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TO CYCLE OR NOT TO CYCLE. THE APPLICATION OF AN EXTENDED INNOVATION DIFFUSION MODEL FOR SUSTAINABLE MOBILITY

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ABSTRACT*. The high levels of pollution in cities and their impact on the quality of life of their citizens make it necessary to investigate healthier and more sustainable modes of mobility. Among the measures applied to achieve more environmentally friendly behaviour, cycling appears to be a less polluting mode of transport. It is therefore important to identify the combination of conditions that would explain the use of urban bicycles and those that lead people not to use them, as well as the existence of causal mechanisms in these relationships. To this end, the Multi-Level Perspective (MLP) and Set Theoretic Multi-Method Research (SMMR) were applied to a sample of 90 cities worldwide. The results show how the combination of landscape and regime conditions explains both the use and non-use of cycling as an urban mode of transport. The existence of a causal mechanism explaining bicycle use in German cities is also identified.

KEYWORDS: sustainable mobility; adoption; cycling; QCA; process tracing.

JEL classification: M31, O33.

Introduction

The growth of mobility poses significant urban challenges in terms of congestion, pollution and accidents (Braun *et al.*, 20-23; Gössling, 2013). Many cities around the world are characterised by the pursuit of creative solutions to these challenges (Jurene and Jureniene, 2017). Cities around the world are seeking sustainable mobility solutions to mitigate the social and environmental externalities associated with mobility (Gan *et al.*, 2021; Schaefer *et a*l., 2021). Active mobility has emerged as a viable alternative to traditional mobility systems, with a focus on cycling (Schering and Gómez, 2022; Song *et al*., 2021; Von Schneidemesser *et al*., 2020). Many cities are emphasising cycling to promote healthier environments and reduce congestion, as evidenced by several studies (Bieliński *et al*., 2021; Eren and Uz, 2020; Nigro *et al*., 2022; Nikolaeva and Nelo-Deakin, 2020; Nikolaeva *et al*., 2019; Osama *et al*., 2017; Peer, 2019; Te Brömmelstroet *et al*., 2020; Wessel, 2020). As a result, investment in bicycle-related infrastructure and promotion programs is increasing due to the aforementioned benefits (Braun *et al*., 2023).

Despite this, the use of bicycles in urban mobility practices remains marginal compared to other transport modes (Behrendt, 2016; Gössling, 2013). To address these low rates of bicycle usage, it is essential to identify the factors that drive citizens to choose environmentally friendly mobility systems (Lin *et al*., 2018; Moschis, 2021; Nigro *et al*., 2022; Wessel, 2020). As there are multiple reasons why these sustainable interventions are needed (Kemper and Ballantine, 2017), this article aims to identify the conditions that determine frequent bicycle use in urban areas. A better understanding of consumption in specific contexts provides a broader basis for the design of future interventions (Dalpian *et al*., 2015).

Recently, there has been increasing interest in sustainability within the marketing discipline. At times, this need has been associated with reducing consumption, in line with the anti-consumption approach, which manifests itself in various ways (Lee *et al*., 2020). In other cases, the focus is on identifying the antecedents of pro-environmental behaviour (Casalegno *et al*., 2022; Koval *et al*., 2023). Within the latter approach, considering cycling in the context of sustainable mobility is seen as an innovative process (Becker *et al*., 2022) that requires an understanding of the interrelationships between the factors involved (Ávila-Robinson *et al*., 2022; Saad, 2020). In sustainability research, cycling is recognised as a key area for innovation in urban mobility transitions (Psarikidou *et al*., 2020; Van Waes *et al*., 2018).

Cycling offers solutions to multiple urban challenges and seeds innovations that redefine its practice and understanding (Nikolaeva and Nelo-Deakin, 2020; Nikolaeva *et al*., 2019; Te Brömmelstroet *et al*., 2020). For example, the transition from a car-dominated mobility regime to one that favours cycling is considered innovative (Becker *et al*., 2022). Cycling innovations should be supported by infrastructure and a supportive regime that encourages their use (Becker *et al*., 2022; Schwarz *et al*., 2022; Te Brömmelstroet *et al*., 2020). This perspective advocates the integration of cycling practices with related technologies and systems, positioning cycling as a dominant mobility mode (Behrendt, 2016; Nikolaeva *et al*., 2019; Nikolaeva and Nelo-Deakin, 2020; Te Brömmelstroet *et al*., 2020).

However, despite calls to identify factors that lead to frequent cycling (Buck and Nurse, 2023), few studies quantify the impact of the cycling context on practice at city level (Gao *et al*., 2023). Achieving a truly sustainable and equitable mobility system is complex. While technological advances, such as the introduction of new vehicles, can help mitigate environmental impacts, they alone will not ensure a just transition (Dillman *et al*., 2023). Currently, the interactions between different components of the cycling ecosystem remain unclear (Song *et al*., 2021). From a complementary perspective, combining mobility services with complementary service offerings can overcome the disadvantages of using isolated services (Schulz *et al*., 2020; Schulz *et al*., 2023). From a competitive point of view, there are doubts as to whether the players in the mobility ecosystem will ultimately create value for each other, which could have a negative impact on service provision (Schulz *et al*., 2020). Therefore, the first research gap addressed in this paper is the identification of the interrelationship between the factors that explain the use and non-use of bicycles within sustainable mobility.

In addition, adopting a mechanistic perspective can contribute to decision-making regarding innovations and promote their adoption (Capano *et al*., 2019; Pattyn *et al*., 2022; Tiberius *et al*., 2021). Studies analysing bicycle use sometimes employ designs that do not allow causality to be established (Wang and Lindsey, 2019). Even when regularities are identified, they do not imply causal relationships. It is therefore recommended that, where possible, the identification of regularities is supplemented by the application of case-level process tracing (Ragin, 2023, p.8). The use of multi-method designs based on Qualitative Comparative Analysis (QCA) and process tracing, which benefit from combining cross-case analysis with within-case analysis (Pattyn *et al*., 2022), seems appropriate for identifying causal mechanisms. Thus, the second research gap is to identify the mechanisms that trigger bicycle use in the context of sustainable mobility.

The Multi-Level Perspective (MLP) has already been used in the study of the development of sustainable mobility solutions, considering the use of the bicycle as a niche innovation for urban mobility (Becker *et al*., 2022). Therefore, based on the MLP, this study identifies different conditions at landscape and regime levels and an outcome at niche level. As an analytical technique, fsQCA (fuzzy-set Qualitative Comparative Analysis) is applied to a sample of 90 cities worldwide, complemented by process tracing, called Set Theoretic Multi-Method Research (SMMR). This is carried out using R and its SetMethods package, which has become a standard for conducting QCA studies (Mello, 2022).

The next section presents the link between macromarketing and socio-technical transitions to explain innovation. The third section presents the model and rationale for the propositions. The methodology used in the article (SMMR) is then explained. The presentation of the results precedes the discussion and conclusions of the article.

