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The transition towards the implementation of sustainable mobility. Looking for generalization of sustainable mobility in different territories by the application of QCA

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ABSTRACT

Mobility emerges as one of the axes on which cities base their response to the challenges of sustainability. It is a complex phenomenon where elements located at different levels interact, meaning that it is increasingly being studied from a multi-level perspective. There are numerous smart mobility initiatives around the world, although there are doubts about their generalisation. The purpose of this article is to stablish the configurations of elements that determine the degree to which a city is making changes to implement sustainable mobility solution, and to study if those are generalisable across continents. Based on the data of 60 cities from different continets provided by the Urban Mobility Readiness Index, the configurations of elements that explain both the transition towards the implementation of sustainable mobility solutions and the denial of this phenomenon are established, three in each case. QCA was applied to a model that use the multilevel perspective.The main contribution is that infrastructures maintain the pivotal role, although the joint presence of other elements is also required, including certain characteristics of the city, such as its innovative character, as well as a high population density. Individual experiences can be extrapolated between cities on different continents.

Introduction

1.3 million people in the world start living in cities every week, which means that at this rate 68% of the population will be concentrated in urban settings by 2050 (Mendiola & González, 2021; Orlowski, 2021). Many of these cities cover larger geographic areas than in the past, in an urban pattern based on a central core and an orbit of smaller localities causing significant changes in land use, energy demand, biodiversity and lifestyle (European Commission, 2019b). Recognising the need and opportunity for a shift towards a more sustainable and resilient model, cities play a central role in the study of sustainable transition processes (Herrera & MacAskill, 2021; Hölscher & Frantzeskaki, 2021; Köhler et al., 2019; Peris-Blanes et al., 2022; Spickermann et al., 2014). The impact of mobility on the quality of life and sustainability of cities is currently considered one of their greatest challenges due to the negative externalities it generates (Esztergár-Kiss & Kerényi, 2020; European Comission, 2019b; Muller et al., 2021; Spickermann et al., 2014): environmental pollution, congestion, and long commuting times. A decrease in use of private vehicles in favour of efficient and connected public transport and active mobility modes could solve these problems (European Comission, 2019b). This is why cities are seen as vectors for the achievement of the Sustainable Development Goals (Krellenberg et al., 2019).

Society-wide replacement of polluting technologies with alternative sustainability ones, enables consumers to maintain satisfying lifestyles without negatively impacting the environment. Therefore, clean and inclusive mobility, based on sustainable infrastructure, low-emission, smartness and digitalization, is one of the keys to provide answers for these challenges and fostering sustainable development (Doost & Rezaie, 2020; LLopis-Albert et al., 2021a; Planko et al., 2016). To enable people to reduce private car use, a more integrated and systemic design approach is needed to become competitive in everyday mobility (Sopjani et al., 2020). Such design relies on sustainable and inclusive planning processes, which aim to reduce environmental impacts, improve air quality and life in cities through sustainable mobility solutions (Böcker et al., 2020; Ho et al., 2020).

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Four key elements shape the future of mobility: automation, connectivity, decarbonization and sharing (European Comission, 2019c). This process is facilitated by the fact that younger generations, who are keen of more technology experts and environmentally aware, tend to opt for collaborative consumption and largely decline the use of private cars (Butler et al., 2020; Fonzone et al., 2018; Pangbourne et al., 2020). There is a step towards more sustainable mobility solutions, thanks to the advantages that offer (European Comission, 2019a; Ganapati & Reddick, 2018; Krauss et al., 2022; Lin et al, 2018; Moradi & Vagnoni, 2018): solving the issue of first/last mile; flexibility with parking, and accessibility; reduction in road congestion, noise, and emissions; and improvements in the quality of life. The competition that new mobility systems represent for traditional vehicles is increasing, although it can be identified as complementary between the different means of transport. Therefore, they could be part of the solution to the challenges that cities face, it is expected that the number of shared mobility users worldwide will increase from 4% in 2015 to 20% in 2040 (Oliver Wyman, 2018).The emergence of new urban mobility solutions opens the door to a transition process that involves cross-scale and cross-sectoral dynamics, and turns cities into nodes within overlapping social, economic, ecological, political and physical networks that are continuously shaped by flows of people, materials and information across different scales (Bieliński et al., 2020; Hölscher & Frantzeskaki, 2021). It is therefore crucial to keep in mind the role of cities in transitions towards sustainability (Barnes et al., 2018).

The effect of the implementation of the smart city paradigm is conditioned by its interaction with the context in which it is developed (Batarra et al., 2018; Esposito et al., 2021; Ho et al., 2020; Noori et al., 2020), as sustainable mobility policies must be adopted to the local context (Punzo et al., 2022). The implementation of smart mobility innovations thus depends on the characteristics of each city, which implies attributing different meaning to urban innovation and developing strategies dependent on the space and socio-economic context. Therefore, there is no guarantee about speaking of a smart mobility strategy that ensures success (Batarra et al., 2018; Esposito et al., 2021; Ho et al., 2020; Kamargianni & Goulding, 2018; Muller et al., 2021). If the aim is to achieve more sustainable and inclusive mobility in cities, existing mobility initiatives should be evaluated as well as the contextual structures and factors conditioning their implementation (Alonso-Gonzalez et al., 2020; Böcker et al., 2020; Ulmanen & Bergek, 2021), always bearing in mind the causal complexity and the socio-technical approach in the investigation of elements linked to smart mobility (Shamsuzzoha et al., 2021). Being this the first research gap to which this work responds. Therefore, the first research objective is to establish the way in which contextual factors interact at different levels −niche, regimen, and landscape-, and the influence of this interaction on the degree to which a city is making changes to implement sustainable mobility systems.

The uncertainty of future mobility and ambitious visions of smart mobility require universally accepted methodological tools (Chen & Silva, 2021). Efficient planning of sustainable transitions should take into account the characteristic factors of the analyzed territorial level and thus explain why transitions occur in some places more than others (Lantz et al., 2021; Peris-Blanes et al., 2022). In consequence, cross-country differences in urban mobility behaviour have been identified (Punzo et al., 2022). As a result, there is no one recipe that is suitable for all contexts with respect to smart urbanism (Esposito et al., 2021), which means that the lessons learned from sustainable mobility initiatives may not be generalizable to any context different from the one in which they are developed (He & Chen, 2021; Shiau, 2021). This is the second research gap to be addressed. Therefore, the second research objective is to analyze the possibility of extrapolating the results, regarding the factors that determine the readiness of a city to implement sustainable mobility solutions. This question is intended to answer the need to confirm whether the use of smart micromobility services in different countries/cultures requires differential elements and conditions (Elmashhaea et al., 2022).

