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Article

Causal mechanisms in sustainable urban mobility transitions

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Abstract: Cities tackle sustainability challenges by modifying their socio-technical systems to adopt more sustainable production and consumption practices, a process known as transitions. Understanding the mechanisms that either facilitate or hinder these transitions is critical. Therefore, this paper aims to identify the mechanisms that can favor or slow down the implementation of sustainable urban mobility solutions using Set-theoretic Multi-Method Research (SMMR), which combines cross-case of Qualitative Comparative Analysis (QCA) with within-case via process-tracing in a study of 60 cities. The results show how the degree to which cities make structural changes to implement innovative sustainable mobility solutions, as well as their negation, are explained by five distinct conjunctions. It is also found the existence of lock-in mechanisms that prevent cities from making necessary structural changes for implementing innovative sustainable mobility solutions. However, no unlocking mechanisms were found that trigger such transitions. The main contribution of the paper is the systematic approach used for selecting cities for within-case analysis and identifying existing lock-in mechanisms.

Keywords: urban transitions; causal mechanism; SMMR; urban mobility; QCA

1. Introduction

The negative environmental externalities resulting from population concentration in urban areas place them at the core of addressing sustainability challenges (Di Giulio et al., 2018; Irvine and Bai, 2019). Advances in sustainability require radical changes and experimentation with sustainable innovations (Van den Heiligunberg et al., 2022). One of the approaches used to explain how radical innovations contribute to environmental improvements is urban transformation, which identifies the causes behind certain urban areas becoming more sustainable (Grainger-Brown et al., 2022). This transformation is articulated through transitions, complex processes of change, in the long term, occurring across interactions between different socio-technical systems (Aina, 2017; Irvine and Bai, 2019; Jain and Rohracher, 2022; Kanger, 2021; Kanger et al., 2021; Kim, 2022; Kivimaa et al., 2022; Löhr et al., 2022).

The concept of sustainability transitions explores structural and systemic shifts towards sustainability; it delves into changes in production and consumption patterns, as well as associated social challenges (Simoens et al., 2022a). The accumulation of gradual transformations creates space for transitions when dominant regimes are influenced not only by external changes and niche innovations but also by their inherent instabilities (Frantzeskaki and Loorbach, 2010). These dynamics do not guarantee that a transition will emerge, but rather create opportunities for potential transition to occur. As highlighted by Jørgensen (2012) and Geels (2014), the internal dynamics of regimes, including their instabilities, play a crucial role alongside external pressures in shaping the spaces where transitions can potentially unfold. The available resources thus endow cities with significant roles within the transition processes towards sustainability (Loorbach et al., 2020; Tura and Ojanen, 2022; Valketing et al., 2017). The challenge of climate change requires large-scale transitions in mobility systems (Kanger, 2021).

Mobility, as a socio-technical system, plays a central role in the development of cities (Aljoufie et al., 2013), and is also the source of many of the environmental challenges. Cities are therefore urged to alter urban mobility systems through innovations, needing to understand the readiness of and mechanisms of urban adaptation. These challenges highlight the importance of exploring how cities can transition to sustainable urban mobility systems (Kanger et al., 2021). Understanding these mechanisms -the process through which a city becomes ready to adopt sustainable practices and adapts its urban fabric to new realities- is crucial for leading transition towards sustainable urban mobility (Papachristos, 2018). These mechanisms reveal the gears of social processes (Hedström and Wennberg, 2017; Past et al., 2020). In other words, the mechanisms refer to the process of change whereby a treatment variable causally affects an outcome and allows us to distinguish between causality and mere association (Hedström and Swedberg, 1998; Past et al., 2020). A mechanism is not an additional condition to be included in a model, but rather the connection between the identified solution and the outcome (Schneider, 2024). Therefore, in order to deepen the knowledge of the factors that cause transitions it is important to identify the causal mechanism that leads to them (Apajalahti and Kungl, 2022; Geels, 2018).

To drive urban transformation, it is necessary to discern the mechanisms that explain the operation of innovative systems, enabling cities to emerge as leaders in sustainability (De Sá et al., 2019; Grainger-Brown et al., 2022; Irvine and Bai, 2019; Phirouzabadi et al., 2022). This recognition sparks an interest in exploring the interactions within multi-system dynamics that are pivotal for urban transformations (Geels, 2019; Kanger et al., 2021). Despite the relevance of case analysis -within case- using mechanistic evidence (Beach, 2019), there remains a gap in understanding how these mechanisms influence the effectiveness of innovative mobility solutions. Addressing this first gap, this paper employs process tracing—a method that provides a detailed establishment of causal links in individual cases (Mello, 2021)—to answer the following research question: Can we identify the mechanisms that link structural changes related to the implementation of sustainable urban mobility solutions to the conditions enabling their success? This approach aligns with Set-theoretic Multi-Method Research (SMMR), which asserts that causal analysis requires both a cross-case effect and a within-case mechanism, reflecting the perspectives from multiple disciplines (Schneider, 2024).

Transitions do not occur in an easy way due to the existing systems, characterized by stability and lock-in (Verbong and Geels, 2010). Therefore, research on sustainability transitions highlights the critical concepts of path-dependence and lock-in mechanism, which elucidate the stabilizing dynamics that need to be overcome to foster sustainability transitions (Simoens et al., 2022b). Understanding the dynamics of stability and change is essential for accelerating transitions towards sustainability (Simoens et al., 2022a). For this purpose, the drivers conditioning transitions of urban mobility regimes towards sustainable initiatives need to be explored (Pinhate et al., 2020). This is because the mechanisms can support or harm niche innovations depending on the processes in which they are involved (Heiberg and Truffer, 2022; Tongur and Engwall, 2017). It is therefore relevant to unveil those mechanisms that can either facilitate or hinder sustainability transitions pathways (Cecere et al., 2014; Phirouzabadi et al., 2022). In this context, the terms “lock-in” and “unlock” are used to describe the dynamics within these pathways. “Lock-in” refers to a systemic condition caused by technological and institutional path dependencies, leading to rigidity and resistance to changing the prevailing path (De Oliveira et al., 2020; Khöler et al., 2019; Klitkou et al., 2015; Kuokkanen et al., 2017). This concept helps to explain why certain systems, including energy, nuclear power, agricultural innovation, food systems, and transportation, demonstrate persistent adherence to established systems (Kuokkanen et al., 2017). Conversely, “unlock” describes how innovative solutions are delayed or suppressed due to the dominance of existing systems, effectively preventing alternative pathways from emerging (Klitkou et al., 2015). Understanding these dynamics is crucial for cities aiming to implement sustainable urban mobility initiatives. By examining lock-in mechanisms from a socio-technical perspective- an area that remains underexplored (Simoens et al., 2022b), being this the second research gap. This paper aims to identify the mechanisms that are able to link the readiness of cities to adapt to sustainable urban mobility practices with the structural changes and conditions that enable or inhibit such transitions. This is because understanding the interventions, barriers, and opportunities for urban adaptation remains a challenge for scholars and policy makers (Di Giulio et al., 2018). Conceptual frameworks based on middle-range theories, causal mechanisms, and process tracing are relevant for explaining socio-technical transitions (Geels, 2022). Additionally, a comparative perspective on lock-in mechanisms and transition processes provides a clearer understanding of transitions as outcomes of the interactions among path-dependence, path-creation, and path-destruction (Klitkou et al., 2015). Therefore, the objective of this paper is to identify, following a systematic procedure, the existence of mechanisms that link the structural changes related with the implementation of sustainable urban mobility solutions with the conditions that enable them.

Taking into account that the traditional analytical methods receive criticism for how they explain causal mechanisms (Hedström and Wennberg, 2017; Past et al., 2020), in this paper we employ Set-theoretic Multi-Method Research (SMMR) -the union of Qualitative Comparative Analysis (QCA) and process-tracing. This is because QCA through cross-case analysis identifies relevant potentially causal conditions that enable the occurrence of a phenomenon (Alamos-Concha et al., 2021; Haesebrouck and Thomann, 2021; Papachristos, 2018; Rubinson et al., 2019). Subsequent, within-case analysis via process-tracing disassembles the way in which such conditions connect to the outcome allowing for the identification of mechanisms (Haesebrouck and Thomann, 2021; Hedström and Wennberg, 2017; Rubinson et al., 2019). Furthermore, integrating configurational and mechanistic approaches offers an accurate representation of the investigated reality, making it possible to identify potential causes and select cases for within-case analysis (Krupnik and Koniewski, 2022). Indeed, process-tracing is considered suitable for identifying the mechanisms and deepening into its knowledge (Cecere et al., 2014; Khöler et al., 2019; Papachristos, 2018).

On the other hand, historical processes of urban mobility transitions are far from being simple linear processes driven exclusively by technological innovations (De Sá et al., 2019). Therefore, the present work applies the Multi-Level Perspective (MLP) of Socio-Technical Transitions (STT) that directs attention to the co-evolutionary and multi-dimensional interactions of infrastructure, technology, policy, norms and knowledge to explain transitions towards sustainability (Pinhate et al., 2020). The application of QCA to MLP allows us to know the different recipes that explain the presence and negation of the degree to which cities make structural changes to implement innovative sustainable mobility solutions. It also discovers the existence of mechanisms that determine the implementation of sustainable mobility solutions. The main contribution of this work consists of revealing the existence of lock-in mechanisms that slow down the implementation of innovations in sustainable mobility based on a systematic identification of the cities to be used in process-tracing.

