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# Sustainable Daily Mobility and Bike Security

**Sergej Gričar [1,*], Christian Stipanović [2] and Tea Baldigara [2]**

[1] Faculty of Business and Management Sciences, University of Novo Mesto, 8000 Novo Mesto, Slovenia
[2] Faculty of Tourism and Hospitality Management, University of Rijeka, 51410 Opatija, Croatia; christis@fthm.hr (C.S.); teab@fthm.hr (T.B.)
* Correspondence: sergej.gricar@uni-nm.si

**Abstract**

As climate change concerns, urban congestion, and environmental degradation intensify, cities prioritise cycling as a sustainable transport option to reduce $CO_2$ emissions and improve quality of life. However, rampant bicycle theft and poor security infrastructure often deter daily commuters and tourists from cycling. This study explores how advanced security measures can bolster sustainable urban mobility and tourism by addressing these challenges. A mixed-methods approach is utilised, incorporating primary survey data from Slovenia and secondary data on bicycle sales, imports and thefts from 2015 to 2024. Findings indicate that access to secure parking substantially enhances users' sense of safety when commuting by bike. Regression analysis shows that for every 1000 additional bicycles sold, approximately 280 more thefts occur—equivalent to a 0.28 rise in reported thefts—highlighting a systemic vulnerability associated with sustainability-oriented behaviour. To bridge this gap, the study advocates for an innovative security framework that combines blockchain technology and Non-Fungible Tokens (NFTs) with encrypted Quick Response (QR) codes. Each bicycle would receive a tamper-proof QR code connected to a blockchain-verified NFT documenting ownership and usage data. This system facilitates real-time authentication, enhances traceability, deters theft, and builds trust in cycling as a dependable transport alternative. The proposed solution merges sustainable transport, digital identity, and urban security, presenting a scalable model for individual users and shared mobility systems.

**Keywords:** Non-Fungible Tokens; blockchain; bike security; sustainable mobility; QR codes



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## 1. Introduction

In the face of intensifying climate change, urban congestion, and environmental degradation, cities worldwide are prioritising sustainable modes of transportation. Cycling has emerged as a key alternative, offering environmental, economic, and health benefits. Yet despite these advantages, persistent security issues—particularly theft—continue to deter wider adoption among daily commuters and tourists. This study is motivated by the urgent need to address these barriers through innovative, scalable solutions that align with broader sustainability goals.

In Slovenia, mobility patterns reveal both opportunity and challenge. According to our survey (Figure 1), 70% of respondents commute by car, 19% use buses, 18% walk, 16% cycle, and 7% take trains. Notably, the question allowed multiple answers, highlighting the blended nature of modern commuting habits. This figure suggests that while bicycles already play a role in daily mobility, their full potential is hindered. The relatively low

cycling share, especially compared to car usage, signals a missed opportunity for more sustainable travel behaviour.

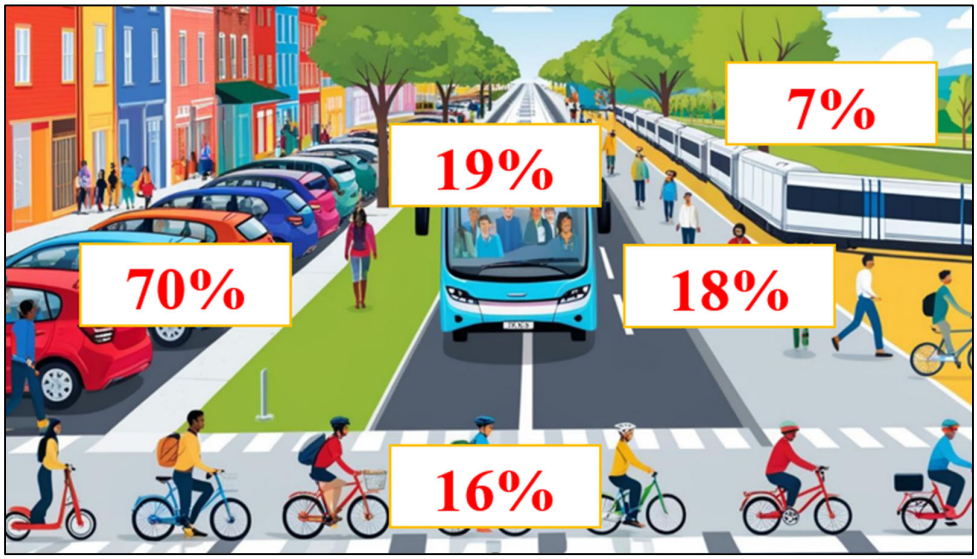



**Figure 1.** Survey data on how people migrate to work. Several possible answers were permitted. The source is the authors' compilation by Canva.