1. Theoretical Background

1.1 Macromarketing in the Analysis of Sustainable Innovations

Cities around the world are facing challenges that require an analysis that takes into account their market interactions (Huff, Barnhart, 2022). Macromarketing delves into these "wicked" problems, which are characterised by their difficult definition and delimitation, their complex and intertwined nature, the high level of uncertainty and divergence in their causes, and the presence of multiple potential solutions with no generally accepted causes or solutions (Akaka *et al*., 2023; Kemper, Ballantine, 2017). Macromarketing sheds light on the complex interplay of societal factors (Mittelstaedt *et al*., 2014; Shultz, Peterson, 2019) and is increasingly recognised for addressing such "wicked" problems (Pittz *et al*., 2020; Shultz, Peterson, 2019).

The sustainability debate has attracted the attention of macromarketing. This debate focuses on whether patterns of economic growth and uncontrolled consumption can solve the same problems they create (Dalpian *et al*., 2015). Thus, sustainability is becoming a focus of macromarketing, addressing systemic change through macro and meso perspectives (Huff, Barnhart, 2022; Kemper and Ballantine, 2017; Mittelstaedt *et al*., 2014; Sheth and Parvartiyar, 2021; Shultz, Peterson, 2019). The meso-level, which bridges micro-actions and macro-structures, facilitates the exploration of markets as potential sustainable solutions (Akaka *et al*., 2023). Within this framework, the phenomenon of urban cycling has been explored through macromarketing studies (Dalpian *et al*., 2015).

The challenges of urban commuting have spurred the search for innovative solutions, with the bicycle emerging as a transformative agent (Nikolaeva, Nelo-Deakin, 2020; Schwarz *et al*., 2022). Understanding the adoption and diffusion of innovations is crucial for sustainable development (Ávila-Robinson *et al*., 2022, Kristensson *et al*., 2020). Although the theories traditionally used to explain the diffusion of innovations in the market provide an optimal framework, these models were developed at a time when market behaviour was known and stable, and firms had considerable control over innovation processes (Kristensson *et al*., 2020; Schot, Steinmueller, 2018a; Verrier *et al*., 2022). In today's markets, such approaches are less realistic.

This can be seen in the two main criticisms of classical models explaining the development of innovation. First, they often overlook the interactions between different resources (Gruber, 2020; Schot, Steinmueller, 2018b; Tiberius *et al*., 2021; Vargo *et al*., 2020). Indeed, the functionality of innovations depends on complementary services embedded in an ecosystem, where innovation is seen as a value proposition shared by different actors (Kristensson *et al*., 2020; Lee *et al*., 2020). Second, they neglect the evolving contexts in which innovations emerge (Bogers *et al*., 2022; Vargo *et al*., 2020). These models also fail to capture the full potential of innovations to drive transitions in the socio-technical systems in which they operate (Ávila-Robinson *et al*., 2022; Kanger *et al*., 2019; Lee *et al*., 2020).

Therefore, a socio-technical systems perspective is essential for innovation research. This perspective encompasses both social and technological change (Ávila-Robinson *et al*., 2022; Gruber, 2020) and addresses elements often overlooked in traditional models: the involvement of multiple actors; evolving user characteristics; and societal constraints that shape socio-technical systems (Kanger *et al*., 2019; Lee *et al*., 2020; Schot, Steinmueller, 2018b; Werner *et al*., 2022). Socio-technical systems reflect the interaction between different elements that meet social needs, such as transport (Keller *et al*., 2022).

1.2 Using the Bicycle as a Socio-Technical System

Sustainable transitions are essential to address some of humanity's most pressing challenges, including climate change, the demand for decarbonised energy, and the provision of clean water and sanitation (Gottschamer, Walters, 2023; Keller *et al*., 2022). These challenges highlight the need to restructure the socio-technical systems that underpin our societies. Socio-technical system transitions (STTs) involve the interconnected co-production of social, behavioural and technological changes (Geels, 2018; Schot, Steinmueller, 2018b). For a deep understanding of these multifaceted issues and complex problems, it is crucial to unravel the aggregated dimensions in their interactions (Akaka *et al*., 2023).

The multilevel perspective (MLP) has emerged as a noteworthy concept in transition studies, especially within the socio-technical framework (Næss and Vogel, 2012). The MLP is one of the most widely used methodologies to understand the dynamic processes in technical systems (Gottschamer, Walters, 2023). Using a nested hierarchy approach, the MLP attempts to understand increasing structuring levels (Eikelenboom, van Marrewijk, 2023). This perspective emphasises that technological innovations result from complex interactions at three different levels: macro (landscape), meso (regime) and micro (niche). These levels adapt to both radical change (within niches) and dynamic stability (within regimes), as well as broader influences and contexts (within the landscape).

The MLP conceptualises sustainable transitions as transitions from one socio-technical regime to another (Svennevik, 2022). The MLP explores the complex dynamics of socio-technical change. Its strength lies in its ability to explore interactions between niches, regimes and landscapes, helping to identify opportunities for radical innovation (Dillman *et al*., 2023). Such transitions are seen as the result of alignments between these levels, with niche innovations often emerging as radical novelties, while the socio-technical landscape provides a gradually evolving context (Næss, Vogel, 2012). The core principle of the MLP suggests that transitions to sustainable systems or innovations are non-linear processes that depend on interactions between the three levels of analysis (Geels, 2020). As conceptualised by Geels and Schot (2007), transitions emerge from these interactions. For example, cities as technical entities are inherently dynamic and their infrastructures and transport systems are constantly evolving. The analysis of eco-innovation processes requires an approach that considers transitions in socio-technical systems, such as mobility (Schot, Steinmueller, 2018a, 2018b). Transformations in mobility systems are particularly challenging as they represent a deeply entrenched sector with complex infrastructures, institutions and interests. These factors can lead to path dependency and make them resistant to change (Dillman *et al*., 2023).

Cycling can be conceptualised as a socio-technical system in transition (Gössling, 2013; Te Brömmelstroet *et al*., 2020). This perspective emphasises transformative changes in urban mobility frameworks, with a focus on the routine practice of cycling. This practice is deeply rooted in various—spatial, historical, social, cultural, economic and political–factors that can potentially hinder radical transformations and the substantial growth of cycling (Te Brömmelstroet *et al*., 2020). Mobility transitions are more likely to occur when they gain momentum, especially when cyclists become more visible, reach a critical mass, and when cycling is normalised as an urban mobility mode, shedding any associated stereotypes (Gössling, 2013). The adoption process for cycling involves several phases: acquiring initial knowledge about cycling, recognising its benefits, deciding to adopt it, implementing it, and confirming the decision. Each stage represents a potential point of rejection, with individuals actively seeking to reduce uncertainties about the innovative features of cycling. For example, individuals may discover that cycling is less strenuous than expected and recognise it as an enjoyable, efficient and healthy mode of transport. Such positive discoveries can reduce uncertainties about the complexity and compatibility of everyday cycling and increase perceptions of cycling as an innovative approach with many relative advantages, especially compared to public transport (Strömberg, Wallgren, 2022). Achieving sustainable consumption patterns is more complex than changing other behaviours because it involves the meaning of consumption and societal practices or what is considered standard. Often, less sustainable behaviours are seen as the norm, while sustainable actions are perceived as deviations (Dalpian *et al*., 2015).