Therefore, the present work analyzes whether the configurations of elements -set of factors- that determine the degree to which a city is carrying out effective changes to implement sustainable mobility systems can be generalized across different contexts -continents-. For this purpose, it deepens the knowledge about the projects that can be the basis of a radical change, the mechanisms that can stimulate the scaling up of such initiatives and whether these processes are linked to the territorial space or whether there are local-global or transnational connections (Köhler et al., 2019). For this purpose, QCA will be applied to a model developed following the MLP in a sample of 60 cities in 6 geographical areas of the world.

In the following, we will first present the methods and model in which the suitability of the analysis method will be justified. Next, we present the theorical background in which we discuss sustainable approaches to urban mobility and the relevance of context in multilevel transitions to mobility. The paper concludes with the analysis, discussion, conclusions and limitations. In addition, future lines of research are presented.

Methods and models

Methods

The need to accelerate transitions that disseminate sustainable environmental technologies is unobjectionable (Werner et al., 2022). Innovations - mobility systems - force a combination of technologies, institutions and behaviors that interrelate and co-evolve, which is critical in achieving sustainability (Gruber, 2020; Spickermann et al., 2014). Thus, one must move beyond the isolated study of innovations and reconceptualize how actors reorganize multiple elements to reconfigure cities and their systems (Peris-Blanes et al., 2022). The complex processes of radical change occurring in cities, increasingly present continuous dynamics that alter urban functions, local needs and interactions between cities and their environment (Hölscher & Frantzeskaki, 2021).

The systemic perspective of innovation emphasizes the development and diffusion of innovations as an interactive process conditioned by institutional factors (Bögel et al., 2022; Ulmanen & Bergek, 2021). Transitions are used to explain innovative processes. Within these, socio-technical transitions represent changes towards a new system that, beyond technical innovations, involve political, behavioural and infrastructural changes (Gruber, 2020). Thus, the implementation of an innovation requires the establishment of a socio-technical system that involves radical social and technological changes (Medina-Molina et al., 2022). Modernizing urban mobility systems requires overcoming both economic, environmental and institutional pressures, as well as the actions of lobbies that try to block their development and prefer gradual innovations with more predictable pathways. Many of the developments studied resort to socio-technical transitions focused on radical change, which favors the commitment to more sustainable systems (Herrera & MacAskill, 2021; Moradi & Vagnoni, 2018; Spickermann et al., 2014).

Understanding urban transformations towards smart mobility requires treating the city as a set of socio-technical systems, through whose transitions its maturity is established (Corazza & Carassiti, 2021; Hölscher & Frantzeskaki, 2021; Peris-Blanes et al., 2022; Truffer et al., 2017). Urban mobility is not only a phenomenon modeled exclusively by the diffusion of individual technological solutions, but also by socio-technical dynamics (Jain & Rohracher, 2022; Schippl & Truffer, 2020). Explaining transitions to new urban mobility solutions makes it advisable to apply a multilevel perspective (MLP) that allows understanding the interactions occurring at different analytical levels -landscape, regime and niche- (Bögel et al., 2022;

Köhler et al., 2019; Köhler et al., 2020; Lin et al., 2018; Sarasini & Linder, 2018; Peris-Blanes et al., 2022; Spickermann et al., 2014; Upham & Gathen, 2021). The application of the MLP provides insight into the pathways followed by transitions towards sustainable mobility (Canitez, 2019; Lin et al., 2018). It is due to this that in this article we will apply the MLP in order to study the conditions that determine whether a city is investing and driving structural changes in pursuit of sustainable mobility.

The urban transformative capacity is an integral and holistic framework to address the contextual conditions that become relevant in a city to advance path-deviant changes towards sustainability. This capacity starts from a comprehensive and relational framework which conforms a measure of urban system dynamics describing a set of key parameters -actors, institutions, physical environs- and their interaction processes (Peris-Blanes et al., 2022). In the process of quantifying this capacity, there are multiple indexes trying to identify the elements that determine it, both from the academic and consulting fields (Muller et al., 2021).

Kamargianni & Goulding (2018) identify an index that measures the city's readiness for Mobility as a Service (MaaS) implementation based on characteristics across five dimensions: (1) transport operators data sharing and openness; (2) citizen familiarity and willingness; (3) policy, regulation and legislation; (4) ICT infrastructure; and (5) transport services and infrastructure. Subsequently, Orlowski & Romanowska (2019) poses the Smart Mobility Indicator with the following dimensions: (1) technical infrastructure; (2) informational infrastructure; (3) information systems for moving people; (4) mobility methods and vehicles used; and (5) legislation. For their part, Sunardi et al. (2020) present the Smart Mobility Indicator, supported by 5 dimensions: (1) local accessibility; (2) multimodal access; (3) international accessibility; (4) information and communication technology supporting mobility; (5) sustainable and safe transportation. From another approach, Doost & Rezaie (2020) establish the seven pillars of sustainability: environmental, economic, social, cultural, technical, political and educational sustainability plays an important role in this theory and helps us to prepare for the future. Finally, Yigitcanlar et al. (2022) identify, based on a literature review, non-ICT indicators related to smart city transformation readiness: (1) remoteness value; (2) proximity to major infrastructure; (3) population density; (4) unemployment level; (5) labor productivity; and (6) cultural diversity.

Among the second type of indices (generated in consulting field), Deloitte (2017) establish the Deloitte City Mobility Index themes based on the following dimensions: (1) performance and resilience; (2) vision and leadership; (3) service and inclusion. Another existing index is the HERE Urban Mobility Index, which identifies four main themes to assess a city's mobility performance: connectivity, affordability, sustainability and innovation (HERE, 2021). Finally, the Urban Mobility Readiness Index (Oliver Wyman Forum, 2022) uses five core dimensions to rank cities (infrastructure, social impact, market attractiveness, system efficiency and innovation), across 56 metrics that act as key performance indicators that identify which cities will excel in mobility. The possibility of accessing data from cities in six areas of the world, the reputation of the source, as well as the availability of information on population density, led us to choose this index. The Oliver Wyman indices have been used as benchmarks in academic work (Allen et al., 2018; Lempp & Siegfried, 2022; Marti & Puertas, 2022).