A critical discrepancy lies in the level of protection and traceability associated with different transport modes. Vehicles such as cars, buses, and trains are registered, insured, and marked with license plates, making them traceable and less prone to theft. On the other hand, bicycles lack a universal identification system and are often left unsecured in public areas, making them easy targets for robbery and challenging to recover once stolen. This absence of formal ownership markers represents a significant barrier to promoting cycling as a reliable and secure commuting option.

This article primarily examines how improvements in bicycle security infrastructure and digital verification systems can support sustainable urban and tourism mobility. Specifically, the study explores the potential of integrating blockchain technology and Quick Response (QR) code verification to enhance ownership transparency and trust in bike security systems. By investigating user perceptions and applying regression analysis to contextual data, the article assesses behavioural and systemic challenges related to cycling adoption.

The article's structure is as follows: Section 2 reviews previous empirical research on bike security and blockchain applications. Section 3 outlines the methodology and data sources, including the survey design and statistical analysis. Section 4 provides the research gap and hypothesis development. Section 5 presents key results on user perceptions and theft patterns. Section 6 discusses broader implications for urban planning and sustainable development. Finally, Section 7 offers conclusions and outlines directions for future research.

This paper explores the intersection of sustainable mobility and digital innovation by enhancing the technical foundation of cycling security through the integration of blockchain architecture, QR code verification, and decentralised ownership systems. The proposed framework addresses the growing issue of bike theft and underutilisation of cycling infrastructure, aligning with a broader shift towards innovative, connected, and climate-resilient urban mobility. By connecting technical design with behavioural insights and sustainability policy objectives, the paper adds to the ongoing discussion about how digital technologies can effectively support green transport systems in both practical and systemic ways.

## 2. Previous Empirical Research

In recent years, the intersection of blockchain technology and sustainable urban mobility has emerged as a focal point for scholarly inquiry and practical application within the industry [1–3]. A considerable body of empirical research has sought to assess the efficacy of blockchain-based solutions, particularly in enhancing security, transparency, and operational efficiency across various domains. Despite the relatively nascent application of blockchain technology in bike security, the existing literature on its applications provides a robust framework for understanding its potential benefits and inherent challenges [4–6].

The initial scholarship concerning blockchain technology predominantly concentrated on its decentralised ledger system, highlighting the capacity of this technology to safeguard transactions against manipulation and fraud [7]. The foundational work of Nakamoto [8] established the conceptual basis for blockchain by demonstrating its transformative potential for trust frameworks in digital transactions. Subsequent empirical analyses conducted within the financial sector have corroborated that blockchain technology can significantly reduce transaction times and enhance security by eliminating the need for intermediaries [9]. These seminal studies elucidate blockchain's ability to provide real-time, tamper-proof data verification, a characteristic of significant relevance for bike security [10].

Building upon these foundational studies, numerous researchers have explored the application of blockchain in asset management and security [11,12]. A noteworthy corpus of empirical research has scrutinised Non-Fungible Tokens (NFTs) to establish digital ownership of physical assets. NFTs possess unique identifiers secured on a blockchain, producing an immutable record of ownership and transactional history. Empirical demonstrations in high-value asset markets, such as art and luxury goods, have shown that NFT-based frameworks significantly enhance traceability while reducing incidents of fraud [13,14]. Although these investigations predominantly target premium asset categories, the underlying principles are inherently applicable to bicycle ownership. One may generate verifiable digital certificates to affirm ownership by tokenising bicycles as NFTs, deterring theft and fraudulent claims [15].

Furthermore, the integration of QR codes with blockchain technology has emerged as a promising approach for bridging the physical-digital divide [16]. Empirical studies conducted within innovative city frameworks have examined QR code-based mechanisms for asset tracking and user authentication [17]. For instance, pilot initiatives in multiple European cities have successfully deployed QR codes to access blockchain-based records across various public services, encompassing ticketing systems and asset management applications [18]. The findings from these studies consistently indicate that QR codes, when integrated with immutable blockchain records, significantly augment system transparency and expedite verification processes [19]. An illustrative case is the recent initiative undertaken by the Belgian government, which sought to integrate QR codes with blockchain technology for enhanced asset security [20] (Figure 2). This government-led innovation bolstered data transparency and established a precedent for modernising security systems within urban mobility contexts [21,22].