Rather than focusing exclusively on innovation studies, it is crucial to understand how different actors reconfigure multiple elements to transform mobility systems (Peris-Blanes *et al*., 2022). The MLP has been used to study innovations in urban mobility (Medina-Molina *et al*., 2022; Medina-Molina and Rey-Tienda, 2022), even when addressing complex challenges through macro-marketing applications (Kemper, Ballantine, 2017). The changes brought about by pandemics can be seen as landscape disruptions, providing a window of opportunity for a rapid transition to sustainable development. Numerous cities have redesigned public infrastructure to explore sustainable mobility alternatives, such as cycling (Becker *et al*., 2022).

2. Model Rationale

2.1 Model and Data Source

A holistic approach is essential, recognising the need for transformative changes in infrastructure, culture and policy (Dillman *et al*., 2023). Urban cycling is influenced by a myriad of factors, including climate, population density, and level of infrastructure (Fricker and Grast, 2016). Given this multifaceted nature, our study adopts a model based on the MLP. In line with previous research (Eren and Uz, 2020), urban bicycle use (BIK) is conceptualised as a niche dimension. Its prevalence can be shaped by a combination of landscape conditions, such as population (POP) and weather (WEA), and regime conditions, including bike lane rating (CARR), number of shared bikes (SHB), and satisfaction with shared bike stations (SHST). We will apply this model to a sample of 90 cities from different regions of the world. Data for the WEA, CARR, SHB, SHST and BIK conditions were taken from the Global Bicycle Cities Index 2022 (Luko, 2022), while the POP data were taken from Demographia (2022). While the population size may seem small for a quantitative analysis approach, it is a medium sample size for fsQCA. In any case, it is sometimes considered more appropriate to work with a reduced sample of elements representative of the phenomenon under study than to use a random sample of the same (Goertz and Mahoney, 2012; Ragin, 2023).

2.2 Landscape Variables. Population and Weather Conditions

Bicycle use (BIK) for urban travel is particularly important for cities with high population (POP), traffic congestion and inefficient public transport systems (Podgórniak-Krzykacz, Trippner-Hrabi, 2021). However, the relationship between population and cycling remains controversial. While some studies suggest that an increase in POP increases bicycle usage (Guidon *et al*., 2020), others find no such relationship (Scott, Ciuro, 2019). Nevertheless, POP has been identified as a predictor of the survival of shared bike operators (Amaya-Boig *et al*., 2021).

Weather conditions (WEA) can influence BIK (Bieliński *et al*., 2021; El-Assi *et al*., 2017; Francke *et al*., 2020; Maas *et al*., 2021; Scott, Ciuro, 2019). It has been found that higher temperatures are positively correlated with BIK, while snow, humidity or precipitation tend to have a negative effect (~BIK) (Bieliński *et al*., 2021; El-Assi *et al*., 2017; Eren, Uz, 2020; Kim and Lee, 2023; Scott and Ciuro, 2019; Tu *et al*., 2019; Wessel, 2020). Indeed, BIK tends to increase with favourable temperature forecasts, while it tends to decrease with unfavourable forecasts, such as low temperatures or expected rainfall (Maas *et al*., 2021; Wessel, 2020).

2.3 Regime Variables. Assessment of Bike Lanes, Satisfaction with Shared Bike Stations and Number of Shared Bikes

Comprehensive mobility infrastructure has a significant impact on the overall development of cities, underlining its high relevance (Zhang, Qi, 2021). Bicycle-related infrastructure influences its use within urban mobility (Kim, Lee, 2023). Therefore, bicycle infrastructure is often developed to promote urban cycling, as it has the potential to determine its usage (Eren, Uz, 2020; Osama *et al*., 2017; Podgórniak-Krzykacz, Trippner-Hrabi, 2021).

We consider three related variables: the number of bike lanes (CARR), the number of shared bicycle stations (SHST), and the number of available shared bicycles (SHB).

One of the factors promoting BIK is a robust network of bike lanes (CARR). In contrast, their absence (~CARR) reduces the motivation to cycle (Bieliński *et al*., 2021). It is often considered the most important predictor of BIK (Tu *et al*., 2019), especially when these lanes are perceived as safe and user-friendly. Conversely, shared or mixed lanes or roads without dedicated bicycle infrastructure discourage BIK (Eren, Uz, 2020).

Providing bicycle parking can improve user perception and increase bicycle use (Francke *et al*., 2020). Therefore, the number of shared bike stations, their location and the planned size of shared bike systems (SHST) are considered (Fricker, Gast, 2016). Attractive bike parking facilities are essential for their combined use with other transport modes (Schering and Gómez, 2022). The strategic placement of shared bike stations influences the number of users, i.e., the more optimally located and accessible they are, the higher their use (Eren, Uz, 2020; Scott, Ciuro, 2019). A sparse distribution of stations or difficulty in finding a bike can limit their use (Fishman *et al*., 2015). On the other hand, a higher number of stations and shorter distances between them encourage more extensive bike use (Kim, Lee, 2023). Indeed, the number of bike-sharing stations is associated with the survival of different operators, with evidence suggesting that in some countries survival is assured with 30 or more stations (Amaya-Boig *et al*., 2021).

Similarly, the number of shared bikes (SHB) can influence BIK (Fricker, Gast, 2016; Podgórniak-Krzykacz, Trippner-Hrabi, 2021). Bieliński *et al*. (2021) showed that a lack of available bicycles (~SHB) discourages bicycle use (~BIK). In addition, the number of shared bikes in circulation also explains their level of use (Amaya-Boig *et al*., 2021). Similarly, increasing or decreasing the bike capacity at a station or an uneven distribution can influence BIK (Eren, Uz, 2020; Francke *et al*., 2020). The relationship between SHB and SHST should also be considered, as the rise of active mobility has been partly attributed to dockless bike-sharing services, which have significantly changed the transport ecosystem in many cities. This rapid expansion of dockless shared bikes led to environmental problems in urban mobility due to careless use, such as inappropriate areas for movement and parking. The response to this situation was the development of designated parking zones and shared bike stations to reduce indiscriminate parking of shared bikes (Song *et al*., 2021; Tu *et al*., 2019).