Models

The indicators of the Urban Mobility Readiness Index 2021 (Oliver Wyman Forum, 2022), for a sample of 60 cities from 6 geographical areas of the world, are used as a starting point for the development of this work. The components used at the different levels are presented in the following table (Table 1).

Table 1
Levels and conditions used.

Level	Condition	Description
Landscape	Population density (DEN)	Number of people residing in the city and with respect to its surface area.
	Innovation (INN)	How well does the city leverage local talent and resources to drive technological advances?
Regime	Infrastructure (INF)	Has the city developed robust infrastructure and expanded connectivity to support future mobility?
	Market Attractiveness (MAT)	How well does the city engage the private sector and secure diverse investments to build out mobility?
	System Efficiency (SEF)	How well does the municipal government coordinate and enhance the city's mobility network through things like traffic management systems?
	Social Impact (SIM)	Does the city maximize societal benefits like mobility-related employment or airport arrivals while minimizing harmful qualities like poor air quality?
Niche	Sustainable Mobility Score (SMS)	To what extent is the city investing and driving structural changes in pursuit of cleaner, healthier, and more risk-conscious mobility systems?

Based on the MLP for the study of transitions towards sustainable mobility, different components are identified at the landscape, regime and niche levels. The first two - landscape and regime - will function as conditions, and the third - niche - as an outcome. The landscape conditions of the present work are population density (DEN) and innovation (INN), because by their definition they are not related to mobility. Density has been considered an important quality of urban form. Compact urban areas are precondition for reducing motorized travel, with potential to reduce natural resource use and CO_2 emissions (Hernandez-Palacio, 2017). Residents in areas with high population density tend to own fewer cars than those in less densely populated areas (González et al., 2021).

There are doubts about the relationship between population density and city sustainability, which is complex and context-dependent (Soltani et al., 2021). However, increasing density tends to improve the perception of mobility, while increasing travel demand and traffic volume (Arimura et al., 2020; Lantz et al., 2021; Mendiola & Gonzalez, 2021; Paköz & Isik, 2022). This is why smart mobility is considered an effective approach for sustainability improvement, especially in densely populated urban areas (Muller et al., 2021; Yigitcanlar et al., 2022).

Local authorities may attribute different meanings to innovation in this field (Esposito et al., 2021). Hence, there are regions that position mobility as a key area of their smart city model by focusing and highlighting innovative objectives in their main transport intervention (Chen & Silva, 2021), while others do not. Poor climate change information can reduce the availability of human resources, and thus condition the entire process of city change and planning (Herrera & MacAskill, 2021).

The regime conditions contemplated are infrastructure (INF), market attractiveness (MAT), system efficiency (SEF) and social impact (SIM), all of which are linked in their definition to the urban mobility system. The design and implementation of a strategy to achieve a smart city, must be adapted to the context conditions and requires infrastructures appropriate to our time (Herrera & MacAskill, 2021; Kim, 2022; Noori et al., 2020; Spickermann et al., 2014). City infrastructures and systems provide utility and services, and influence social dynamics and practices. In many cities and regions, infrastructure development is guided by strategic planning, sustainability, and medium- and long-term spatial direction (Carroli, 2018). Effective adaptation of transport infrastructures is crucial to make urban environments more resilient to climate change impacts (Herrera & MacAskill, 2021).

Multimodal and user-centric, MaaS promotes a shift towards sustainable transport modes and can bring new tools to analyse and monitor the mobility situation, but also implies policy, regulation and technical elements (European Comission, 2019a) The implementation of smart mobility innovations has the potential to deliver the benefits of the multimodal system, which determine the market attractiveness as a cooperator in terms of service, information and data, and according to a price and the distribution of the incomes (European Commission, 2019a; Ho et al., 2020; Lyons et al., 2020; Sarasini & Langeland, 2021).

Sustainable mobility conceives commuting as a value-generating activity (Noy & Givoni, 2018). Therefore, the application of sustainable mobility innovations are linked to an increase in the quality of life in urban areas and to an increased efficiency in the use of transport networks (Batarra et al., 2018; Esztergár-Kiss & Kerényi, 2020). Smart mobility is the main option to pursue more sustainable transport systems (Batarra et al., 2018; European Commission, 2019a; Surdanja et al., 2020), linked to a reduction of social and environmental costs and increasing social equity (Butler et al., 2020; Docherty et al., 2018). Since there is a mismatch between smart and sustainable (Noy & Givoni, 2018), in our model the outcome to be studied, through the niche level, is the sustainable mobility score (SMS). This index indicates the degree to which the city invests and makes the structural changes necessary to achieve sustainable mobility.

Application of QCA to sustainable mobility study

When it comes to establishing multiple and complex causality, fsQCA allows the best of both quantitative and qualitative approaches (Finn, 2022). QCA assume that the influence of different attributes on a specific result depends on the way in which they are combined, rather than the isolated levels of the individual attributes (Wu et al., 2021). The behavior of complex systems such as sustainable mobility is the result of the interaction of multiple components, where the outcome is greater than the sum of the parts involved (Gruber, 2020).

For the study of sustainable transitions –like mobility-, QCA is employed (Becker et al., 2021; Canitez, 2019; Köhler et al., 2019; Medina-Molina et al., 2022). Indeed, QCA has been applied to explain the complex interconnection between factors and actors at different levels involved in the diffusion and adoption of mobility innovations (LLopis-Albert et al., 2021a, 2021b; Medina-Molina et al., 2022; Wu et al., 2021). Finally, QCA is well suited for work with a sample size of around fifty cases (Ide & Mello, 2022), such as the present work.

The use of QCA offers four distinct advantages: the identification of patterns of joint causality; the distinction between necessary and sufficient conditions; a middle ground between quantitative and qualitative approaches; and, the reinforcement of the other methods strength (Ide & Mello, 2022). The last advantage mentioned - the high potential for combination with other methods such as regression analysis - allows for triangulation of results and more nuanced findings (Ide & Mello, 2022). A multi-method approach is advocated because while QCA allows identifying the different parts that make up the causal configuration by answering how, the application of complementary techniques allows answering how the causes contribute to the outcome (Finn, 2022). At other times it refers to a mixed method in which QCA allows the identification of the conditions that determine the emergence of an outcome, while regression establishes the individual impact of the different conditions (Wagemann et al., 2016).

