting a smart mobility system because it may support urban sustainability in all its dimensions. City managers should use communication activities to inform citizens about SC projects or the adoption of SUTs. Moreover, city managers adopting SUTs in SCs can evaluate their actual benefits, using the impact of SUTs on urban sustainability given in Table 2 as indicators.

Tourism businesses can use this study to extend their offer. For instance, they can include city itineraries developed by citizens in their organised trips.

High-tech companies can use this study to develop SUTs that are both based on the smartness feature and usable by citizens, namely with an easy-to-use and intuitive technology interface.

Policymakers that want to develop plans for SC projects need to include a budget for city-dwellers' involvement in city projects. Initiatives such as communication plans and sessions on digital technology use should be financeable. Moreover, our study confirms that SC projects positively affect urban sustainability outcomes. Thus, SC projects must include urban sustainability outcomes to be financially feasible. Companies developing digital solutions for smart cities need to develop an easy-to-use and intuitive interface for their technologies; citizens will thereby be able to use them effectively.

5.2. Implications for researchers

This study offers implications for researchers. We encourage researchers to conduct quantitative studies to validate our findings. We also encourage researchers to advance our study with similar analyses in different nations, especially in America, Asia and Africa. Scholars investigating SC projects for achieving urban sustainability may conduct comparative studies between the potential contribution of SUTs to urban sustainability and those that have actually been achieved.

Since our study advocates that SC projects are used to address urban challenges, researchers can investigate how municipalities can detect such issues. Researchers can also review the most common and current societal issues and relate them to SC initiatives.

One promising research avenue is exploring how city-dwellers are involved in SC projects. Our study reports that city-dwellers need to be informed of SC projects and educated about digital technologies. Thus, scholars can investigate a suitable communication strategy for SC projects to involve the public. On the other hand, information system scholars can investigate how to develop a plan to educate city-dwellers on technology use. They can also explore how to develop easy-to-use technologies to reduce the difficulty in their usage and increase the acceptance rate. To achieve this, more in-depth and process-tracing research is needed to unpack how governmental actors (e.g. elected officials, government bureaucrats, and civil servants) develop SC policy visions in conjunction with citizens. It is important to understand the formation of networks of public, private, and civic actors and the process through which they develop relational ties, with a view to developing a truly bottom-up SC program that sustains social change and promotes the public interest.

Additionally, this study discusses SC topics related to tourism research, such as city attractiveness mobility systems and event management. Accordingly, future research may investigate the relationship between SCs and tourism or the joint development of an SC and a Smart Tourism City.

Moreover, future studies should investigate how government-led coercive isomorphic pressures create a conducive environment for city-level managers to develop SC projects. Indeed, so far, scholars have argued that SC projects develop because of mimetic and normative isomorphic processes (Duygan et al., 2022), while they overlook coercive isomorphic pressures. These scholars stress the importance of inter-city networks which can serve as knowledge hubs and spaces for exchange and collaboration among city managers whose municipal administrations face similar sustainability challenges, and who are interested in finding and implementing similar SUT solutions. Hence, such networks can contribute to the diffusion of innovative ideas, as cities tend to search elsewhere for solutions and mimic successful examples (i.e. mimetic isomorphism). Likewise, the standards and visions set by pioneering cities can also influence other members to follow a similar innovative culture (i.e. normative isomorphism). Adding to this debate, our study of the Wallonia regional government's *Smart Territory* call for projects shows that supra-municipal administrations (i.e. regional governments) can create pressures on municipal administrations to develop SC projects through the use of public programs and public financial incentives (i.e. coercive isomorphism). Therefore, our study invites researchers to investigate further the role of regional governments, whose SC policies can have a powerful influence on city managers, for example, by offering financial support to municipalities in return for compliance with proposed regional policies when developing SUTs for boosting urban sustainability.

5.3. Study limitation

Our study has some limitations. The potential impact of SUTs on the three dimensions of urban sustainability may vary when adopted in practice. Nevertheless, Belgium is an important and relevant empirical site because it is one of the highest-performing European Union countries in digital policy and SC development, and as such can be regarded as an inspirational example (European Commission, 2018). Indeed, the study provides evidence that local governments can use SUTs to overcome a wide variety of sustainability problems (environmental, social, and economic), reflecting what they perceive as the most pressing socio-economic needs of their territories and populaces (Esposito et al., 2021). The study does not claim statistical generalisation.

6. Conclusion

This study is motivated by a lack of studies exploring the impact of SC project SUTs on the three dimensions of urban sustainability (economic, environmental and social). We address this gap by conducting STM on SC projects collected from the *Smart Territory* call for projects. In these, city managers report extensively on how SUTs will support urban sustainability. The results show a variety of urban and sustainability challenges that can be addressed by nine groups of SUTs. Thanks to the technological capabilities of SUTs and through the involvement of the city's community in their use, SUTs will support at least two urban sustainability dimensions, while smart mobility systems can support all three dimensions of urban sustainability.

CRediT authorship contribution statement

Emanuele Gabriel Margherita: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Stefania Denise Escobar:** Methodology, Conceptualization, Visualization, Writing – original draft, Writing – review & editing. **Giovanni Esposito:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Nathalie Crutzen:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, 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.

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