2.4 Niche Variable. Use of Bicycles for Urban Mobility

The dynamism inherent in cities often leads to an increase in BIK as a means of avoiding traffic congestion, reducing pollution and shortening travel times (Podgórniak-Krzykacz, Trippner-Hrabi, 2021). This upward trend is further supported by policies aimed at improving the well-being of urban residents through sustainable measures (Bieliński *et al*., 2021; Podgórniak-Krzykacz, Trippner-Hrabi, 2021). The perceived connectivity and quality of cycling facilities play an important role in influencing the choice of cycling as a mode of transport (Gan *et al*., 2021; Song *et al*., 2021). There is a positive relationship between the expansion and quality of the CARR network and BIK (Osama *et al*., 2017). As a result, many cities are prioritising the development of bike lanes and parking facilities as part of their urban transformation initiatives. Some researchers highlight the lack of infrastructure, inefficient performance of bike-sharing systems (~SHST or ~SHB) and/or WEA as factors determining ~BIK (Song *et al*., 2021, Wessel, 2020).

Based on the above, the following propositions are made:

Proposition 1a: Landscape and regime conditions are combined to explain urban cycling.

Proposition 1b: Landscape and regime conditions are combined to explain the absence of cycling in cities.

Proposition 2a: The combination of landscape and regime conditions generates a causal mechanism that explains bicycle use in cities.

Proposition 2b: The combination of landscape and regime conditions generates a causal mechanism that explains the non-presence of bicycle use in cities.

3. Methodology. Set-Theoretic Multi-Method Research

In order to investigate complex phenomena from a macromarketing perspective, it is essential to have a methodology capable of capturing the complexity arising from a myriad of systemic interactions and connections (Lucarelli, Gipvanardi, 2019). We therefore employ QCA for its ability to elucidate causal complexity through asymmetry, equifinality and conjunctural causation (Wang *et al*., 2021; Zhao *et al*., 2022). This positions it as an appropriate technique for applying the MLP, given its ability to interpret the intricate interplay between conditions associated with different levels.

Rooted in set theory, QCA identifies the necessary and sufficient conditions that explain the presence or negation of an outcome (Beach, Rohlfing, 2015; Mikkelsen, 2017; Rohlfing, Schneider, 2018). QCA facilitates the emergence of behavioural models from systematic cross-case analysis. Crucially, these models are not causal mechanisms; they do not provide a causal explanation linking cause and effect. Instead, they represent regularities that emerge from underlying causal mechanisms (Beach, Rohlfing, 2015; Medina-Molina, Pérez-Macías, 2022; Mello, 2021; Rutten, 2020; Williams, Gemperle, 2017).

A robust causal claim requires evidence of a relationship between the cause and the outcome, coupled with the identification of a mechanism that elucidates how the cause produces the outcome (Beach, Rohlfing, 2015; Capano *et al*., 2019; Marchionni, Reijula, 2019; Rubinson *et al*., 2019).

Mechanism-based theorisation sheds light on how the study of individual cases can enhance our understanding of social phenomena (Ylikoski, 2019). Mechanistic evidence reveals the existence and nature of a causal mechanism that links a cause to an effect within a specific application context (Capano *et al*., 2019; Marchionni, Reijula, 2019). This specific context is referred to as “scope conditions”, the domain in which causal effects remain stable. Consequently, causal mechanisms are expected to be present in a population of cases when the triggering conditions are present (Beach, 2018; Beach, Rohlfing, 2015; Iannacci, Cornford, 2018; Pattyn *et al*., 2022). Whereas a contextual condition acts as a facilitator, a causal condition acts as an activator of causal forces, initiating a mechanism (Pattyn *et al*., 2022). Therefore, the causes identified through QCA at cross-case level make the outcome plausible. When agents realise the outcome, it can be elucidated by within-case analysis through process-tracing (Pattyn *et al*., 2022; Rutten, 2020).

Process-tracing extracts causality from within-case studies by tracing the process that links a cause (or set of causes) to an outcome, thereby facilitating inference (Beach, Rohlfing, 2015; Crasnow, 2017; Millstein, 2019; Pattyn *et al*., 2022; Rutten, 2020; Williams, Gemperle, 2017). The evidence found in the within-case studies through process-tracing provides a segmented understanding of the phenomenon. As such, process-tracing relies on the ability to tell the story of the case (Crasnow, 2017). A central component of process-tracing is the creation of a causal narrative that highlights and accentuates specific elements of the case and clarifies the relationship between evidence and theory (Crasnow, 2017; Millstein, 2019).

An in-depth study of selected cases using a within-case technique (process-tracing), after applying a cross-case technique (QCA), constitutes a theory-first research method called SMMR. This method confirms the existence of a causal mechanism (Beach, 2019; Beach, Rohlfing, 2015; Iannacci, Cornford, 2018; Mello, 2022; Rihoux *et al*., 2021). SMMR deepens the dialogue between theoretical assumptions and empirical data, thereby fostering novel conclusions (Williams, Gemperle, 2017). The primary goal of SMMR is to uncover the causal mechanisms involved. QCA, in answering the “why”, reveals the conditions under which a difference occurs and the core combinations of conditions that lead to the outcome. In answering the “how?”, process-tracing identifies the causal mechanisms at play between specific framework conditions (Pattyn *et al*., 2022; Rihoux *et al*., 2021). SMMR demonstrates the existence of causal relationships and strengthens robust causal inferences (Beach, 2019; Medina-Molina, Pérez-Macías, 2022; Mikkelsen, 2017; Oana, Schneider, 2018; Oana *et al*., 2021; Rohlfing and Schneider, 2018). Within SMMR, process-tracing requires appropriate case-selection strategies for comparison (Williams, Gemperle, 2017). The SetMethods smmr command allows for the systematic selection of typical cases suitable for process-tracing applications (Medina-Molina, Pérez-Macías, 2022; Oana, Schneider, 2018; Oana *et al*., 2021).

4. Results

4.1 Identification of Necessary and Sufficient Conditions through QCA

QCA identifies the necessary and sufficient conditions for the presence or absence of an outcome. In addition, Necessary Condition Analysis (NCA) complements QCA by identifying the degree of a necessary condition that must be satisfied to reach a certain level of an outcome, i.e., the so-called necessary conditions in degree or bottlenecks (Dull, 2016; Sukhiv *et al*., 2022). Finally, SMMR is applied to identify causal mechanisms. *Table 1* presents the conditions and outcomes considered in the model, as well as their descriptive statistics.

Table 1. Description of the model´s conditions and the outcome

Label	Type	Codification	Min	Max	Median	Stand dev
POP	Condition	Fuzzy set	126,851.000	37,732,000.000	6,540,560.522	8,358,472.947
WEA	Condition	Fuzzy set	23.620	89.820	63.448	12.780
CARR	Condition	Fuzzy set	1.430	66.490	43.820	15.007
SHB	Condition	Fuzzy set	1.000	100.000	19.212	20.302
SHST	Condition	Fuzzy set	1.000	100.000	20.734	20.091
BIK	Outcome	Fuzzy set	0.030	51.000	8.807	9.376

Source: own calculations.

Both the conditions and the result were calibrated by percentiles 95, mean and 5. The existence of necessary conditions is then analysed for BIK and ~BIK (*Table 2*), and we find that only ~POP for BIK was close to the necessary levels (Cons.Nec=0.900; Cov.Nec=0.504; RoN=0.504). However, as the RoN was close to 0.5, it was not considered a necessary condition in kind.