Theoretical background

A sustainable approach to urban mobility

In this section we present different solutions linked to sustainable mobility that have been developed in recent years. Legislation and appropriate governance measures will be needed to ensure that new mobility systems complement, rather than compete with, public transport (European Comission, 2019b). Public authorities will need to ensure that all the players contribute to a more efficient, flexible and convenient mobility system (European Comission, 2019c; Ganapati & Reddick, 2018).

The challenge of shared mobility emerges as different additional sustainable mobility options (Arias-Molinares & García-Palomares, 2020; Bieliński et al., 2020; European Comission, 2019a, 2021; Luo et a., 2021; Sarasini & Langeland, 2021): free floating car sharing and public bike rental systems, e-scooter sharing and e-moped sharing, and on-demand mobility concepts (ride hailing and ride sharing). Shared mobility is defined as the short-term access to shared vehicles according to the user's needs and convenience, instead of requiring vehicle ownership (Arias-Molinares & García-Palomares, 2020). These services operate in central zones for short distances and can supplement traditional public transport, in situations where they can not fulfill alone the user's needs, and round out a comprehensive transport supply to provide a viable alternative to private vehicles (Arias-Molinares & García-Palomares, 2020; European Comission, 2019a). Shared mobility services are seen as a possible basis of a more sustainable mobility system in terms of improvements in energy efficiency and urban air quality; greater use of renewable fuels; reduced congestion and improved accessibility (Sarasini & Langeland, 2021).

Smart mobility encompasses both people and goods transport, as well as the dissemination of information through digital media (Del Vecchio et al., 2019; Orlowski & Romanowska, 2019). Smart mobility, a dominant paradigm within sustainable mobility, involves an integrated system - not the union of several projects - and a set of actions related to urban transport and aimed at sustainability (Batarra et al., 2018). The main objective of smart mobility is to connect city resources - people, vehicles and infrastructure - through information flows managed in real time (Fonzone et al., 2018; Kim, 2022; Orlowski & Romanowska, 2019; Surdanja et al., 2020). It is a user-generated and user-centric information approach that emerges from the union of technical and business model disruptions (Docherty et al., 2018; Pangbourne et al., 2020). Therefore, it tries to influence changes in the transportation system with the view to improve the overall environmental, social, and economic outcomes of cities (Butler et al., 2020) and more efficient use of infrastructure (Butler et al., 2020; Sunardi et al., 2020). Therefore, smart mobility is considered as a fundamental part of the smart city strategy (Del Vecchio et al., 2019; Fonzone et al., 2018; Surdanja et al., 2020).

Combining different means of shared transport is becoming a common process supported by the rise of MaaS, that proposes a sustainable, healthy, and inclusive urban transport (Böcker et al., 2020; Hensher et al., 2021; Muller et al., 2021; Pangbourne et al., 2020). MaaS integrates all public and private transportation modes available in a city into a single platform, offering the user the option to plan, book and pay for their transportation within the same application (Sarasini & Langeland, 2021). MaaS may be a valuable ally for cities to reach their mobility goals (European Comission, 2019a y 2019c; Kamargianni & Goulding, 2018). MaaS aims to provide valid alternatives to private car ownership and is thus billed for its sustainability potential, achieved via changes in travel behaviour (Sarasini & Langeland, 2021). MaaS faces challenges (Lyons et al., 2020) related to its commercial viability (European Comission, 2019a; Hensher et al., 2021; Ho et al., 2020), and to the sustainability of its implementation, since it seeks to maximize travel (Pangbourne et al., 2020).

Although MaaS has a high potential to increase the use of public transport, it is unclear whether it will be sufficient to bring about a real transition (Ho et al., 2020; Pangbourne et al., 2020). MaaS systems are innovations that require changes on both the supply side (infrastructure, governance, regulation and delivery) and demand side (preferences and behaviour of individuals and organisations)

(Li et al. 2021; Lyons et al., 2020). Different scenarios have been proposed to analyse the impact of these systems on emission reductions (3-4% the most conservative alternative, and 43-54% the most optimistic one) (Labee et al., 2022).

The relevance of context in multilevel transitions to mobility

Sustainability requires considering the space where the activity takes place, not only from a physical perspective, but also from a social one in which cultural, regulatory and physical processes converge (Bögel et al., 2022). In fact, the maturity of smart mobility services is established in terms of their social acceptance (Corazza & Carassiti, 2021). The diffusion and adoption of radical innovations, such as those linked to sustainable mobility, face increasingly complex contexts that condition their development (Gruber, 2020; Ulmanen & Bergek, 2021).

The context is the place where transitions occur and its study encompasses the institutional conditions, networks, actors and resources that endow it with diversity, and impact the development of transitions to sustainability (Peris-Blanes et al., 2022). Since mobility systems are not monolithic and transitions require interdisciplinary analyses, explaining transitions to new mobility solutions requires applying the MLP. These levels are called landscape, regime and niche. The landscape is the environment -economic, political and legal- in which organisations operate, the space in which different regimes compete with their own rules, structures and actors (Canitez, 2019). The regime represents the interdependence between actors, technologies and institutions and explains how stability emerges through complex socio-technical configurations (Schippl & Truffer, 2020). Niches are the space where innovation is developed, which in case of being successful, it will be a departure from the dominant regime.

Propositions

To analyse changes in cities, urban transformation is an approach that considers both the processes and dynamics occurring in cities and their interaction with the context (Hölscher & Frantzeskaki, 2021). Such approach recalls the need for radical innovations to take place in order for cities to achieve the necessary social and environmental improvements (Kokko & Fischer, 2021). Smart city projects are often used to support city transformation (Ntafalias et al., 2022), as turning a city into a sustainable smart city requires an effective and efficient transformation process (Ibrahim et al., 2018). Although the terms transition and transformation are sometimes used synonymously, there are differences between the two. Thus, while transformations are related to a "change in form" indicating a relative and contextual change that is known as the difference between two points in time, transitions focus on "going across" processes (Maasen & Galvin, 2019).

Smart city initiatives, including smart mobility, are complex transformational processes consisting of deep modifications in the hard and soft components of the existing urban regime (Esposito et al., 2021). Many mobility-related debates discuss whether the property-linked regime will persist, or will be replaced by an access-linked one (Köhler et al., 2020; Truffer et al., 2017). The urban view is important in the study of transitions, as they mobilize different actors and facilitate the diffusion of niche innovations (Köhler et al., 2019). As protected spaces, niches allow the rooting of radical innovations such as the one corresponding to micromobility (Corazza & Carassiti, 2021; Köhler et al., 2019; Sarasini & Langeland, 2021).