2. Review of literature

2.1. The multilevel perspective in the study of sustainable transitions

Middle-range theories provide a limited set of interrelated propositions that aid in understanding phenomena by the combination of concepts and clarification of abstract patterns alongside explanatory mechanisms (Geels, 2007, 2011). These theories provide a satisfactory balance between accuracy of representation, generality, and parsimony -the criteria of good theory-, needing to deepen the analysis of the mechanisms (Geels, 2007; Hedström and Wennberg, 2017; Papachristos, 2018). In this context, Kaidesoja (2019) breaks down three interconnected components within middle-range theories: a conceptual framework about the studied phenomenon; a schema of the mechanism that abstractly and incompletely describes it; and a cluster of explanations based on the mechanisms of the phenomenon. The attributes of such theories render them valuable for the study of transitions towards sustainable systems (Geels, 2007, 2011). Therefore, these theories make it possible to identify the underlying conditions and mechanisms that constrain the development of sustainability transitions.

Among the middle-range theories, the Multi-Level Perspective (MLP) is a predominant framework for explaining the dynamics of socio-technical transitions to sustainable systems (Geels 2007, 2014; Van Rijnsoever and Leendertse, 2020). The MLP employs three heuristic levels: landscape, regime, and niche to explain the processes where multiple configurations of actors, resources, institutions and rules create stability and windows of opportunity for change (Irvine and Bai, 2019). In the MLP, the key question is related to how innovations evolve over time, including different pathways of change in current systems (Thaler and Penning-Rowsell, 2023). MLP argues that the introduction of niche innovations, along with changes in the context (landscape), puts pressure on socio-technical systems (regime) and triggers the transition. Despite its influence, MLP has been criticized for being too functionalist (Geels and Schot, 2007); too instrumental in the development of the concept of socio-technical transitions (Jørgensen, 2012); and also, for an excessive focus on niches as the primary locus of change, neglecting the importance of existing regimes and actors (Geels and Schot, 2007; Smith et al., 2005). Geels (2014) emphasize the relevance of the regime in processes of resistance against the implementation of innovations in the field of sustainability, proposing to consider both barriers and opportunities within existing regimes. According to MLP, social functions (such as mobility) result from socio-technical systems (Van Rijnsoever and Leendertse, 2020). Transitions towards sustainable cities involve radical and systematic changes, supported by causal links between their different levels (Costales, 2022; Jain and Rohracher, 2022).

Previous studies emphasize bottom-up dynamics when explaining the emergence of innovations. Thus, radical innovations emerge in technological niches to later enter small market niches, and subsequently diffuse into markets, replacing existing mechanisms (Geels, 2011). To overcome this bottom-up niche bias, Geels and Schot (2007) propose a typology of transition pathways based on multiple multi-level interactions, incorporating both timing and the nature of interactions, resulting in the following: (1) Reproduction process. If there is no landscape pressure, then the regime remains stable and reproduces itself. (2) Transformation. Developments in landscape when niche-level innovations are not well-developed exert pressure on the regime. Actors modify the direction of innovative activities and development paths, leading to a gradual adjustment of regimes to landscape pressures. Although innovations do not break through in this pathway, niche experiences can be transferred and accommodated within the regime. (3) De-alignment and re-alignment. If the change in landscape is large and sudden, increasing problems with the regime could cause regime actors to lose faith, leading to de-alignment and erosion of the regime. If niche innovations are not sufficiently developed, there is no clear substitute. This creates a space for the emergence of multiple niche innovations that coexist and compete for attention and resources. Eventually, one niche innovation becomes dominant, forming the core for the realignment of a new regime. Both pathways are dominated by a distributed generation and a higher focus on local infrastructures, resulting in a greater reliance on political interventions (Verbong and Geels, 2010). (4) Technological substitution. If there is a lot of landscape pressure at a time when niche innovation is sufficiently developed, it will emerge and replace the existing regime. (5) Pathways of reconfiguration. Symbiotic innovations developed in niches are initially adopted within the regime to address local issues. Additionally, they will trigger subsequent adjustments in the basic architecture of the regime. However, these pathways are not deterministic and in fact, they are influenced by social processes (Verbong and Geels, 2010).

Later, Geels et al. (2016) reformulated some of these pathways. Within the substitution pathway, two options could follow: limited institutional change through incremental adjustment, when innovations with better features disrupt existing technologies; or alternatively, rules and institutions are adjusted to conform to niche innovation. In the transformation pathway, actors may reorient towards radical niche innovations, thus breaking the lock-in in the regime and therefore being able to change their strategic direction and reorient themselves. The reconfiguration process likely coexists with limited institutional change, followed by more substantial changes as actors encounter new problems. In de-alignment and re-alignment, three situations could arise: (1) intervening actors may collapse due to landscape pressures, creating new opportunities for new entrants; (2) the decline of old technologies could create space for competing innovations; and (3) institutions may be disrupted by shocks and replaced.

The basic mechanism underlying MLP relies on actors framed by the existing regimes, which follow certain development patterns. The "gray zone" of the meso level is of great importance due to its role in societal change and coherence, emphasizing coordinated institutions and networked innovations (Jørgensen, 2012). The regime level is of primary interest since transitions are defined as changes from one regime to another (Geels, 2011; Verbong and Geels, 2010). The socio-technical regime accommodates a broad community of social groups as well as the align of their activities (Geels and Schot, 2007); therefore, they tend to be understood in terms of networks of actors and institutions situated around the development of social and economic functions (Smith et al., 2005). MLP analyzes existing regimes not only as barriers to overcome but also recognizing that ongoing processes within them provide opportunities to connect them with innovations emerging in the niche (Geels, 2007). Thus, the regime is continuously reproduced by those actors who adhere to its rules (Van Rijnsoever and Leendertse, 2020). The theory of transition is built on the idea that socio-technical regimes are developed from the stabilization of technologies and institutions within society's sectors, leading to path dependencies (Jørgensen, 2012). However, stability of the regime is a result of active resistance from the agents who operate in the niche (Geels, 2014).

2.2. The role of mechanisms in sustainable transitions

According to MLP, a transition involves the disruption of a socio-technical system and its eventual replacement or fusion with a new socio-technical system (Geels and Schot, 2007; Van Rijnsoever and Leendertse, 2020). The transition towards sustainable cities is a process involving radical and systemic changes, supported by causal links between its different levels (Costales, 2022; Jain and Rohracher, 2022; Valketing et al., 2017). Considering that socio-technical systems evolve as a result of dependencies and dynamics produced by mechanisms, different mechanisms could contribute to accelerate transitions towards sustainable mobility (Ehnert et al., 2018; Gorissen et al., 2018; Loorbach et al., 2020; Valketing et al., 2017). In this process developed at different levels, different categories of mechanisms are identified (Hedström and Swedberg, 1998; Papachristos, 2018). Understanding these mechanisms is crucial for accelerating transitions towards a sustainable mobility, considering that socio-technical systems evolve due to the dependencies and dynamics produced by these mechanisms (Ehnert et al., 2018; Gorissen et al., 2018).

A challenge for sustainable mobility transitions is the dominant and stabilized position of certain technologies, actors and social structures that could hinder some innovations. This is because an initial advantage of an innovation over competitors could lead to path dependence (Cecere et al., 2014). In sustainability transitions incumbents and followers are conditioned by lock-in mechanisms and path dependencies that benefit the market leader and may lead to maintaining unsustainable practices (Apajalahti and Kungl, 2022; Cecere et al., 2014; Geels, 2021; Gorissen et al., 2018). These path-dependency and lock-in explain the mechanisms that need to be overcome or unlocked to promote the change towards sustainability (Simoens et al., 2022a). Regime resilience refers to the extent to which it is able to withstand external pressure and co-opt niches without fundamental transformations in its basic architecture, operational node, and direction in evolution (Kanger, 2021).

Lock-in mechanisms favor the status quo by developing inertia resistant to large-scale systemic change; they are causal pathways that link systemic problems, under certain contextual conditions, leading to poor system functioning and making it difficult for innovation (De Oliveira et al., 2020; Heiberg and Truffer, 2022; Simoens et al., 2022b; Trencher and Wesseling, 2022).

Historical developments could shape the existing positive feedback mechanisms and create self-reinforcing mechanisms that reproduce (and lock-in) the actual socio-technical configuration. This self-reinforcing nature is what distinguishes lock-in mechanisms from other barriers to transition or inertia (Simoens et al., 2022a). There are different types of lock-in mechanisms (Apajalahti and Kungl, 2022; Cecere et al., 2014; Eitan and Heckkert, 2023; Geels, 2007, 2019, 2021). Path-dependency reflects the idea that the historical developments of a system or process can strongly influence its actual state and future developments, moreover, past choices and events can create a path or trajectory that constrains and shapes its possibilities (Apajalahti and Kungl, 2022; Eitan and Hekkert, 2023). When a system or process becomes path-dependent, the investments, choices, and accumulated developments can create a momentum that favors the existing path, making it difficult to deviate or switch into alternative paths. This can result in lock-ins: the system or process becomes resistant to change and perpetuates its current state or trajectory (Eitan and Hekkert, 2023).