Table 2. Analysis of necessary conditions

	Outcome BIK			Outcome ~BIK		
	Cons.Nec	**Cov.Nec**	**RoN**	**Cons.Nec**	**Cov.Nec**	**RoN**
WEA	0.604	0.467	0.669	0.629	0.822	0.858
CARR	0.865	0.555	0.619	0.614	0.665	0.684
SHST	0.624	0.609	0.806	0.439	0.724	0.855
SHB	0.664	0.626	0.804	0.428	0.682	0.829
POP	0.331	0.368	0.758	0.475	0.889	0.947
~WEA	0.769	0.551	0.674	0.592	0.716	0.766
~CARR	0.477	0.423	0.705	0.589	0.880	0.920
~SHST	0.717	0.431	0.520	0.762	0.774	0.732
~SHB	0.633	0.407	0.523	0.765	0.794	0.756
~POP	0.900	0.504	0.504	0.663	0.626	0.574

Source: own calculations.

Next, the existence of combinations of conditions that might be necessary for the presence or negation of the study outcome was analysed. Occasionally, a theory could propose the substantive equivalence of two or more conditions as necessary, where the presence of one of them could be necessary for the outcome (Oana *et al*., 2021). From the results obtained (*Table 3*), it can be seen that none of the combinations correspond to a previously existing theoretical interpretation, so their acceptance is rejected. An interpretation of the results obtained without a previous theory would imply a mechanical application based on the data (Mello, 2021; Schneider, Wagemann, 2010). Only one of the condition combinations exceeds the silver thresholds of 0.9 for coverage and 0.6 for RoN (Bazzan *et al*., 2022), but it was composed of three conditions.

Table 3. Analysis of the combinations of necessary conditions

Outcome	Superset	inclN	RoN	covN
Bike	~POP	0.900	0.504	0.504
	CARR+SHST	0.907	0.553	0.532
	CARR+SHB	0.915	0.561	0.540
~Bike	WEA+~CARR+~SHST	0.915	0.584	0.765
	WEA+~CARR+~SHB	0.906	0.612	0.773
	WEA+~SHST+~SHB	0.902	0.589	0.761
	~WEA+~SHST+POP	0.901	0.500	0.723
	~WEA+~CARR+SHST+POP	0.906	0.510	0.729
	WEA+~CARR+SHST+POP	0.902	0.567	0.751
	~WEA+~CARR+SHB+POP	0.906	0.506	0.727
	WEA+~CARR+SHB+POP	0.909	0.521	0.735

Source: own calculations.

To deepen the analysis, NCA was applied. This shows that a high level of WEA (d=0.130, p=0.066) and CARR (d=0.291, p=0.003) is necessary to obtain a high BIK. However, these conditions hardly act as a bottleneck to achieve average levels of outcome (BIK), as 9.5% of WEA and 25.1% of CARR are sufficient (*Table 4*).

Table 4. Bottleneck analysis

Bike	WEA	CARR
0	NN	NN
10	NN	NN
20	NN	NN
30	NN	3.2
40	3.6	14.2
50	9.5	25.1
60	15.5	36.1
70	21.5	47.0
80	27.4	58.0
90	33.4	68.9
100	39.4	79.9

Source: own calculations.

Truth tables were then constructed using a consistency threshold of 0.85 for inclusion. Given the objective of this study, which is to draw conclusions from the SMMR results, the conservative solution was chosen. As there are no conflicting simplifying assumptions or necessary conditions, the solution derived from the standard analysis is consistent with what would be obtained from the extended standard analysis. In addition, four cases with membership scores of 0.5 were eliminated. However, to facilitate the identification of core conditions (those with a strong causal relationship with the outcome) and peripheral conditions (those with a weaker causal relationship), we also computed the parsimonious solution.

Table 5. Sufficient conditions (outcome Bike)

	Model	Term1	Term2	Term3	Term4
WEA	-	○		⬤	⬤
CARR	-	◯	●	◯	●
SHST	-	⬤	◯	⬤	⬤
SHB	-	●	⬤	●	◯
POP	-	⬤	◯	○	○
inclS	0.793	0.834	0.861	0.880	0.860
PRI	0.495	0.552	0.412	0.365	0.458
covS	0.514	0.415	0.202	0.265	0.326
covU	-	0.118	0.030	0.018	0.041

Black circles indicate the presence of the condition; white circles indicate the negation. Large circles represent core conditions; small circles represent peripheral conditions

Source: own calculations.

Four sufficient conjunctions explain the conservative solution for BIK: CARR*~SHST*SHB*~POP + ~WEA*~CARR*SHST*SHB*~POP + WEA*~CARR*SHST*SHB*~POP + WEA*CARR*SHST*~SHB*~POP. As shown (*Table 5*), this solution has a high inclS (0.793) and a moderate covS (0.514). The value of PRI (0.495) indicates that the solution explains both BIK and its denial (~BIK).

Table 6. Sufficient conditions (outcome ~Bike)

	Model	Term1	Term2	Term3	Term4	Term5	Term6	Term7	Term8	Term9
WEA	-	○	○			●	●	○	●	●
CARR	-	●		○		●	●	○	●	
SHST	-			○	○	●		●	●	●
SHB	-		●	○	○		●		●	●
POP	-	●	●		●	○	○	○		○
inclS	0.852	0.938	0.913	0.912	0.931	0.854	0.843	0.912	0.869	0.846
PRI	0.780	0.857	0.761	0.863	0.894	0.626	0.603	0.721	0.664	0.604
covS	0.775	0.209	0.163	0.518	0.422	0.282	0.274	0.212	0.279	0.268
covU	-	0.004	0.000	0.086	0.036	0.012	0.004	0.004	0.001	0.003

Source: own calculations.

The conservative solution for ~BIK is explained by nine sufficient conjunctions: ~WEA*CARR*POP + ~WEA*SHB*POP + ~CARR*~SHST*~SHB + ~SHST*~SHB*POP + WEA*CARR*SHST*~POP + WEA*CARR*SHB*~POP + ~WEA*~CARR*SHST*~POP + WEA*CARR*SHST*SHB + WEA*SHST*SHB*~POP. This solution has optimal parameters (inclS=0.852, covS=0.780, PRI=0.775) (*Table 6*).

To establish the robustness of the results, we performed fit-oriented and case-oriented tests (Oanna, Schneider, 2021) using three models comparative to the initial one (calibration Perc.95, mean, Per.5 and consistency 0.80; calibration Perc.90, mean, Per.10 and consistency 0.85; calibration Perc.90, mean, Per.10 and consistency 0.80). The fit-oriented robustness shows the following parameters for BIK and ~BIK: RF_cov (0.56; 0.659); RF_cons (0.929; 1.001); RF_SC_minTS (0.577; 0.562); RF_SC_maxTS (0.571; 0.755). For both results we have cases in the two shaded areas–possible and shaky cases–so we have a robustness rank of 4.