Demographic changes and environmental issues are increasingly influencing local policies. Macro elements, linked to landscape, can condition the adoption of policies to achieve sustainable development. They are presented as landscape pressures on a market-oriented urban regime (Hernandez-Palacio, 2017). Transitions studies emphasize place specificities and interconnections between actors, levels and scales in transformation processes involved in radical and multidimensional urban changes (Peris-Blanes et al., 2022). The MLP analysis of city transformation suggests the need to develop actions at two levels: (1) at the regime level, new planning instruments towards a gradual regime evolution are required; (2) at the niche level, new and diverse niche experiments should be implemented (Hernandez-Palacio, 2017). Assessing the readiness of cities to implement innovations linked to the smart city is essential (Noori et al., 2020). Readiness refers to the willingness or state of being ready for something, a concept that goes beyond maturity, treated as a measure of repetitive and defined organizational processes (Orlowski, 2021).

Some studies detect a spatial influence on mobility, which could imply the existence of externalities and interrelationships between influential factors at different levels (Mendiola & González, 2021). Thus, there are interrelationships between population density and infrastructure in determining the mobility technologies and services used (Schippl & Truffer, 2020). It is necessary to promote the conditions required for sustainable mobility through the development of intelligent transportation technology and systems (Esztergár-Kiss & Kerényi, 2020), as well as to increase smart infrastructures (Docherty et al., 2018). A more efficient use of vehicles and infrastructures, optimizes the performance of the intelligent mobility system (Butler et al., 2020; Docherty et al., 2018; European Commission, 2019a; Sunardi et al., 2020). Based on the above, the following proposition is suggested:

Proposition 1. MLP conditions interact with each other to explain the suitability of implementing sustainable mobility solutions.

From the sociotechnical transitions approach, the context is the configuration of characteristics - local, regional or national - that condition its performance (Canitez, 2019; Ulmanen & Bergek, 2021). A wide range of socio-demographic, economic and environmental aspects determine urban mobility behaviour (Punzo et al., 2022). While context is deeply rooted in local conditions, it is also shaped by regional, national and global issues (Peris-Blanes et al., 2022). Transformation in cities focuses on unraveling the diverse, local, regional and global factors, processes and interactions that converge in cities as places of transformations, conditions that could shape trajectories and block the development of others (Hölscher & Frantzeskaki, 2021; Schippl & Truffer, 2020).

In this sense, identifying barriers to transit towards sustainable mobility does not help its development, as it could require adaptation to the context, as well as identifying what kind of barriers could emerge depending on each context (Herrera & MacAskill, 2021). Territorial factors such as density, urban design, transit or accessibility have an impact on the mobility option chosen, which may differ from country to country (Cervero, 2013; Mendiola & González, 2021), and transitions towards sustainability behave in a non-homogeneous way in different territories depending on different factors (Lantz et al., 2021; Mendiola & González, 2021). These arguments allow us the following proposition to be put forward:

Proposition 2. The MLP conditions that explain the implementation of sustainable mobility solutions differ between continents.

Analysis

The first step in the analysis of our work was calibrating the valuations received by the components of the landscape, regime and niche dimensions using the 95th and 5th percentiles for complete inclusion or exclusion, and the mean for the point of maximum ambiguity (LLopis-Albert et al., 2021a,b; Pappas & Woodside, 2021). To avoid the impact of unsustainable hypotheses, Enhanced Standard Analysis was used, opting for the complex solution by describing the cases in great detail (Oana et al., 2021). The interest explaining in detail the solutions reached, determined to discard the parsimonious solution. In addition, the intermediate solution was not chosen due to the lack of directional expectations strongly supported by the literature.

Analysis of the interaction between MLP conditions in explaining the suitability for implementing sustainable mobility solutions

To explain how the different conditions of the MLP interact in the suitability for implementing sustainable mobility solutions, the Two-Step Protocol was applied given that between landscape and regime conditions, a distinction can be made between remote (landscape) and proximate (regime) factors. This protocol proposes a first phase corresponding to a necessity analysis for the remote conditions, and a sufficiency analysis for the nearby conditions and those that have proved to be necessary (Schneider, 2019). The SetMethods package of RStudio was used in this analysis.

Within the first step of the Two-Step Protocol, the analysis of the necessary conditions was carried out. No atomic condition was found to be necessary for the suitability of implementing sustainable mobility solutions (SMS) or its negation (~SMS). Therefore, supersubset with a consistency of inclusion (incl.con) of 0.9 and a Relevance of Necessity (RoN) of 0.6 were identified and a supersubset for SMS consisting of INN+DEN (inclN=0.905; RoN=0.604; covN=0.665), which was named CIT, was necessary. It can be considered a supersubset that innovations emerge the best in dense and mixed urban structure (Kiuru & Inkinen, 2017). In the analysis of the necessary conditions, both coverage and RoN were used in line with literature recommendations (Mattke et al., 2021).

Enhanced Standard Analysis was then applied to establish sufficient conditions. No simplified contradictory hypotheses were identified, so only implausible counterfactuals had to be eliminated (not applicable to the ~SMS analysis as there were no necessary conditions).

The enhanced complex solution for SMS can be observed (Table 2), composed of three conjunctions with parameters exceeding the required levels: INF*MAT*SEF*CIT (inclS=0. 916; PRI=0.865; covS=0.776; covU=0.029), INF*MAT*SIM*CIT (inclS=0.903; PRI=0.843; covS=0.765; covU=0.018) and INF*SEF*SIM*CIT (inclS=0.922; PRI=0.876; covS=0.786; covU=0.039). This solution can be synthesised as INF*CIT*(MAT*SEF+MAT*SIM+SEF*SIM).

The complete solution (see Table 3) has a consistency of 0.902 and a coverage of 0.833, thus correctly explaining the result under analysis.

The complex solution for ~SMS, which exceeds the required levels, is presented in Table 3 and is composed of three conjunctions: ~INF*~SEF (inclS=0.959; PRI=0. 936; covS=0.806; covU=0.496), ~INF*MAT*SIM (inclS=0.905; PRI=0.629; covS=0.330; covU=0.019) and MAT*~SEF*SIM (inclS=0.924; PRI=0.651; covS=0.352; covU=0.042). This solution can be synthesised as MAT*SIM*(~INF +*~SEF) +~INF*~SEF. Again, the values achieved allow us to affirm that it correctly explains the ~SMS with a consistency of 0.923 and a coverage of 0.877.