Path dependency holds that the current configuration of a system is a consequence of its history and of the lock-in mechanisms. This mechanism acts as reinforcing feedback loops that generate an inertia that conditions the transition to sustainability reproducing a natural trajectory -regime- (Irvine and Bai, 2019; Simoens et al., 2022b). This is also called a reproductive pathway, in which the system remains relatively stable and changes occur within the logic of the dominant regime. It is also called competition, in which two innovative systems interact to generate blocking mechanisms (Phirouzabadi et al., 2022). In fact, socio-technical regimes are coherent, interrelated and stabilized configurations (Geels, 2007; Keller et al., 2022). These stabilizing lock-in mechanisms reinforce a given development pathway and involve incremental and path-dependent innovations making transitions and changing the development pathway difficult (Apajalahti and Kungl, 2022;

Cecere et al., 2014; Geels, 2007, 2019, 2021; Keller et al., 2022; Loorbach et al., 2020). Based on the above, the following proposition is put forward:

Proposition 1: The combination of conditions across various levels can explain the presence of lock-in mechanisms that prevent cities from being ready to implement sustainable mobility systems

Dominant urban socio-technical configurations need to be unlocked to move towards sustainability (Simoens et al., 2022), focusing attention on pathways of change towards emerging socio-technical systems (Jain and Rohracher, 2022). The creation of new path is generated from new or existing resources related to a certain social phenomenon (Panori et al., 2022). Over time, the combination of different technologies, processes of social learning, and the so-called "knock-on" effects can bring about a radical change to the current system (Thaler and Penning-Rowsell, 2023). Four resource formation processes are essential for path creation: knowledge generation, market formation, investment mobilization, and technology legitimation (Panori et al., 2022). Different pathways can be followed to achieve an efficient response to climate challenges (Di Giulio et al., 2018). Therefore, it is necessary to establish whether the pathways lead towards the intended sustainability (Jain and Rohracher, 2022). In this sense, there are two modes of pathway break-out: pathway dissolution, which is the unintended sequence of events leading to the weakening of multiple self-reinforcing mechanisms resulting from developments outside the control of the main actors; and, path breaking, which occurs when the main actors generate and mobilize resources that benefit emerging sectors (Apajalahti and Kungl, 2022). The creation of a path reflects a complex system of dynamics that emerge among local actors (Panori et al., 2022). The factors that weaken the lock-in mechanisms must be continuously and simultaneously reinforced to produce the path break-out (Apajalahti and Kungl, 2022).

Urban systems exhibit multiple trajectories influenced by their tolerance and resilience to external drivers of change (Grainger-Brown et al., 2022). Therefore, the reorientation of existing regimes from niche innovations requires agents to escape from lock-in to new routines, capabilities and cultural-cognitive beliefs (Cecere et al., 2014; Geels, 2021). In fact, when a socio-technical regime becomes unstable a window of opportunity for innovations is created, so that the existing lock-in becomes temporarily unlocked (Tongur and Engwall, 2017). Such a situation can be caused by a symbiosis when two innovative systems interact with a positive effect on each other, facilitating the mechanisms of change (Phirouzabadi et al., 2022). Therefore, the following proposition is put forward:

Proposition 2: The combination of conditions at different levels explains the existence of unlocking mechanisms that cause cities to be ready for the implementation of sustainable mobility systems.

3. Methodology

3.1. Model

The model proposed in this paper is the Multi-Level Perspective (MLP) framework to analyze transitions towards sustainable mobility. The MLP framework is apt for examining the urban transformation as it considers the city as an integrated socio-technical system where multiple levels interact to facilitate or hinder transitions (See **Table 1**).

Table 1. MLP-based model for sustainable urban mobility transition.

Level	**Condition/outcome**	**Description**
Landscape	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 or investment in e-charging stations?
	Social Impact-SIM	Does the city maximize societal benefits while minimizing harmful qualities like poor air quality?
Niche	Sustainability 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?

This model delineates a hierarchical structure where "conditions" at the landscape and regime levels influence the "outcomes" at the niche level. The conditions are not merely inputs but are dynamic components that interact within the city's socio-technical system to either favor or impede sustainable mobility. Then, conditions are factors at the landscape and regime levels that create the socio-technical environment necessary for transition. They include elements like innovation, infrastructural readiness, market conditions, system efficiency, and social impact. Each condition influences how the city can adapt to and integrate sustainable mobility solutions. The outcome at the niche level, is represented by the Sustainable Mobility Score (SMS), which is a result of the interplay of the various conditions. The SMS is a composite measure that reflects the city's overall readiness and success in moving towards sustainable mobility.

The conditions at the landscape and regime levels set the stage for potential transitions by providing necessary resources, infrastructural backbones, and social and market readiness. The interaction between these conditions either facilitates or constrains the city's ability to achieve high scores in sustainable mobility, thus influencing the outcome at the niche level.

Then, improving innovation within cities and moving towards more sustainable models requires engaging residents and investors (INN) (Nathanshon and Lahat, 2022). Indeed, cities take an approach aligned with the SDG and improving well-being by incorporating the human capital variable (Kim, 2022), as attracting skilled human capital is key to sustainable urban development (Marchesani et al., 2022; Nathanshon and Lahat, 2022). Innovative activity location strategies, such as coworking or networking, have positive externalities on the urban economy and the development of creative cities (Marchesani et al., 2022; Méndez-Ortega et al., 2022) that innovate in order to solve mobility-related problems. On their side, among the regime conditions, the implementation of a sustainability strategy require infrastructures (INF), which enable the provision of goods and services (Kim, 2022) and whose good management, especially those required by major alternatives to dominant mobility regimes, will facilitate the growth of cities (Aljoufie et al., 2013;

Cecere et al., 2014; Costales, 2022). In fact, the focus on the city shifts to service provision (Kim, 2022), favoring market attractiveness (MAT) in terms of economic strength and perception of quality of life. This attractiveness may be influenced by the city's capacity to generate and promote innovation. (Marchesani et al., 2022). Cities around the world are competing to improve their INF to attract talent and become more effective, sustainable and efficient (SEF) improving quality of life (Costales, 2022; Hajek et al., 2022). Cities pursue environmental resilience and seek to identify new forms of SEF (Kim, 2022), although they may increase their economic SEF to a greater extent than the ecological one. A transformation towards ecologically safe and equitably distributed INF is crucial to make the urban environment more resilient to the impacts of climate change (SIM) (Currie et al., 2017). Lastly, the implementation of mobility innovations depends on the interaction of city characteristics. The consolidation of sustainable mobility based on sustainable infrastructures, low emissions and digitalization is key to achieve sustainable development and improve the quality of life in cities. Therefore, the outcome considered at the niche level is the Sustainable Mobility Score (SMS).

3.2. Data

Within the framework of the Multilevel Perspective Model proposed this paper uses the indicators of Oliver Wyman's Sustainable Mobility Index 2021 for a sample of 60 cities from 6 regions of the world (Oliver Wyman Forum, 2022). A sample of cities that ranges from sprawling cities; to more compact cities; to fast-developing metropolises. These cities differ in their mobility challenges and the solutions they pursue and tend to be leaders in understanding the importance of mobility (Oliver Wyman Forum, 2022). SMS is conceptualized as a comprehensive measure that evaluates cities' readiness and performance in key aspects of sustainable mobility. SMS index is composed of five dimensions that synthesize 56 key indicators. As explanatory conditions, the following will be employed. Innovation (INN): considers the city's capacity to adopt and foster new mobility technologies and solutions, including mobility as a service (MaaS) and autonomous vehicles. Infrastructure (INF): includes the quality and extent of the infrastructure needed to support a sustainable mobility, such as efficient public transportation networks and accessibility to unmonitored mobility options. Market Attractiveness (MAT): this indicator reflects cities' commitment to attract and facilitate businesses in the mobility sector, evaluating both existing infrastructure and policies and strategies supporting innovation in mobility. System Efficiency (SEF): measures the effectiveness in traffic and mobility management, including optimizing traffic flow and the integration of intelligent transportation systems. Social Impact (SIM): evaluates how systems and mobility policies affect the population, especially in terms of accessibility, equity, and inclusion in accessing mobility services. Several studies have shown the suitability of applying QCA to index analysis across its components (Crespo and Crespon, 2016; Medina-Molina et al., 2024; Yu and Huarng, 2023; Yu and Huarng, 2024).

3.3. Method

Focusing on interactions across different levels, MLP offers a narrative explanation that does not fit into a classification of dependent and independent variables but instead emphasizes patterns that result from these interactions (Geels and Schot, 2007). QCA is used for its ability to explain causal complexity, through asymmetry, equifinality and conjunctural causation. Also, it is considered a suitable technique for applying MLP to sustainability transitions as it explains the complex interaction between conditions linked to different levels involved in the diffusion of mobility innovations. Likewise, it is a cross-case technique based on the set theory that identifies those conditions -necessary and sufficient- that explain the presence/absence of an outcome in a population of cases (Beach and Rohlfing, 2018; Mikkelsen, 2017; Rohlfing and Schneider, 2018). MLP transcends causality and simple dynamics. There are no simple causes of transition, but rather processes involving multiple dimensions and simultaneous levels (Geels, 2007). QCA therefore responds to the challenge of analyzing the trajectories of processes that occur in urban contexts; explaining how multiple conditions interact (Chang and Gernts, 2022).

QCA does not provide a causal explanation of the processes that links the cause to the outcome; as the cross-case regularities identified are not causal mechanisms per se, but manifestations of underlying causal mechanisms (Beach and Rohlfing, 2018; Mello, 2021; Rutten, 2020; Williams and Gemperle, 2016). However, the causes identified at the cross-case level make the outcome possible. Now, if the agents achieve the outcome, it would be explained by within-case analysis through process-tracing (Rutten, 2020). This is particularly relevant since the description and analysis of these mechanisms is crucial to explain causation (De Oliveira et al., 2020; Mello, 2022; Oana et al., 2021).