4.2 Identification of Causal Mechanisms through Process-Tracing

Although SMMR can have different applications, we will focus on investigating the mechanisms that explain why a sufficient term identified in QCA produces the result under investigation. The key to SMMR is the selection of specific cases to study the processes in depth, for which they must be classified in the single within-case analysis. The comparative within-case analysis is then carried out between some of the identified cases.

Within the single within-case analysis, we identified the typical cases (*Table 7*). For each conjunction, we analyse the effect of the different conjunctions–conditions that conform to it, distinguishing between the conjunct under study–focal conjunct FC–and the rest of the conjunctions that make up the conjunction–complementary conjunct CC. Typical cases must conform to the attribution principle; they are better because their membership in the sufficient term is higher; and the most typical cases are those on or near the diagonal and closer to the upper right corner (Williams, Gemperle, 2017).

Table 7. Typical Cases

City	FC	Outcome	CC	Term	UniqCov	Best	MostTypFC	Rank
FC CARR								
Berlin	0.76	0.71	0.62	0.62	TRUE	0.48	TRUE	2
Bremen	0.88	0.85	0.51	0.51	TRUE	0.55	FALSE	2
Dusseldorf	0.76	0.63	0.54	0.54	TRUE	0.72	FALSE	2
Nuremberg	0.82	0.65	0.59	0.59	TRUE	0.75	FALSE	2
FC ~SHST								
Nuremberg	0.59	0.65	0.64	0.59	TRUE	0.53	TRUE	1
Dresden	0.53	0.61	0.67	0.53	TRUE	0.63	FALSE	1
Hamburg	0.53	0.71	0.80	0.53	TRUE	0.83	FALSE	1
Bremen	0.55	0.85	0.51	0.51	TRUE	1.09	FALSE	2
FC SHB								
Berlin	0.62	0.71	0.76	0.62	TRUE	0.56	FALSE	1
Bremen	0.51	0.85	0.55	0.51	TRUE	1.17	FALSE	1
Nuremberg	0.64	0.65	0.59	0.59	TRUE	0.43	TRUE	2
Dusseldorf	0.64	0.63	0.54	0.54	TRUE	0.48	FALSE	2
FC ~POP								
Dusseldorf	0.54	0.63	0.64	0.54	TRUE	0.64	FALSE	1
Berlin	0.77	0.71	0.62	0.62	TRUE	0.50	TRUE	2
Bremen	0.95	0.85	0.51	0.51	TRUE	0.69	FALSE	2
Hamburg	0.90	0.71	0.53	0.53	TRUE	0.85	FALSE	2

Source: own calculations.

We focus on the results obtained for the first sufficient term for BIK, the only conjunction for which the requirements for inferring the mechanism to all typical cases are met. For FC CARR, the attribution principle is not fulfilled, although a good value for the corridor principle is obtained for Berlin and Bremen (FC 0.76/0.88 and result 0.71/0.85). On the other hand, the attribution principle is fulfilled for some of the typical FC cases: ~SHST (Nuremberg, Dresden, Hamburg), SHB (Berlin, Bremen) and ~POP (Düsseldorf). We can therefore confirm the existence of a mechanism.

We then proceeded to the comparative within-case analysis, starting with the comparison of a typical and an Individually Irrelevant (IIR) case (*Table 8*). For this, the typical case must be uniquely covered and the IIR globally uncovered.

Table 8. Comparative analysis Typical-IIR

Typical	IIR	UniqCov	GlobUncov	Best	PairRank
FC CARR					
Bremen	Warsaw	TRUE	TRUE	0.86	5
FC ~SHST					
Nuremberg	Vancouver	TRUE	TRUE	1.65	1
FC SHB					
Berlin	Seattle	TRUE	TRUE	1.13	1
FC ~POP					
Dusseldorf	Chicago	TRUE	TRUE	1.88	1

Source: own calculations.

All FCs have pairs that meet the criteria. Moreover, in three of the FC (~SHST, SHB and ~POP) there are pairs whose pair rank is 1. Thus, the existing mechanism triggers the cause-effect relationship.

Table 9. Comparative analysis Typical1-Typical2

Typical1	Typical2	UniqCov1	UniqCov2	Best	PairRank
FC CARR					
Berlin	Dusseldorf	TRUE	TRUE	1.36	4
FC ~SHST					
Nuremberg	Dresden	TRUE	TRUE	1.21	1
FC SHB					
Berlin	Bremen	TRUE	TRUE	2.10	1
FC ~POP					
Dusseldorf	Hamburg	TRUE	TRUE	2.11	2

Source: own calculations.

Finally, the comparison of two typical cases (*Table 9*) allows us to establish the generalisation of the mechanism to all typical cases, the basis for causal inference. Since the typical cases meet the requirement that the two typical cases are uniquely covered, we can generalise the existence of a causal mechanism to all typical cases of the term.

5. Discussion

A primary observation from the results is the absence of necessary conditions for both the use and non-use of the bicycle as a mode of urban mobility. Thus, neither the presence of BIK nor ~BIK requires the presence of any of the conditions considered.

The results present four solutions that explain the use of bicycles in urban mobility, which can be simplified into two primary solutions. Consequently, the first and fourth solutions can be expressed as CARR*~POP*(~SHST*SHB+WEA*SHST*~SHB). In cities with a smaller population and a well-developed network of bike lanes, cycling is widespread when complemented by a fleet of shared bicycles. This is true even if there is not a satisfactory number of shared bike stations. In these cities, the infrastructure that supports cycling emphasises the presence of bike lanes and an extensive fleet of shared bike stations. In particular, these cities do not require the high number of stations suggested by Amaya-Boig *et al*. (2021). In other cases, a satisfactory number of shared bike stations is combined with favourable weather conditions, even in the absence of a shared bike fleet.

This highlights the importance of infrastructure in promoting bicycle use, especially in cities with low population density. The absence of such infrastructure can discourage the uptake of cycling (Franckle *et al*., 2020). Landscape variables, such as weather, also play a key role. For example, cities such as Utrecht and Portland experience lower levels of cycling during their long, cold winters (Eren and Uz, 2020; Wessel, 2020). The way in which conjunctural causation is presented is striking, as the combination of conditions associated with shared bicycles requires the negation of one of the two. As this study examines the adoption of bicycles for urban mobility, it contributes to the ongoing debate on the influence of population size on bicycle use, especially as we look at patterns of bicycle use in different types of cities.

The second and third recipes for BIK can be simplified as ~CARR*SHST*SHB*(~WEA*POP+WEA*~POP). Even in the absence of a comprehensive network of bike lanes, if infrastructure elements such as shared bike stations and fleets of shared bicycles are in place, cycling will manifest itself. This can be seen in cities with large populations who use bicycles to avoid traffic congestion, despite unfavourable weather conditions. Ranked seventh in the Global Bicycle City Index 2022, Hangzhou is an example of this. This is in line with Guidon *et al*. (2020), who suggest that the traffic congestion typical of densely populated cities encourages cycling. This is further supported by studies suggesting that cycling is more satisfying in medium to large cities due to the optimal distances travelled (Jiménez and Nogal, 2021). Conversely, in less populated cities, where bicycle usage may not be as essential due to reduced congestion, favourable weather conditions combined with the right infrastructure can still encourage bicycle usage (El-Assi *et al*., 2017; Wessel, 2020). Cities that fit this description include Dublin, known for its frequent rainfall, and Tel Aviv, where mild temperatures encourage bicycle use. Given these findings, we accept Proposition 1a.