The graphical representation of the solutions (Fig. 1) shows the existence of three cases of deviant coverage for the solution explained by SMS, all of them European cities (Madrid, Barcelona and Milan). These are cities that present the result of interest, but are not explained by the solution reached. The three cities show a common pattern, with low levels of NNI, which is a component of the CIT supersubset. Moreover, in all three cases, their position in the index analysed worsens, with Madrid moving from 30th to 35th position between the 2020 and 2021 indices, Barcelona from 26th to 34th and Milan from 24th to 32nd. In the case of the ~SMS there are also deviating coverage cases, three of which correspond to US/Canadian cities. In all three cases (Dallas, Houston and Atlanta), SIM is the indicator in which they have the best rating, a component that puts them on the road to SMS implementation.

Table 2
SMS complex solution.

	inclS	PRI	covS	covU
INF*MAT*SEF*CIT	0.916	0.865	0.776	0.029
INF*MAT*SIM*CIT	0.903	0.843	0.765	0.018
INF*SEF*SIM*CIT	0.922	0.876	0.786	0.039
Solution	0.902	0.846	0.833	

Table 3
~SMS complex solution.

	inclS	PRI	covS	covU
~INF*~SEF	0.959	0.936	0.806	0.496
~INF*MAT*SIM	0.905	0.629	0.330	0.019
MAT*~SEF*SIM	0.924	0.651	0.352	0.042
Solution	0.923	0.877	0.868	

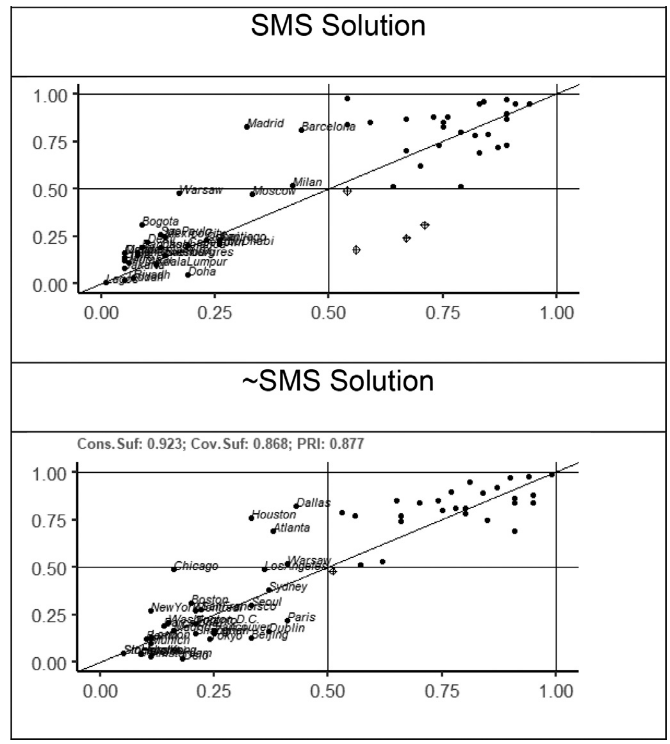

Fig. 1. Sufficiency solutions for SMS and ~SMS.

Analysis of the differences between continents in the explanation of the MLP conditions that explain the implementation of sustainable mobility solutions

To establish whether the solutions obtained are generalisable across continents, a cluster analysis was performed to indicate whether the solution obtained for the pooled data using QCA is appropriate for each sub-population's data. In this case, the grouping used for the data would be correct, otherwise it would not be correct, being an artifice to group cases that follow different causal logics (Oana & Schneider, 2018). The cities were grouped by continent that acts as a cluster.

As can be seen in Table 4, consistency, distance and coverage allow us to establish that there are no differences between continents among countries in achieving the SMS.

Table 4
Cluster analysis SMS result.

	INF*MAT*SEF*CIT	INF*MAT*SIM*CIT	INF*SEF*SIM*CIT
Consistencies			
Pooled	0.916	0.903	0.922
Between Africa (5)	1.000	1.000	1.000
Between Asia-Pacific (13)	0.994	0.978	0.994
Between Europe (16)	0.999	0.989	0.998
Between Latin-America (8)	0.989	0.989	0.966
Between Middle-East (5)	0.831	0.692	0.831
Between US/Canada (12)	0.781	0.778	0.799
Distances			
From Between to Pooled	0.04	0.055	0.037
Coverages			
Pooled	0.776	0.765	0.786
Between Africa (5)	0.537	0.537	0.687
Between Asia-Pacific (13)	0.772	0.653	0.720
Between Europe (16)	0.707	0.746	0.742
Between Latin-America (8)	0.524	0.530	0.506
Between Middle-East (5)	1.000	1.000	1.000
Between US/Canada (12)	0.966	0.964	0.986

The data presented in Table 5, allow us to establish that there are no differences between continents among countries in achieving the ∼SMS.

As can be observed in Fig. 2, a common pattern emerges in the consistency of the different solutions that make up the SMS explanation. While the clusters corresponding to the cities of Africa, Asia/Pacific, Europe and LatinAmerica present higher consistencies than the pool of all, the cities of MiddleEast and US/Canada present lower levels. However, we recall that such differences are not relevant for discarding the pooling of cities. In the case of the ∼SMS explanation, the situation is more ethereal but the differences are not relevant.

Regression analysis in order to establish net effects

To establish the individual effects, a multiple regression was performed, in which SMS was explained on the basis of INF, SIM, MAT, SEF and INN. This regression has an adjusted coefficient of determination of 0.821, and an F-value of 55.052 with 5 degrees of freedom. The resulting equation, shows that the corresponding probabilities are the resulting SMS= -2.236(0.608) +0.347INF(0.008) -0.055SIM(0.598) -0.032MAT(0.721) +0.704SEF(0.000) -0.070INN(0.234). Thus, the multiple regression shows that SEF and INF are the conditions with a significant effect on the explanation of SMS, with SEF (0.704) having twice the effect of INF (0.347).

Table 5
Cluster analysis ∼SMS result.