A causal mechanism—from a minimalist definition—describes how a cause contributes to produce an outcome; so, unless we formulate a causal mechanism, we cannot explain why cause ‘X’ determines outcome ‘Y’ (Beach and Rohlfing, 2018). Mechanisms are not causes, but the nexus that links causes to outcomes (Beach, 2019). That is, they are “causal pathways” between causes and outcomes that occur under certain scope conditions -factors that must be present for the relationship to work- or contextual conditions (De Oliveira et al., 2020). A scope condition is a statement regarding the domain in which causal effects are stable. Thus, in SMMR, causal mechanisms are expected to be present in a population of cases when the condition that triggers them is present (Beach, 2018; Beach and Rohlfing, 2018; De Oliveira et al., 2020). Explicitly tracing the mechanisms between causes and outcomes can result in what was initially thought to be a cause turning out to be a scope condition (Beach, 2018).

Process-tracing involves studying causal mechanisms across individual cases by tracing the process that links a cause, or set of causes, to an outcome to generate an inference (Beach and Rohlfing, 2018; Rutten, 2020). The integration of the cross-case analysis of QCA and within-case analysis of process-tracing, referred to as SMMR, can be applied when causal relationships are conceptualized in terms of set theory (Beach, 2019; Beach and Rohlfing, 2018; Mello, 2022). QCA allows identifying causes and selecting appropriate cases to apply within-case analysis (Beach, 2019). Once a sufficient conjunction is identified, process-tracing provides within-case evidence of existing causal mechanisms allowing causal inferences to be made about the functioning of the mechanism (Beach, 2018; Oana et al., 2021; Thomann and Maggetti, 2020).

SMMR, gains relevance as a method to show the existence of causal relationships and to reinforce robust causal inferences (Beach, 2019; Mikkelsen, 2017; Oana and Schneider, 2018; Oana et al., 2021; Rohlfing and Schneider, 2018). "R" is used to carry out this since it has become a standard for conducting QCA studies (Mello, 2022). Within it, the Setmethods smmr command allows a systematic selection of typical cases suitable for applying process-tracing (Oana and Schneider, 2018; Oana et al., 2021).

4. Results

While SMMR can be applied starting with QCA or process-tracing, we opt for the QCA-process tracing alternative where process-tracing is performed based on QCA results (Rohlfing and Schneider 2018): solutions are obtained with QCA; cases are selected to apply process-tracing; process-tracing is applied to examine the mechanisms linking conditions and results (Mikkelsen 2017; Oana et al. 2021).

4.1. QCA analysis to identify necessary and sufficient conditions

In our study, we employed the fuzzy-set Qualitative Comparative Analysis (fsQCA) to identify necessary and sufficient conditions for achieving the Sustainable Mobility Score (SMS) and its negation (~SMS) (see **Table 2**). FsQCA is particularly suitable for our analysis because it allows for the examination of complex causal relationships in cases where variables interact in a non-linear, asymmetric manner, typical in socio-technical studies like ours. Since it calibrates values within a range between 0 and 1, it allows the identification of both, differences in kind and differences in degree. The conditions were calibrated using the 95th and 5th percentiles to define complete inclusion and exclusion, respectively, with the mean serving as a point of maximum ambiguity.

Table 2. Analysis of the necessary conditions.

	SMS			**~SMS**		
Condi	**Cons.Nec**	**Cov.Nec**	**RoN**	**Cons.Nec**	**Cov.Nec**	**RoN**
INF	0.917	0.858	0.863	0.420	0.402	0.598
SIM	0.903	0.793	0.790	0.490	0.440	0.581
MAT	0.926	0.788	0.772	0.517	0.450	0.567
SEF	0.933	0.871	0.873	0.438	0.418	0.604
INN	0.839	0.829	0.854	0.397	0.401	0.625
~INF	0.360	0.378	0.643	0.851	0.913	0.928
~SIM	0.363	0.410	0.686	0.770	0.891	0.922
~MAT	0.354	0.417	0.704	0.756	0.912	0.940
~SEF	0.377	0.396	0.651	0.865	0.929	0.941
~INN	0.394	0.390	0.621	0.831	0.841	0.863

The thresholds for the necessary conditions are 0.9 for consistency and 0.5 for coverage and Relevance of Necessity (RoN). While consistency (Cons.Nec) determines empirical evidence with an assumed set-theoretic relationship, coverage (Cov.Nec) shows empirical relevance (Mello, 2022). The RoN evaluates the relevance of the necessary conditions by taking values between 0 and 1 -lower values indicate triviality and higher relevance (Mello 2022). For SMS, four conditions reach the required thresholds for necessity: INF, SIM, MAT, and, SEF. For ~SMS no condition meets the required thresholds.

Sufficient conditions were established. The truth table was created requiring a consistency level of 0.85 and one case per configuration. We selected the conservative solution as it is the most appropriate for a design that combines a causal counterfactual understanding at the cross-case level with a deep mechanistic explanation at the within-case level with SMMR (Alamos-Concha et al., 2021; Haesebrouck and Thomann, 2021). It is also the solution that tends to present a higher consistency (Mello, 2022).

The solution for SMS, is formed by 5 combinations of conditions (see **Table 3**). Of these five combinations, two of them are composed exclusively by the presence of conditions (INF*MAT*SEF + INF*SEF*SIM*INN), the remaining three include the presence of conditions and negations of conditions. Two of them contain the ~INN and can be simplified as MAT*SIM*~INN*(INF+SEF). The last one contains two conditions and three negations (~INF*MAT*~SEF*~SIM*INN). The first four conjunctions respect the identified necessary conditions. Of the five conjunctions that explain SMS, only ~INF*MAT*~SEF*~SIM*INN has a parameter that casts doubt on its relevance (PRI = 0.181).

Table 3. Sufficient conditions for SMS.

Conjunctions	**inclS**	**PRI**	**covS**	**covU**
INF*MAT*SEF	0.911	0.862	0.843	0.063
INF*MAT*SIM*~INN	0.926	0.740	0.329	0.011
INF*SEF*SIM*INN	0.921	0.877	0.768	0.036
MAT*SEF*SIM*~INN	0.897	0.669	0.328	0.008
~INF*MAT*~SEF*~SIM*INN	0.875	0.181	0.206	0.007
Solution	0.879	0.814	0.907	-

The consistency (inclS) of the results obtained is high (0.879). Consistency evaluates the degree to which cases that share a combination of conditions show the result, the closer it is to 1 the greater the confidence regarding the relationship between sets (Mello, 2022). In the analysis of sufficient conditions, consistency plays a similar role to test-ratios. The Coverage (covS) of our solution is 0.814. This measures the ability of the recipe to explain all observations, and can be assimilated to R2 (Mello, 2022). Finally, the Proportional Reduction in Consistency (PRI) reached a value of 0.907 and identifies simultaneous subset relations, which imply a logical contradiction (Mello, 2022).

Regarding ~SMS, the solution presents adequate parameters of consistency (0.948), PRI (0.914) and coverage (0.785) (see **Table 4**).

Table 4. Sufficient conditions for ~SMS.

Conjunctions	inclS	PRI	covS	covU
~INF*~MAT*~SEF*~INN	0.980	0.968	0.681	0.424
~INF*MAT*SIM*~INN	0.944	0.765	0.296	0.011
MAT*~SEF*SIM*~INN	0.933	0.704	0.298	0.008
~INF*MAT*~SEF*~SIM*INN	0.972	0.819	0.224	0.026
INF*MAT*SEF*~SIM*~INN	0.921	0.185	0.206	0.007
Solution	0.948	0.914	0.785	-

Again, the solution is composed of five conjunctions in which only the fifth term presents a parameter that does not reach the required thresholds (PRI = 0.185). Of the five conjunctions, only the first conjunction is composed of negations of conditions (~INF*~MAT*~SEF*~INN) presenting a high covU (0.424). The second and third conjunctions can be simplified as MAT*SIM*~INN*(~INF+~SEF). The fourth and fifth conjunctions simplify as MAT**~SIM*(~INF*~SEF*INN + INF*SEF*~INN).

4.2. Identification of mechanisms by process-tracing analysis

Process-tracing is a within-case analysis that allows the systematic study of causal mechanisms that link a cause, or set of causes, with a result through three steps: a single within-case that identifies the mechanisms that link the sufficient term with the outcome; a comparative within-case of a typical case with an Individual Irrelevant Case (IIR) that identifies whether the sufficient condition triggers the mechanism; and, a within-case comparative analysis of two typical cases that allows to establish whether the identified mechanism is generalizable to all typical cases (Oana et al., 2021). Analysis performed for each of the conjunctions that make up the solution.

Process tracing applied to typical cases tries to identify the causal mechanism that links the sufficient term to the outcome. Typical cases are part of both the solution and the outcome; they help to identify the underlying causal mechanisms. A sufficient term will be causal if each of its conjuncts, that is, each of the conditions that together with others form a conjunction, produces a difference in the mechanism (Oana et al., 2021). For this purpose, each of the conjuncts that compose the conjunction is analyzed to verify whether the mechanism disappears when isolating each of the conjuncts. In each analysis, the Focal Conjunct (FC) is responsible for identifying whether the difference for the mechanism occurs. In turn, Complementary Conjunct (CC) represents the other sets in the conjunction (Oana et al., 2021).