In this case, the importance of the regime in promoting innovation success is evident (Becker *et al*., 2022; Schwarz *et al*., 2022; Te Brömmelstroet *et al*., 2020). Bicycles are used for urban mobility in cities with a large number of shared bicycles and where citizens are satisfied with the existing shared bicycle stations. Through the provision of shared bicycles and dedicated parking stations, the cycling regime has stimulated innovations that support its adoption (Nikolaeva and Nelo-Deakin, 2020; Nikolaeva *et al*., 2019; Te Brömmelstroet *et al*., 2020).

This study challenges the perceived importance of bike lanes. Many of the conjuncts explaining urban cycling are associated with cities with low bike lane ratings, while high ratings are associated with non-use. This contrasts with previous research (Bieliński *et al*., 2021; Eren and Uz, 2020; Tu *et al*., 2019).

Five recipes, derived from an initial nine, shed light on the negation of bicycle use. The first, ~WEA*POP*(CARR+SHB), suggests that a combination of adverse weather and high population negates bicycle use, regardless of the presence of bike lanes or shared bicycle stations. The importance of landscape conditions, especially weather, is confirmed (Bieliński *et al*., 2021). The third and fourth recipes, SHST*SHB*(~CARR+POP), indicate that in the absence of key infrastructure, such as negative satisfaction with shared bicycle stations and low numbers of shared bicycles, combined with either a lack of bike lanes or a high population, bicycles are not adopted for urban mobility. The critical role of regime variables is evident, as their absence explains ~BIK. This trend can be seen in cities such as Lagos, Hong Kong, Bangkok, Seoul, Jakarta, Moscow, New Delhi, Beijing, Mexico City, Istanbul, Buenos Aires, London, Santiago, Bogotá, Cairo and Sao Paulo. The non-shared ones reflect the differentiating component of the recipe. The importance of bike lanes is highlighted in cities such as Prague, Tbilisi, Medellin, Rome, Athens, Cali, Auckland, Sydney, Casablanca and Melbourne. In the Global Bicycle City Index 2022, these cities score particularly low (below 43 points) in lane-related infrastructure, with some, such as Medellin, Cali and Tbilisi, scoring as low as 9.27, 13.07 and 14.85 points, respectively.

The fifth and sixth recipes can be summarised as WEA*CARR~POP*(SHB+SHST). This solution includes cities where, despite favourable weather conditions and infrastructure such as bike lanes and shared bikes or stations, bicycles are not used for urban mobility if the population is not high. In other words, even with favourable landscape and regime conditions, bicycles remain unused. It is noteworthy that the fifth and sixth recipes apply to the same cities, with the exception of Portland, Utrecht, Dortmund and Düsseldorf. This is in line with Jiménez and Nogal (2021), who showed that a higher density of bicycles, stations and docking points does not necessarily lead to increased bicycle use. The seventh solution explains the negation of cycling in cities such as Krakow, Warsaw, Milan, Oslo or Ljubljana.

The eighth and ninth solutions, which are common to all cities except Paris, Dublin and Tel Aviv, can be summarised as WEA*SHST*SHB*(CARR+~POP). These configurations show that despite favourable weather conditions and extensive infrastructure, including bike lanes, shared bike stations and shared bikes, bicycles remain unused in cities such as Dublin, Tel Aviv, Barcelona, San Francisco, Nantes, Seville, Vancouver, Nice, Bordeaux and Frankfurt. In cities with smaller populations, cycling is not the preferred mode of transport, even when the weather and infrastructure are suitable. This could be due to the existence of alternative, more convenient means of transport, such as an efficient public transport system (Barcelona, San Francisco, Nantes, Seville, Vancouver, Nice, Bordeaux, Frankfurt). We therefore accept proposition 1b.

We then analysed the existence of mechanisms explaining the results studied. The typical cases present in all the FCs of the first term of the sufficient solutions of bicycle use demonstrate the existence of a causal mechanism. In order to determine whether such a mechanism actually triggers the occurrence of the outcome, we carried out a comparative analysis between typical-IIR cases. For FC CARR, Bremen has a long tradition of bicycle commuting, with 25% of trips made via bike sharing in 2014. Impressively, there were 916 bicycles per 1,000 inhabitants, available on an extensive 450 km cycle route network. In 2019, Bremen will launch an initiative to replace car parking spaces with bicycle parking and infrastructure (Schering and Gómez, 2022). Meanwhile, Warsaw has an efficient public transport system, which may explain its lower bicycle use (Kłos-Adamkiewicz and Gutowski, 2022). Nuremberg, which represents the typical case of an insufficient number of shared bike stations, has 48 shared bike stations in its old town. This seems inadequate for the 1,816 bikes in circulation according to bikesharemap.com. In contrast, Vancouver's robust bike share program has 240 stations for 2,191 bikes. Thus, despite having a similar number of bikes, Vancouver offers 400% more stations than Nuremberg; in fact, Nuremberg scored 18.43 in the Global Bicycle City Index 2022 in this regard, while Vancouver scored 42.72.

In FC SHB, Berlin is the typical case. Attitudes and lifestyles in Berlin favour cycling, which accounts for 18% of trips. The city has invested in bike lanes to encourage a shift to sustainable mobility (Becker *et al*., 2022; Von Schneidemesser *et al*., 2020), supported by the Mobility Act, and is also making efforts in other infrastructure, such as the number of bicycles, which, although not very high at 24.43, is much better than its peer city Seattle, which scores 4.62 according to the Global Bicycle City Index 2022. In the case of Seattle, satisfaction with the dockless system is higher than with the docked system (Kutela *et al*., 2021). The FC ~POP represents cities without large populations. The typical case here is Düsseldorf, with around 630,000 inhabitants, compared to around 9 million in Chicago.

Finally, in order to establish the possibility of extrapolating the existence of the mechanism to all the typical cases of the solution, we need to compare the typical cases for each FC. For FC CARR, the typical cases are Berlin and Düsseldorf. In 2020, Düsseldorf recognised the need to improve its infrastructure in order to transition to sustainable mobility, as outlined in its Mobility Plan 2030. Both cities have similar scores in the Global Bicycle City Index 2022 for rail infrastructure, with 50.79 for Berlin and 50.87 for Düsseldorf. Along with Nuremberg, Dresden is a typical case of FC ~SHST. This may be due to an uneven distribution of stations, especially near the central station and the university (Steinacker *et al*., 2022). For FC ~SHB, the typical cases are Berlin and Bremen, which are already exposed. Finally, for FC ~POP, Düsseldorf is joined by Hamburg, a city of around two million inhabitants. This supports proposition 2a, which confirms the existence of different mechanisms that promote sustainability in different contexts (Dalpian *et al*., 2015). These mechanisms allow the identification of possible actions in the field of macromarketing that can stimulate and activate systemic change (Kemper, Ballentine, 2017). However, proposition 2b is rejected because we were unable to identify a mechanism for any of the conditions of the sufficient solution for the negation of bicycle use.