	∼INF*∼SEF	∼INF*MAT*SIM	MAT*∼SEF*SIM
Consistencies			
Pooled	0.959	0.905	0.924
Between Africa (5)	0.983	1.000	1.000
Between Asia-Pacific (13)	0.981	0.789	0.989
Between Europe (16)	0.870	0.820	0.797
Between Latin-America (8)	0.922	1.000	1.000
Between Middle-East (5)	1.000	1.000	1.000
Between US/Canada (12)	1.000	0.996	0.971
Distances			
From Between to Pooled	0.02	0.04	0.031
Coverages			
Pooled	0.806	0.330	0.352
Between Africa (5)	0.961	0.115	0.115
Between Asia-Pacific (13)	0.911	0.266	0.277
Between Europe (16)	0.705	0.760	0.883
Between Latin-America (8)	0.901	0.191	0.191
Between Middle-East (5)	0.848	0.312	0.298
Between US/Canada (12)	0.450	0.494	0.544

Discussion

Among the indicators developed from the academic field, the importance given to infrastructure is common, both mobility and technological. In the case of the indicators developed by consultancy firms, the efficiency of the system, innovation and social impact are added to the above. This is a pattern that is reaffirmed by the results of the present study. We recall that based on the analysis of net effects, only INF and SEF are significant when studying the effects in isolation. We recall that the relevance played by the required changes in infrastructures makes the STT perspective particularly suitable for explaining transitions in mobility (Medina-Molina et al., 2022).

In the analysis of the necessary conditions shows that for SMS a high population density and high level of innovation in the city are the only ones that appear. If we focus on the first element (DEN), smart mobility is shown to be an effective approach for sustainable mobility in cities with high density (Muller et al., 2021). It has already been stated that high population density is identified as one of the factors explaining mild urban smartness levels (Yigitcanlar et al., 2022). Regarding innovation, this could be reinforced through optimal dissemination of information on climate change and the effects it will have on the city (Herrera & MacAskill, 2021).

From the analysis of sufficient conditions for SMS, the decisive role of infrastructure for the successful implementation of sustainable mobility is evident (Butler et al., 2000; Docherty et al., 2018; European Commission, 2019a; Sunardi et al., 2020). However, one of the main findings of the present work is that this role requires conjunction with three other conditions. The first one refers to the city characteristics referred to the above, the other two are combinations of three of the regime conditions contemplated -MAT, SEF, SIM-. Thus, in line with Kim (2022) we can state that, while previously the focus of the smart city was on urban infrastructures, the current focus needs to be complemented by the provision of smart city services. The development of sustainable infrastructures can, and in our case must, involve changes in other areas of the city (Jain & Rohracher, 2022). Secondly, it is observed that the union of SIM and MAT are part of a conjunction that is sufficient for SMS to occur. Such a conjunction of conditions is very close to Butler et al. (2020), for whom the activation of smart mobility can help to generate social equality. Finally, in line with Docherty et al. (2018), SEF appears as a

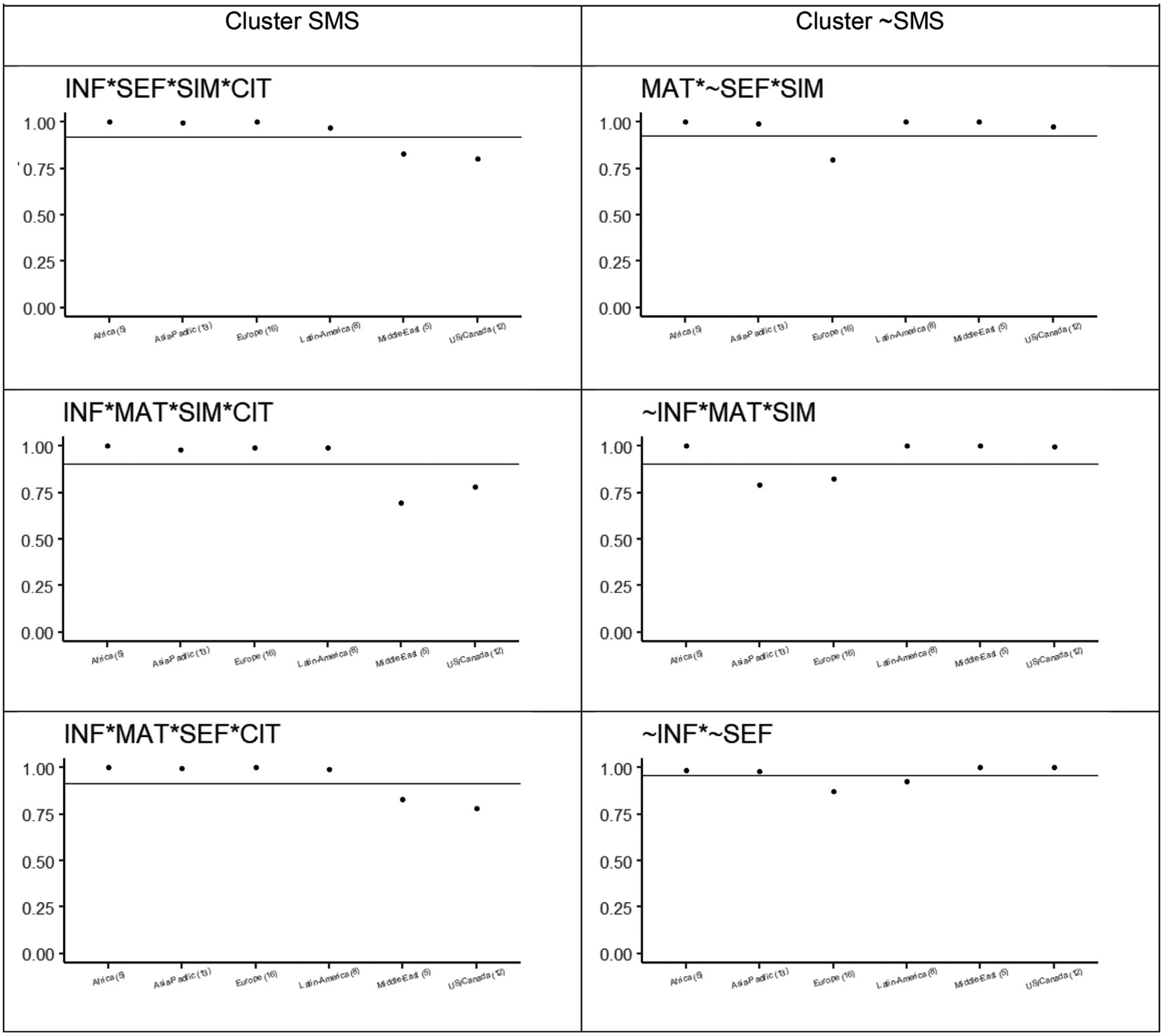

Fig. 2. Cluster analysis for SMS and ∼SMS.

condition for achieving smart mobility in the case of possessing the necessary infrastructures. This efficiency, when linked to new forms of governance, makes it possible to coordinate supply and demand (European Commission, 2019c). In cities with good mobility systems, ICT is an interesting way to increase their efficiency (Batarra et al., 2018). The fact that landscape conditions are part of the sufficient conditions alongside regime conditions puts us in line with those who claim that mobility is following a transformational path (Boons et al., 2021).