In the single-within case analysis, the best typical case must comply with four requirements: the attribution principle, whereby the FC defines the membership of the typical case in the term; the reduction of the corridor for the mechanism; a high membership in the sufficient term; and that the case is uniquely covered by the solution term (Oana and Schneider, 2019; Schneider and Rohlfing, 2018). Starting with SMS, in the first term of the solution only in the FC INF there are typical cases uniquely covered, a situation that also occurs for the second term for the FC MAT, however for none of the conjunctions the requirement is met for all its FCs. In contrast, for the first conjunction of ~SMS there are typical cases that exceed the criteria (**Table 5**).

Table 5. Typical cases.

	FC	Outcome	CC	Term	UniqCov
Focal Conjunct ~INF					
Casablanca	0.80	0.81	0.87	0.80	TRUE
Cape-Town	0.75	0.80	0.81	0.75	TRUE
Focal Conjunct ~MAT					
Manila	0.84	0.84	0.91	0.84	TRUE
Mexico City	0.69	0.75	0.85	0.69	TRUE
Focal Conjunct ~SEF					
São Paulo	0.66	0.74	0.68	0.66	TRUE
Abu Dhabi	0.53	0.79	0.67	0.53	TRUE
Focal Conjunct ~INN					
Riyadh	0.81	0.97	0.88	0.81	TRUE
Jeddah	0.77	0.98	0.94	0.77	TRUE

In the comparative within case analysis the typical case should be uniquely covered by the sufficient term under investigation, while the IIR case should be globally uncovered (Oana et al., 2021). As in the previous case, in none of the SMS conjunctions were there any pairs of typical cases and IIRs that meet the requirements. In contrast, there are cases that meet the criteria established for the first conjunction of the ~SMS solution (**Table 6**).

Table 6. Typical—IIR.

Typical	IIR	UniqCov	GlobUncov
Focal Conjunct ~INF			
Casablanca	Zürich	TRUE	TRUE
Focal Conjunct ~MAT			
Manila	Helsinki	TRUE	TRUE
Focal Conjunct ~SEF			
São Paulo	Singapore	TRUE	TRUE
Focal Conjunct ~INN			
Riyadh	Tokyo	TRUE	TRUE

Finally, the analysis of the identified pairs of typical cases was performed identifying only in the first conjunction of the ~SMS solution (see **Table 7**). This provides a solid basis for causal inference.

Table 7. Typical1-typical2.

Typical1	**Typical2**	**UniqCov1**	**UniqCov2**
Focal Conjunct ~INF			
Casablanca	Cape-Town	TRUE	TRUE
Focal Conjunct ~MAT			
Manila	Mexico City	TRUE	TRUE
Focal Conjunct ~SEF			
São Paulo	Abu Dhabi	TRUE	TRUE
Focal Conjunct ~INN			
Riyadh	Jeddah	TRUE	TRUE

5. Discussion

This study demonstrates that the four regime conditions (Infrastructure-INF, Social_Impact-SIM, Market_Attractiveness-MAT, and System_Efficiency-SEF) are necessary for achieving the Sustainable_Mobility_Score-SMS. Our analysis, anchored in the fuzzy-set Qualitative Comparative Analysis (fsQCA), underscores the pivotal role of sustainable cities strategies and comprehensive infrastructural frameworks in transitioning away from traditional vehicle-dominant regimes (Aljoufie et al., 2013; Cecere et al., 2014; Kim, 2022). Conversely, we did not identify any necessary conditions for the absence of SMS (~SMS), suggesting a complex and intertwined set of factors that mitigate against sustainable mobility outcomes.

The analysis of sufficient conditions reveals five distinct combinations of landscape and regime conditions that either facilitate or impede the Sustainable Mobility Score (SMS; ~SMS). These combinations underscore the complex interplay across different socio-technical levels—landscape, niche, and regime—highlighting how sustainable mobility innovations result from multi-level interactions (Irvine and Bai, 2019; Jain and Rohracher, 2022; Kanger et al., 2021). This complexity makes the use of MLP suitable. On the one hand, because it allows us to analyze the multi-level interactions between different elements to create specific regimes and windows of opportunity (Irvine and Bai, 2019). On the other hand, because it enables treating the city as a set of socio-technical systems through which transitions occur.

Our analysis identifies crucial conjunctions such as INF*INN and ~INF*~INN which are pivotal in explaining SMS and ~SMS in half of the terms, reflecting findings that combining Infrastructure with Innovation accelerates urban mobility transitions (Tongur and Engwall, 2017). Similarly, the conjunction underscores a critical pathway to enhancing sustainability and urban life quality (Costales, 2022; Hajek et al., 2022). Additionally, Innovation is also complemented by Market_Attractiveness-MAT by enhancing city attractiveness (Marchesani et al., 2022). These combinations not only show factors facilitating or obstructing sustainable mobility but also emphasize the need for understanding underlying mechanisms through process-tracing to discern causal relationships in urban mobility transitions (Geels, 2021; Kanger et al., 2021).

The exploration of causal mechanisms begins by identifying typical cases associated with each conjunction. For SMS, only some Focal_Conjunct-FC of certain conjunctions present uniquely covered typical cases, with no typical cases for each FC of each conjunction. In contrast, the first conjunction for ~SMS, with a high unique coverage, includes typical cases that meet the criteria for all FCs (FC ~INF Casablanca; FC ~MAT Manila; FC ~SEF São Paulo; FC ~INN Riyadh). This situation is reproduced in the identification of the pairs of typical-IIR cases, showing how the conjunction triggers the mechanism leading to the result. In addition, as they are not identified for SMS, we rule out the existence of unlock mechanisms, thus proposition 2 is not accepted. In this way, it is not confirmed that socio-technical systems are pushed towards disruptive sustainable pathways. This is due to the fact that the existence of a mechanism that causally links SMS with the conditions that explain it is not confirmed; we can only confirm the existence of scope conditions that enable the presence of SMS.

To identify how the lock-in mechanism occurs in the first conjunction of ~SMS, the pairs of typical-IIR cases selected for each FC are compared (FC ~INF Casablanca-Zürich; FC ~MAT Manila-Helsinki; FC ~SEF São Paulo-Singapore; FC ~INN Riyadh-Tokyo). This detailed comparison across pairs emphasizes differences in infrastructure and innovation strategies that significantly affect mobility outcomes. Remembering that, a typical case is covered by the solution and the results, while the Individual_Irrelevant_Case-IIR is not, as these are cities at the forefront of innovation. In fact, if we look at the pairs, we observe that cities such as Casablanca and Zürich, Manila and Helsinki, Singapore and São Paulo, and Tokyo and Riyadh are compared.

While Zürich holds the 12th position in the Sustainable Mobility Rank (SMR), Zürich ranks 12th, showcasing robust infrastructure (best Infrastructure-INF score), Casablanca stands at 43rd due to lesser road quality and challenges like pollution and inadequate bus services. Zürich GDP is notably higher (16 times that of Casablanca), and it has effectively incorporated cycling into its mobility strategy (Menendez and Ambühl, 2022). In contrast, Casablanca struggles with progressing its urban infrastructure, impacting its smart city initiatives (Chamseddine and Boubkr, 2020; El Hilali and Azougagh, 2021).

Manila, ranking 48th in the SMR, faces significant challenges due to a lack of an integrated public transportation system, which leads to severe traffic and pollution (Morley, 2018). With a higher density and population for Manila than Helsinki, Helsinki has a GDP 6 times higher. In response, plans like the Mega Manila Dream Plan have been introduced to enhance mobility infrastructure (Morley, 2018). Helsinki, ranked 3rd, is recognized for its innovative urban solutions, (e.g., in 2013 launched a project associated with smart and collaborative urban innovations) (Jiang, 2021), including smart traffic initiatives and excellent foreign investment conditions, contributing to its status as one of Europe’s top smart cities (Csukás and Szabó, 2021; Shamsuzzoha et al., 2021). Also, Helsinki´s smart traffic initiative includes shared and smart mobility services (Deloitte, 2021; Shamsuzzoha et al., 2021).

Singapore ranks 6th in the SMR, excels in System_Efficiency-SEF, securing the 2nd spot, mainly due to its advanced public transport network and the Nation Smart initiative which enhances its city capabilities ICT infrastructure (Csukás and Szabó, 2021; Jiang, 2021). It also leads in innovative mobility initiatives (Shamsuzzoha et al., 2021; Wang and Wong, 2022), and is well prepared to mitigate climate change impact across transport, buildings, or industry (Deloitte, 2021). In contrast, São Paulo, ranking 35th, faces challenges from its automobile-dominated landscape, which influences its socio-technical environment and urban policies (De Sá et al., 2019; Di Giulio et al., 2018; Pinhate et al., 2020). Although it promotes alternative transport solutions like Bilhete Unico and E-Fácil (rapid bus lines, bus lanes, and bicycle and pedestrian infrastructure) path dependency remains a significant barrier to its mobility transition (De Sá et al., 2019).

Finally, Tokyo, sharing the 6th position in the SMR with Singapore, leverages its high population density and technological innovation to discourage car usage and enhance its public transport system, ranking 15th in innovation (INN) (Saeidizand et al., 2022). Riyadh, positioned a 58th, lags in infrastructure and faces pollution challenges but is striving towards becoming a city with new public transport and traffic monitoring initiatives as part of Saudi Vision 2030 (Aina, 2017; Sultan et al., 2021).

Thus, through the comparison of cities with different profiles -selected by a systematic method-, the existence of a mechanism that makes the conjunction ~INF*~MAT*~SEF*~INN be causally linked to ~SMS is confirmed.