From a theoretical perspective, the importance of equifinality, causal asymmetry and conjunctural causation in explaining BIK and ~BIK is evident. Both results are explained by different combinations of conditions. Moreover, the separate explanations involve different recipes or conjunctions: four for BIK, and nine for ~BIK. Each recipe is made up of a combination of conditions, not in isolation. Separately, we used SMMR to verify the existence of a causal mechanism linking CARR*~SHST*SHB*~POP to BIK. This mechanism is uniquely identified with respect to German cities, highlighting the importance of site-specific elements in sustainable innovation processes and transitions. How context influences the interactions between niche, regime and landscape is verified, shaping mobility evolution (Jiménez, Nogal, 2021; Pachoud *et al*., 2022; Schaefer *et al*., 2021; Van Waes *et al*., 2020). Consequently, the strategies adopted by bicycle operators are profoundly shaped by the different configurations of the physical and institutional context (Von Schneidemesser *et al*., 2020). In particular, a solution with modest robustness parameters indicates the presence of a mechanism. Therefore, the identification of mechanisms is more influenced by the behaviour of typical cases than by general parameters for evaluating solutions.

From a practical perspective, the results highlight the interconnectedness and compensatory nature of landscape and regime variables. Bicycle use for urban commuting is influenced by the presence and absence of both landscape and regime conditions. However, such use appears to be habitual in less densely populated cities. As noted above, regime level conditions counterbalance each other, with the presence (or absence) of bike lanes being complemented by the presence (or absence) of shared bike-related mobility services. Cities should therefore look beyond simply providing infrastructure, such as bike lanes, or encouraging operators to act within the regime, such as increasing the number of shared bikes in circulation or creating parking facilities/stations for them. Perhaps more importantly, there needs to be public recognition of a shift towards sustainable mobility, driven by government action, i.e., landscape conditions.

This study has two main limitations that could inform future research. First, our sample includes 90 cities, which could be expanded in subsequent studies. It would also be beneficial to include additional conditions to further elucidate bicycle use as a mode of urban mobility.

The findings of this study can guide urban planners and policymakers. We can suggest the potential applicability of some of the findings to similar contexts. Firstly, the use of bicycles as a sustainable mobility mode is presented in cities with low population density and suitable weather conditions. However, city administrators should take advantage of the positive impact of citizen satisfaction with the number of shared bike stations. Secondly, for cities with a significant number of shared bicycles in circulation and a high population, it is beneficial to equip the city with numerous stations; conversely, cities with a smaller population should have fewer stations. These last relationships are confirmed by the fact that in almost none of the cities with a low level of bicycle use are there both shared bicycles and stations.

Conclusions

The aim of this paper is to identify the conditions that explain both the use and non-use of bicycles for urban mobility. Through our research we have explored how cities can turn a challenge like increasing mobility into an opportunity, specifically by promoting the use of bicycles for urban commuting. Our findings indicate the absence of a single necessary condition, while revealing several sufficient combinations of conditions that explain both BIK and ~BIK. In other words, no single condition universally dictates bicycle use in urban areas; instead, its adoption depends on different combinations of conditions.

In this study, we used an MLP-based model to address criticisms of conventional adoption models. This approach facilitated the investigation of interactions between the different dimensions of the MLP: landscape and regime (related to conditions); and niche (related to outcome). It also confirmed the importance of external actors, such as shared bike operators and urban infrastructure, in the innovation process.

Our systemic change analysis highlights the value of integrating a macromarketing perspective with socio-technical transition (STT) to explore the mechanisms underpinning the emergence of sustainability. Macromarketing, through its meso lens, offers insights into pathways to sustainability. Beyond landscape-level changes, the interplay of different elements within the mobility ecosystem can shed light on the dynamics of bicycle adoption. Furthermore, our findings confirm that adoption of an innovation requires changes to the socio-technical system it inhabits, addressing the first research gap. The multiple solutions proposed to either encourage or discourage bicycle use, coupled with the complex nature of their explanations, suggest that their behaviour is consistent with the characteristics of 'wicked' problems, a complexity also evident in our study.

Finally, the application of SMMR allowed us to identify the causal mechanisms that link conditions and outcomes. While the various conjunctions that form the sufficient solution in QCA act as scope conditions, the mechanisms explain the existence of a causal relationship between conjunction and outcome. A mechanism was identified for BIK, but not for ~BIK, which addresses the second research gap.

In conclusion, this study highlights the crucial intersection between marketing and sustainability. By exploring how marketing strategies, particularly those related to shared bike operators and urban infrastructure, can influence sustainable urban mobility, we have demonstrated how marketing tactics can be used to promote sustainability. This finding highlights the importance of integrating marketing practices into efforts to promote sustainability and sustainable innovation. Ultimately, this work contributes to clarifying the relationship between marketing and sustainability, two fields that are increasingly interdependent in the context of current global challenges.

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VAŽIUOTI AR NEVAŽIUOTI DVIRAČIU. IŠPLĖSTINIO INOVACIJŲ SKLAIDOS MODELIO TAIKYMAS TVARIAM JUDUMUI

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SANTRAUKA

Dėl didelės taršos miestuose ir jos poveikio gyventojų gyvenimo kokybei būtina ieškoti sveikesnių ir tvaresnių judumo būdų. Tarp priemonių, taikomų siekiant aplinkai palankesnio elgesio, dviračių transportas yra mažiau tarši transporto rūšis ir teigiamai veikia piliečių gerovę. Todėl svarbu nustatyti sąlygų, kurios paaiškintų naudojimąsi miesto dviračiais, ir sąlygų, dėl kurių žmonės nesinaudoja dviračiais, derinį, taip pat priežastinių mechanizmų egzistavimą šiuose santykiuose. Tai leis parengti konkretesnius ir (arba) labiau pritaikytus veiksmų planus, skirtus skatinti važiavimą dviračiais mieste. Šiuo tikslu 90 pasaulio miestų imčiai buvo taikoma daugiapakopė perspektyva (MLP) ir teoriniai daugiaetapiai tyrimai (SMMR). Rezultatai rodo, kaip kraštovaizdžio ir režimo sąlygų derinys paaiškina dviračių, kaip miesto transporto priemonės, naudojimą ir nenaudojimą. Taip pat nustatyta, kad egzistuoja priežastinis mechanizmas, paaiškinantis dviračių naudojimą Vokietijos miestuose.

REIKŠMINIAI ŽODŽIAI: darnus judumas; pritaikymas; važiavimas dviračiu; QCA; proceso stebėjimas.