With the results achieved, we can see how, thanks to joint causation, three of the conditions that had a non-significant and negative effect -SIM, MAT and INN-, come to play a relevant role in the sufficient conditions that explain the emergence of SMS. In fact, the third of the conditions that turns out not to be significant when studied in isolation is part of the supersubset necessary for SMS.

The analysis of the sufficient conditions for ∼SMS shows that they are composed of different conjunctions of ∼INF, ∼SEF, MAT and SIM. The case of ∼INF reaffirms how cities lacking the required infrastructure need to make an additional effort to implement smart mobility solutions (Bartarra et al., 2018; Kammargianni & Goulding, 2018). The absence of infrastructure hinders the development of the smart transition (Butler et al., 2020; Docherty et al., 2018; Sunardi et al., 2020). In contexts lacking of transport infrastructure, the use of technologies can be converted into a label rather than an integrated element of urban policies (Batarra et al., 2018). Furthermore, the presence of ∼SEF shows how the absence of system efficiency can be a necessary and sufficient condition for such an outcome (European Commission, 2019a). Less in line with previous literature is the aforementioned role played by the conjunction between SIM and MAT. Las ciudades cubiertas por estas solcuiones se encontrarían ante la dificultad planteada de no poder ser smart sin ser sostenible (Yigitcanlar et al., 2019; Zhao et al, 2021). In this sense, we are facing cities that are not ready to implement sustainable mobility solutions, but could perhaps strengthen their position in one of the other axes of the smart city strategy.

As discussed above, the components of the MLP interrelate with each other in the emergence of SMS and ∼SMS. Thus, proposition 1 is accepted.

In relation to proposition 2, it is worth mentioning that the results of the cluster analysis bring us in line with those authors who claim that systemic interventions linked to climate change adaptation can be replicated in different parts of the world (Herrera & MacAskill, 2021). However, such a statement does not mean that the process we study should be considered in isolation from the context in which it develops, since the conditions analyzed at the landscape level are present in the explanation of the development of SMS but not of ∼SMS.

Therefore, the explanation of ∼SMS is a phenomenon whose explanation is alien to the context in which it develops, but it can be generalized across continents. Thus, most of the barriers to effective adaptation planning, are originated in the social infrastructure component of socio-technical systems and not in the technical component (Herrera & MacAskill, 2021). Thus, proposition 2 cannot be accepted since it establishes the non-existence of specific clusters when analysing the explanation of SMS and ∼SMS between different geographical areas. This possibility of extrapolating the results between different geographical areas, has been favoured by equifinality. It is the existence of different possible solutions, the underlying cause behind the fact that the lessons learned regarding the conditions which lead to the occurrence of SMS or ∼SMS can be considered extrapolated between cities in different geographical areas.

In this line of similarity between solutions applicable to different geographical areas, previous work has already tried to identify globally shared patterns between countries with different contexts regarding the development of smart city projects (Neirotti et al., 2014). The attention to landscape conditions as well as the existence of different explanatory combinations of SMS and ∼SMS allow us, as has been claimed, to link perspectives and overcome limitations by linking place-based learning in a global discussion that enables learning between cities (Hölscher & Frantzeskaki, 2021). Furthermore, the results do not place us in opposition to previous literature, but allow us to clarify some approaches. Thus, we can understand that the results are in line with Esposito et al. (2021) when they indicate that there is no single recipe for the implementation of smart city solutions. In fact, in our work there are three recipes for both SMS and ∼SMS.

Conclusions and limitations

Conclusions

This paper attempts to analyze whether the configurations of elements that determine the implementation of urban sustainable mobility systems are generalizable in different contexts (continents). As an answer to the first objective, it has been found that the elements included in the different levels of the MLP interact in the determination of SMS and ∼SMS. While landscape and regime level conditions interact in the determination of SMS, the determination of ∼SMS is generated exclusively by regime level conditions. The answer to the second research objective is that, contrary to our proposition, the patterns determining SMS and ∼SMS can be extrapolated between continents. However, this does not mean that the explanation of SMS is context-independent, as the landscape condition reflects whether the city is densely populated or innovative.

Theoretical and management contributions

Among the theoretical contributions of the paper it is found the suitability of QCA to analyse transitions towards sustainable mobility. This is based on the fact that the SMS and ∼SMS are explained by different combinations of conditions, which can only be ascertained from the asymmetry. Secondly, and thanks to equifinality, we see that different combinations of conditions -three in each case-, serve to explain the study results. Finally, we show the effect of conjunctural causation, so that the effect of the conditions depends on those to which they are related. Thus, the MAT*SIM conjunction, part of one of the solutions that determines SMS, is also part of another that ∼SMS. As we have indicated, some of the conditions whose net effect is not significant on the basis of regression results, come to play a relevant role in explaining SMS and ∼SMS when QCA is applied.

Finally, there are two ways to explain ∼SMS. The first one could be considered in line with previous literature (∼INF*∼SEF). It shows that the lack of infrastructure and efficiency of the system would be sufficient for ∼SMS. The second path, to whose first component attention has already been drawn, is that the conjunction between MAT and SIM is part of two additional solutions leading to ∼SMS, the one linked to ∼INF and the one corresponding to ∼SEF. Thus, we can establish that ∼INF and ∼SEF act as catalysts for the effect of other conditions on ∼SMS.

Within the management contributions, it stands out that infrastructure maintains a relevant role in the implementation of sustainable mobility systems. However, it requires the existence of other characteristics of the city and elements of the mobility system, without which its presence would not allow us to affirm that cities are making the necessary effort and investments to implement sustainable mobility services. According to the results, the implementation of sustainable mobility systems can be achieved without explicitly considering the social impact of the system.

Limitations and future lines of research

The main limitation of the study is that we only worked with a sample of 60 cities, as well as that certain geographical areas were under-represented. Regarding future lines of research, it would be interesting to analyse the combinations that determine to what extent cities are ready to implement mobility innovations and not only those linked to sustainable mobility.

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.

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