To analyze the generalization of the mechanism to all typical cases of the solution, pairs of typical cases are compared for each FC. Those identified for the first conjunction of ~SMS are: FC ~INF Casablanca-Cape-Town; FC ~MAT Manila-Mexico City; FC ~SEF São Paulo-Abu Dhabi; FC ~INN Riyadh-Jeddah.

Casablanca and Cape-Town are cities with a similar SMR ratings and face comparable challenges with high populations (3.8 and 4.6 million inhabitants), dense urban environment (8001 and 5504 persons per km^2), and similar GDP ($6201 and $6534). Despite this, Cape Town is advancing towards an integrated mobility network aimed at reducing energy consumption, guided by the Transport for Cape Town Directorate, which serves as a key tool for mobility assessment and improvement (Currie et al., 2017).

Manila and Mexico City rank 48th and 36th in the SMR with a population of 13.9 and 21.8 million, respectively, and a high population density (7434 and 9133 people per km^2). Transportation planning in Mexico City has focused on providing better infrastructure for vehicles, leading to an increase in the number of cars on the streets (Mejía-Dorantes and Soto, 2020). Mexico City, in particular, is leveraging its Laboratory for the City to foster innovative solutions and urban creativity to tackle these challenges (Deloitte, 2021).

São Paulo and Abu Dhabi have a similar position in the SMR, despite their disparate populations (22 vs. 1.5 million) and economic scales, both cities share similar challenges in terms of SEF and public transport usage, indicative of border mobility issues. Abu Dhabi's expected population increase to 3.1 million by 2030 will mean a fivefold increase in daily commutes to 10 million trips, exacerbating congestion, pollution and environmental issues. Despite its car-dominated landscape, Abu Dhabi is striving for efficient, safe and economically sustainable mobility solutions (Abulidbeh, 2018; Saeidizand et al., 2022).

Riyadh and Jeddah, both with low SMR scores, share similar population densities (4322 vs 3656), and a surface area of (1673 vs 1261 km^2), but differ significantly in GDP ($22,411 vs. $32). Both cities are focused on leveraging local talent and resources to drive technological advances (INN). Riyadh and Jeddah have previously been used as city pairs to analyze mobility patterns (Rahman et al., 2021). Jeddah, is an example of rapid urban development and expansion in an emerging economy (Mandeli, 2019). Its level of economic activity and population growth puts pressure on its transportation system, which has responded by expanding its transportation infrastructure that has facilitated mobility and accessibility (Aljoufie et al., 2013; Mandeli, 2019).

Based on the above, proposition 1 is accepted, demonstrating that lock-in mechanisms prevent cities from implementing mobility innovations effectively. The analysis identifies a clear causal mechanism linking ~INF*~MAT*~SEF*~INN and the negation of Sustainable Mobility Score (~SMS). Notably, Social_Impact-SIM does not significantly influence these outcomes, suggesting it primarily serves as a scope condition rather than a causal mechanism. Likewise, when analyzing the mechanism, it must be in mind that we are dealing with a conjunction in which the conjuncts that make up the first term of the SMS solution to which ~INN is attached are inverted. It seems that Market_Attractiveness-MAT can also be found among the circumstances that prevent a lock-in mechanism from appearing, since it appears in all the conjunctions that explain ~SMS, but with a role limited to the scope conditions' role.

The comparative analysis of the typical cases with the IIR highlights that deficiencies in road quality (~INF), shared mobility (~MAT), public transport (~SEF), and research centers and universities (~INN), characterize the mechanism that determines ~SMS. Cities struggling with these deficiencies have been slow to invest in necessary public transport, exacerbating issues related to traffic congestion

6. Conclusion

6.1. Implications

Among the most significant implications of this study, the utility of applying SMMR stands out. Through the use of QCA analysis, we have been able to distinguish the existence of necessary and sufficient conditions for the adoption of sustainable mobility. Specifically, we have identified that the negation of INF, SIM, MAT, and SEF prevents the achievement of SMS, while no necessary conditions for ~SMS are observed. Furthermore, the equifinality of the model allows us to see that different combinations of these conditions can explain both the presence of a phenomenon (SMS) and its negation (~SMS). Finally, the asymmetry in the results reveals that SMS and its negation (~SMS) require different explanations. However, it is crucial to consider the explanatory potential of joint causation, where the impact of certain conditions may be conditioned by their interaction with others. Consider the example of the second term of SMS and ~SMS. Both share the combination MAT*SIM*~INN; however, is the presence of INF what determines that they serve to explain SMS, while its negation (~INF) explains the negation of the outcome (~SMS).

From a methodological point of view, the application of process tracing complements the results obtained through QCA and facilitates the identification of causal mechanisms. Although these mechanisms are theoretically relevant, their identification is complex. In this study, we have identified the existence of lock-in mechanisms that hinder the incorporation of mobility innovations, demonstrating a path dependence that favors the dominant mobility regime. Therefore, there is a reproduction pathway by which the system remains relatively stable, reflecting the existence of a mechanism that confirms the causal influence of the conditions that explain ~SMS. This mechanism could be framed as a techno-economic mechanism (Apajalahti and Kungl, 2022; Cecere et al., 2014; Geels, 2007, 2019, 2021).

From a theoretical perspective, this work aligns with MLP, interpreting sustainable transition processes as the result of the interaction of different conditions, all located at the regime level in our study. When explaining SMS, the role of the condition at the landscape level (INN) is relegated to the background; not only because it remains unnecessary, but it also appears negated (~INN) in terms that constitute the sufficient solution. However, it plays a key role with MLP when explaining ~SMS, where it is negated (~INN) in most of the terms that explain this phenomenon.

From an applied perspective, the results of this study provide valuable guidance for municipal managers interested in promoting sustainable mobility. First, it is crucial to recognize that the existence of certain conditions - Infrastructure-INF, Social Impact-SIM, Market Attractiveness-MAT, and System Efficiency-SEF -can act as bottlenecks if their development is not adequate. These conditions are necessary for the successful implementation of sustainable mobility solutions and therefore, should be prioritized by urban policies. Additionally, Infrastructure-INF plays a central role, along with combinations between SEF and SIM, conforms to the majority of the terms that explain SMS. Although INN appears to be less relevant in our research, as it is negated in most combinations that explains SMS, it is essential to note that even with high levels of innovation, many cities have managed to be prepared for the implementation of sustainable mobility solutions. This underscores that innovation, while helpful, is not a fundamental prerequisite for achieving sustainable innovation. Additionally, it is crucial for local managers to understand that isolated efforts to improve specific conditions may not be sufficient to achieve SMS. Our analysis shows that in four out of the five terms that explains the negation of SMS (~SMS), the conditions are not negated, indicating that the lack of an integrated action across all key conditions may hinder progress towards sustainable mobility. Therefore, to overcome barriers and move towards smarter and more sustainable mobility systems, the integration of planning and investment in public transportation and innovation is essential. Urban planners must address these critical gaps in infrastructure and system efficiency to facilitate an effective transition towards sustainability.

6.2. Conclusions

The development of sustainability transitions requires a deeper understanding of the pathways that shape the development in the regimes, which dictate our current production and consumption patterns. We must recognize the dynamic stability in which these regimes exist, and that shapes its evolution. Given the determining role that the different mechanisms can play in these processes, various researchers have raised the need to identify analysis methods that enable their application. This study addresses the critical research gap of identifying causal mechanisms that influence the implementation of sustainable urban mobility solutions. Specifically, it analyzes the existence of lock-in and unlock mechanisms that can be linked to mobility transitions.

The results indicate that while lock-in mechanisms are prevalent and obstruct the adoption of such innovations, unlock mechanisms were not evident. Therefore, this paper establishes the scope conditions enabling the presence of the SMS and its negation (~SMS). However, causality can only be established for ~SMS, where a consistent lock-in mechanism was identified across all typical cases analyzed. In a situation resembling a de-alignment pathway. Despite these insights, the study was unable to pinpoint the unlock mechanism that could explain advancements in sustainable mobility through the interactions of landscape and regime factors, particularly from a macromarketing perspective.

The existence of lock-in mechanisms leads us to argue that historical legacy, beliefs, and shared patterns within the regime, is what perpetuate the mode of performing the mobility function. Thus, the non-identification of mechanisms in the case of SMS is interpreted as a confirmation of the role played by the conditions analyzed as scope conditions. These conditions explain the situation of the analyzed cities that are shown to be ready for the adoption of sustainable mobility solutions. Therefore, cities are very close to a reproduction pathway situation.

6.3. Limitations and further analysis

This research faces two primary limitations. First, while a sample size of 60 cities is appropriate for QCA, expanding the number of cities analyzed could enhance the robustness of the findings. Additionally, implementing a longitudinal analysis across different time points would pro mailto:petrucci.vide deeper insights into the dynamics of urban mobility transitions. Future research could benefit from incorporating additional landscape-level variables and examining the role of public transportation within the sustainable mobility strategies of cities. Further studies should also explore how broader economic, social, and technological trends influence these strategies, potentially integrating more comprehensive macromarketing and policy analysis perspectives to better understand the systemic barriers and facilitators of sustainable urban mobility.

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References

Abulibdeh, A. (2018). Implementing congestion pricing policies in a MENA Region City: Analysis of the impact on travel behaviour and equity. Cities, 74, 196–207. https://doi.org/10.1016/j.cities.2017.12.003

Aina, Y. A. (2017). Achieving smart sustainable cities with GeoICT support: The Saudi evolving smart cities. Cities, 71, 49–58. https://doi.org/10.1016/j.cities.2017.07.007

Álamos-Concha, P., Pattyn, V., Rihoux, B., et al. (2021). Conservative solutions for progress: on solution types when combining QCA with in-depth Process-Tracing. Quality & Quantity, 56(4), 1965–1997. https://doi.org/10.1007/s11135-021-01191-x

Aljoufie, M., Zuidgeest, M., Brussel, M., et al. (2013). Spatial–temporal analysis of urban growth and transportation in Jeddah City, Saudi Arabia. Cities, 31, 57–68. https://doi.org/10.1016/j.cities.2012.04.008

Apajalahti, E.-L., & Kungl, G. (2022). Path dependence and path break-out in the electricity sector. Environmental Innovation and Societal Transitions, 43, 220–236. https://doi.org/10.1016/j.eist.2022.03.010

Beach, D. (2018). Achieving Methodological Alignment When Combining QCA and Process Tracing in Practice. Sociological Methods & Research, 47(1), 64-99. https://doi.org/10.1177/0049124117701475

Beach, D. (2019). Multi-Method Research in the Social Sciences: A Review of Recent Frameworks and a Way Forward. Government and Opposition, 55(1), 163–182. https://doi.org/10.1017/gov.2018.53

Beach, D., & Rohlfing, I. (2018). Integrating Cross-case Analyses and Process Tracing in Set-Theoretic Research. Sociological Methods & Research, 47(1), 3–36. https://doi.org/10.1177/0049124115613780

Cecere, G., Corrocher, N., Gossart, C., et al. (2014). Lock-in and path dependence: an evolutionary approach to eco-innovations. Journal of Evolutionary Economics, 24(5), 1037–1065. https://doi.org/10.1007/s00191-014-0381-5

Chamseddine, Z., & Ait Boubkr, A. (2020). Exploring the place of social impacts in urban transport planning: the case of Casablanca City. Urban, Planning and Transport Research, 8(1), 138–157. https://doi.org/10.1080/21650020.2020.1752793

Chang, R. A., & Gerrits, L. (2022). What spatially stabilises temporary use? A qualitative comparative analysis of 40 temporary use cases along synchronised trajectories of stabilisation. Cities, 130, 103868. https://doi.org/10.1016/j.cities.2022.103868

Costales, E. (2022). Identifying sources of innovation: Building a conceptual framework of the Smart City through a social innovation perspective. Cities, 120, 103459. https://doi.org/10.1016/j.cities.2021.103459

Crespo, N. F., & Crespo, C. F. (2016). Global innovation index: Moving beyond the absolute value of ranking with a fuzzy-set analysis. Journal of Business Research, 69(11), 5265–5271. https://doi.org/10.1016/j.jbusres.2016.04.123

Csukás, M. S., & Szabó, R. Z. (2021). The many faces of the smart city: Differing value propositions in the activity portfolios of nine cities. Cities, 112, 103116. https://doi.org/10.1016/j.cities.2021.103116

Currie, P. K., Musango, J. K., & May, N. D. (2017). Urban metabolism: A review with reference to Cape Town. Cities, 70, 91–110. https://doi.org/10.1016/j.cities.2017.06.005

De Oliveira, L. G. S., Subtil Lacerda, J., & Negro, S. O. (2020). A mechanism-based explanation for blocking mechanisms in technological innovation systems. Environmental Innovation and Societal Transitions, 37, 18–38. https://doi.org/10.1016/j.eist.2020.07.006

Deloitte. (2021). Urban Future With a Purpose. 12 trends shaping the future of cities by 2030.

Di Giulio, G. M., Bedran-Martins, A. M. B., Vasconcellos, M. da P., et al. (2018). Mainstreaming climate adaptation in the megacity of São Paulo, Brazil. Cities, 72, 237–244. https://doi.org/10.1016/j.cities.2017.09.001

Eitan, A., & Hekkert, M. P. (2023). Locked in transition? Towards a conceptualization of path-dependence lock-ins in the renewable energy landscape. Energy Research & Social Science, 106, 103316. https://doi.org/10.1016/j.erss.2023.103316

El Hilali, S., & Azougagh, A. (2021). A netnographic research on citizen's perception of a future smart city. Cities, 115, 103233. https://doi.org/10.1016/j.cities.2021.103233

Frantzeskaki, N., & Loorbach, D. (2010). Towards governing infrasystem transitions. Technological Forecasting and Social Change, 77(8), 1292–1301. https://doi.org/10.1016/j.techfore.2010.05.004

Geel, F. W. (2018). Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. Energy Research & Social Science, 37, 224-231.

Geels, F. W. (2007). Feelings of Discontent and the Promise of Middle Range Theory for STS. Science, Technology, & Human Values, 32(6), 627–651. https://doi.org/10.1177/0162243907303597

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions, 1(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. Theory, Culture & Society, 31(5), 21–40. https://doi.org/10.1177/0263276414531627

Geels, F. W. (2019). Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. Current Opinion in Environmental Sustainability, 39, 187–201. https://doi.org/10.1016/j.cosust.2019.06.009

Geels, F. W. (2021). From leadership to followership: A suggestion for interdisciplinary theorising of mainstream actor reorientation in sustainability transitions. Environmental Innovation and Societal Transitions, 41, 45–48. https://doi.org/10.1016/j.eist.2021.10.021

Geels, F. W. (2022). Causality and explanation in socio-technical transitions research: Mobilising epistemological insights from the wider social sciences. Research Policy, 51(6), 104537. https://doi.org/10.1016/j.respol.2022.104537

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. Research Policy, 36(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geels, F. W., Kern, F., Fuchs, G., et al. (2016). The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Research Policy, 45(4), 896–913. https://doi.org/10.1016/j.respol.2016.01.015

Gorissen, L., Spira, F., Meynaerts, E., et al. (2018). Moving towards systemic change? Investigating acceleration dynamics of urban sustainability transitions in the Belgian City of Genk. Journal of Cleaner Production, 173, 171–185. https://doi.org/10.1016/j.jclepro.2016.12.052

Grainger-Brown, J., Malekpour, S., Raven, R., et al. (2022). Exploring urban transformation to inform the implementation of the Sustainable Development Goals. Cities, 131, 103928. https://doi.org/10.1016/j.cities.2022.103928

Haesebrouck, T., & Thomann, E. (2021). Introduction: Causation, inferences, and solution types in configurational comparative methods. Quality & Quantity, 56(4), 1867–1888. https://doi.org/10.1007/s11135-021-01209-4

Hajek, P., Youssef, A., & Hajkova, V. (2022). Recent developments in smart city assessment: A bibliometric and content analysis-based literature review. Cities, 126, 103709. https://doi.org/10.1016/j.cities.2022.103709

Hedström, P., & Swedberg, R. (1998). Social Mechanisms. Cambridge University Press. https://doi.org/10.1017/cbo9780511663901

Hedström, P., & Wennberg, K. (2016). Causal mechanisms in organization and innovation studies. Innovation, 19(1), 91–102. https://doi.org/10.1080/14479338.2016.1256779

Heiberg, J., & Truffer, B. (2022). The emergence of a global innovation system – A case study from the urban water sector. Environmental Innovation and Societal Transitions, 43, 270–288. https://doi.org/10.1016/j.eist.2022.04.007

Irvine, S., & Bai, X. (2019). Positive inertia and proactive influencing towards sustainability: systems analysis of a frontrunner city. Urban Transformations, 1(1). https://doi.org/10.1186/s42854-019-0001-7

Jain, M., & Rohracher, H. (2022). Assessing transformative change of infrastructures in urban area redevelopments. Cities, 124, 103573. https://doi.org/10.1016/j.cities.2022.103573

Jiang, H. (2021). Smart urban governance in the ‘smart’ era: Why is it urgently needed? Cities, 111, 103004. https://doi.org/10.1016/j.cities.2020.103004

Jørgensen, U. (2012). Mapping and navigating transitions—The multi-level perspective compared with arenas of development. Research Policy, 41(6), 996–1010. https://doi.org/10.1016/j.respol.2012.03.001

Kaidesoja, T. (2018). A dynamic and multifunctional account of middle-range theories. The British Journal of Sociology, 70(4), 1469–1489. Portico. https://doi.org/10.1111/1468-4446.12621

Kanger, L. (2021). Rethinking the Multi-level Perspective for energy transitions: From regime life-cycle to explanatory typology of transition pathways. Energy Research & Social Science, 71, 101829. https://doi.org/10.1016/j.erss.2020.101829

Keller, M., Sahakian, M., & Hirt, L. F. (2022). Connecting the multi-level-perspective and social practice approach for sustainable transitions. Environmental Innovation and Societal Transitions, 44, 14–28. https://doi.org/10.1016/j.eist.2022.05.004

Kim, J. (2022). Smart city trends: A focus on 5 countries and 15 companies. Cities, 123, 103551. https://doi.org/10.1016/j.cities.2021.103551

Klitkou, A., Bolwig, S., Hansen, T., et al. (2015). The role of lock-in mechanisms in transition processes: The case of energy for road transport. Environmental Innovation and Societal Transitions, 16, 22–37. https://doi.org/10.1016/j.eist.2015.07.005

Köhler, J., Geels, F. W., Kern, F., et al. (2019). An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions, 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Krupnik, S., & Koniewski, M. (2022). Choosing a qualitative comparative analysis solution in multi-method impact evaluation. Evaluation, 28(2), 192–209. https://doi.org/10.1177/13563890221088015

Kuokkanen, A., Nurmi, A., Mikkilä, M., et al. (2018). Agency in regime destabilization through the selection environment: The Finnish food system's sustainability transition. Research Policy, 47(8), 1513–1522. https://doi.org/10.1016/j.respol.2018.05.006

Loorbach, D., Wittmayer, J., Avelino, F., et al. (2020). Transformative innovation and translocal diffusion. Environmental Innovation and Societal Transitions, 35, 251–260. https://doi.org/10.1016/j.eist.2020.01.009

Mandeli, K. (2019). Public space and the challenge of urban transformation in cities of emerging economies: Jeddah case study. Cities, 95, 102409. https://doi.org/10.1016/j.cities.2019.102409

Marchesani, F., Masciarelli, F., & Doan, H. Q. (2022). Innovation in cities a driving force for knowledge flows: Exploring the relationship between high-tech firms, student mobility, and the role of youth entrepreneurship. Cities, 130, 103852. https://doi.org/10.1016/j.cities.2022.103852

Medina-Molina, C., Pérez-Macías, N., & Coronado-Vaca, M. (2024). Searching for complexity. Application of the set-theory to the analysis of urban mobility readiness index. Discover Sustainability, 5(1). https://doi.org/10.1007/s43621-024-00187-5

Mejía-Dorantes, L., & Soto Villagrán, P. (2020). A review on the influence of barriers on gender equality to access the city: A synthesis approach of Mexico City and its Metropolitan Area. Cities, 96, 102439. https://doi.org/10.1016/j.cities.2019.102439

Mello, P. A. (2022). Qualitative Comparative Analysis. Routledge Handbook of Foreign Policy Analysis Methods, 385–402. https://doi.org/10.4324/9781003139850-29

Méndez-Ortega, C., Micek, G., & Malochleb, K. (2022). How do coworking spaces coagglomerate with service industries? The tale of three European cities. Cities, 130, 103875. https://doi.org/10.1016/j.cities.2022.103875

Menendez, M., & Ambühl, L. (2022). Implementing Design and Operational Measures for Sustainable Mobility: Lessons from Zurich. Sustainability, 14(2), 625. https://doi.org/10.3390/su14020625

Mikkelsen, K. S. (2015). Negative Case Selection: Justifications and Consequences for Set-Theoretic MMR. Sociological Methods & Research, 46(4), 739–771. https://doi.org/10.1177/0049124115591015

Mirzadeh Phirouzabadi, A., Blackmore, K., Savage, D., et al. (2022). Modelling and simulating a multi-modal and multi-dimensional technology interaction framework: The case of vehicle powertrain technologies in the US market. Technological Forecasting and Social Change, 175, 121412. https://doi.org/10.1016/j.techfore.2021.121412

Morley, I. (2018). Manila. Cities, 72, 17–33. https://doi.org/10.1016/j.cities.2017.07.022

Nathansohn, R., & Lahat, L. (2022). From urban vitality to urban vitalisation: Trust, distrust, and citizenship regimes in a Smart City initiative. Cities, 131, 103969. https://doi.org/10.1016/j.cities.2022.103969

Oana, I.-E., & Schneider, C., Q. (2018). SetMethods: an Add-on R Package for Advanced QCA. The R Journal, 10(1), 507. https://doi.org/10.32614/rj-2018-031

Oana, I.-E., Schneider, C. Q., & Thomann, E. (2021). Qualitative Comparative Analysis Using R. Cambridge University Press. https://doi.org/10.1017/9781009006781

Oliver Wyman Forum. (2022). Available online: https://www.oliverwymanforum.com/mobility/urban-mobility-readiness-index/rankings.html (accessed on 13 June 2022).

Panori, A., Kostopoulos, I., Karampinis, E., et al. (2022). New path creation in energy transition: Exploring the interplay between resource formation and social acceptance of biomass adoption in Europe. Energy Research & Social Science, 86, 102400. https://doi.org/10.1016/j.erss.2021.102400

Papachristos, G. (2018). A mechanism based transition research methodology: Bridging analytical approaches. Futures, 98, 57–71. https://doi.org/10.1016/j.futures.2018.02.006

Pinhate, T. B., Parsons, M., Fisher, K., et al. (2020). A crack in the automobility regime? Exploring the transition of São Paulo to sustainable urban mobility. Cities, 107, 102914. https://doi.org/10.1016/j.cities.2020.102914

Post, C., Sarala, R., Gatrell, C., et al. (2020). Advancing Theory with Review Articles. Journal of Management Studies, 57(2), 351–376. Portico. https://doi.org/10.1111/joms.12549

Rahman, S. M., Ratrout, N., Assi, K., et al. (2021). Transformation of urban mobility during COVID-19 pandemic – Lessons for transportation planning. Journal of Transport & Health, 23, 101257. https://doi.org/10.1016/j.jth.2021.101257

Rohlfing, I., & Schneider, C. Q. (2016). A Unifying Framework for Causal Analysis in Set-Theoretic Multimethod Research. Sociological Methods & Research, 47(1), 37–63. https://doi.org/10.1177/0049124115626170

Rubinson, C., Gerrits, L., Rutten, R., & Greckhamer, T. (2019). Avoiding common errors in QCA: A short guide for new practitioners. Sociology, 9, 397-418.

Rutten, R. (2020). Applying and Assessing Large-N QCA: Causality and Robustness From a Critical Realist Perspective. Sociological Methods & Research, 51(3), 1211–1243. https://doi.org/10.1177/0049124120914955

Sá, T. H. de, Edwards, P., Pereira, R. H. M., & Monteiro, C. A. (2019). Right to the city and human mobility transition: The case of São Paulo. Cities, 87, 60–67. https://doi.org/10.1016/j.cities.2018.12.024

Saeidizand, P., Fransen, K., & Boussauw, K. (2022). Revisiting car dependency: A worldwide analysis of car travel in global metropolitan areas. Cities, 120, 103467. https://doi.org/10.1016/j.cities.2021.103467

Schneider, C. Q. (2023). Set-Theoretic Multi-Method Research. A Guide to Combining QCA and Case Studies. Cambridge University Press. https://doi.org/10.1017/9781009307154

Schneider, C. Q., & Rohlfing, I. (2019). Set-theoretic Multimethod Research: The Role of Test Corridors and Conjunctions for Case Selection. Swiss Political Science Review, 25(3), 253–275. https://doi.org/10.1111/spsr.12382

Shamsuzzoha, A., Nieminen, J., Piya, S., et al. (2021). Smart city for sustainable environment: A comparison of participatory strategies from Helsinki, Singapore and London. Cities, 114, 103194. https://doi.org/10.1016/j.cities.2021.103194

Simoens, M. C., Fuenfschilling, L., & Leipold, S. (2022). Discursive dynamics and lock-ins in socio-technical systems: an overview and a way forward. Sustainability Science, 17(5), 1841–1853. https://doi.org/10.1007/s11625-022-01110-5

Simoens, M. C., Leipold, S., & Fuenfschilling, L. (2022). Locked in unsustainability: Understanding lock-ins and their interactions using the case of food packaging. Environmental Innovation and Societal Transitions, 45, 14–29. https://doi.org/10.1016/j.eist.2022.08.005

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. Research Policy, 34(10), 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005

Sultan, B., Katar, I. M., & Al-Atroush, M. E. (2021). Towards sustainable pedestrian mobility in Riyadh city, Saudi Arabia: A case study. Sustainable Cities and Society, 69, 102831. https://doi.org/10.1016/j.scs.2021.102831

Thaler, T., & Penning-Rowsell, E. C. (2023). Policy experimentation within flood risk management: Transition pathways in Austria. The Geographical Journal, 189(4), 701–714. https://doi.org/10.1111/geoj.12528

Thomann, E., & Maggetti, M. (2017). Designing Research With Qualitative Comparative Analysis (QCA): Approaches, Challenges, and Tools. Sociological Methods & Research, 49(2), 356–386. https://doi.org/10.1177/0049124117729700

Tongur, S., & Engwall, M. (2017). Exploring window of opportunity dynamics in infrastructure transformation. Environmental Innovation and Societal Transitions, 25, 82–93. https://doi.org/10.1016/j.eist.2016.12.003

Trencher, G., & Wesseling, J. (2022). Roadblocks to fuel-cell electric vehicle diffusion: Evidence from Germany, Japan and California. Transportation Research Part D: Transport and Environment, 112, 103458. https://doi.org/10.1016/j.trd.2022.103458

van Rijnsoever, F. J., & Leendertse, J. (2020). A practical tool for analyzing socio-technical transitions. Environmental Innovation and Societal Transitions, 37, 225–237. https://doi.org/10.1016/j.eist.2020.08.004

Verbong, G. P. J., & Geels, F. W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technological Forecasting and Social Change, 77(8), 1214–1221. https://doi.org/10.1016/j.techfore.2010.04.008

Wang, Y., & Wong, Y. D. (2020). Repositioning urban heritage for active mobility: Indications from news coverage in Singapore. Cities, 98, 102525. https://doi.org/10.1016/j.cities.2019.102525

Williams, T., & Gemperle, S. M. (2016). Sequence will tell! Integrating temporality into set-theoretic multi-method research combining comparative process tracing and qualitative comparative analysis. International Journal of Social Research Methodology, 20(2), 121–135. https://doi.org/10.1080/13645579.2016.1149316

Yu, T. H.-K., & Huarng, K.-H. (2023). Configural analysis of GII's internal structure. Journal of Business Research, 154, 113323. https://doi.org/10.1016/j.jbusres.2022.113323

Yu, T. H.-K., & Huarng, K.-H. (2024). Causal analysis of SDG achievements. Technological Forecasting and Social Change, 198, 122977. https://doi.org/10.1016/j.techfore.2023.122977