The burgeoning research on bicycle security is advancing, with early empirical investigations yielding noteworthy findings. Studies related to bike systems have unveiled persistent challenges, including theft, vandalism, and asset misuse. Traditional security measures, such as physical locks and centralised registration systems, have demonstrated inadequacies in effectively addressing these challenges [23]. Conversely, case studies incorporating blockchain-based registration systems have reported measurable declines in theft incidents and enhancements in operational efficiency [24]. These findings support the assertion that integrating blockchain technology with digital verification tools such

as QR codes can significantly strengthen the security framework for bike initiatives and individual bike ownership.

**Figure 2.** The Belgian Solution of QR code. The source is https://mybike.belgium.be/fr/media-kit (accessed on 23 June 2025).

Furthermore, beyond technology-centric inquiries, a substantial body of research has scrutinised user perceptions and behavioural responses to emerging security technologies. Surveys and field experiments consistently indicate that user trust and technology acceptance are pivotal determinants for successfully implementing blockchain-based solutions. For instance, studies that deploy structured questionnaires have identified that factors such as perceived ease of use, transparency, and system reliability substantially influence users' propensity to adopt novel technologies [25]. Within bike security, these insights suggest that a blockchain-based system, when integrated with NFTs and QR codes, could achieve higher adoption rates if users perceive the system as accessible and practical [26].

Furthermore, additional empirical research has investigated the economic implications of blockchain integration. Cost-benefit analyses across various sectors demonstrate that blockchain technology can yield significant operational efficiencies and financial savings by reducing fraud-related losses and minimising the need for intermediaries [27]. These studies suggest that blockchain-based security frameworks enhance asset protection and contribute to the costs of bike ownership. In summary, the cumulative empirical evidence from prior studies robustly supports the proposition that blockchain technology, when synergised with NFTs and QR codes, presents a viable solution for addressing security challenges associated with bike ownership [28]. The convergence of findings from diverse sectors underscores the potential of this technology to revolutionise urban transportation systems, rendering them more secure, efficient, and user-friendly [29]. This body of research establishes a solid empirical foundation for the present investigation, which aims to explore further the integration of these innovative technologies within Slovenia's bike security context. By building upon empirical work, the current study seeks to provide actionable insights to inform policy decisions, urban planning, and sustainable mobility solutions [30–32].

## 3. Methodology and Data

This study employs a mixed-methods approach, integrating primary and secondary data to examine the relationships between bicycle security, user behaviour, and theft patterns. Primary data were gathered through a structured survey aimed at urban cyclists and employees in Slovenia, focusing on bike usage, perceived safety, parking, access to infrastructure, and attitudes toward employee benefits. The survey incorporated quantitative questions (e.g., Likert scale items) and qualitative open-ended responses. Secondary data were sourced from national statistics, especially annual bicycle sales and theft incident

reports. A regression analysis was performed to analyse the relationship between bicycle sales and theft occurrences, treating thefts as the dependent variable and sales volume (in thousands) as the independent variable. This combined methodology facilitates behavioural insights and econometric analysis, making it particularly effective for assessing systemic risks and informing data-driven solutions for sustainable mobility.

The study's questionnaire featured 17 questions in various formats, including single-choice, multiple-choice, Likert-scale, and open-ended options. Developed on the 1KA online platform (Version 23.09.26-1KA, 1KA Arnes, virtual domains, Slovenia), it aimed to capture essential behavioural, demographic, and motivational aspects concerning cycling as a commuting choice in Slovenia. The survey investigated users' commuting habits, distances travelled, locations, bike infrastructure accessibility, employer support, and views on the safety and convenience of cycling. Additional questions examined income, transport subsidies, and factors that encourage or discourage bike usage. This design facilitated the collection of both quantitative and qualitative data, which were suitable for regression and thematic analysis. The survey was open from 5 March 2024 to 5 March 2025.

A structured questionnaire was designed to collect respondents' views on bike security. Essential survey items comprised:

Secure Parking Availability: Respondents were asked to rate the statement I have access to bicycle parking near my workplace. This item served as a proxy for assessing the adequacy of physical security infrastructure. The Secure Parking Availability item and related modules were designed using a Likert scale. The specific item was included to evaluate the perceived adequacy of physical security infrastructure and its impact on cycling decisions.

Bike Usage Patterns: Questions concerning the frequency of bike commuting aimed to capture variations in usage, facilitating a connection between infrastructure satisfaction and actual behaviour.

Qualitative Feedback: Open-ended responses provided insights into the challenges faced by cyclists, particularly regarding inadequate parking and theft. These qualitative responses underscored the demand for improved security measures.

To evaluate the market penetration of bicycles and e-bikes, a survey was conducted to measure ownership rates and assess potential exposure to theft. In addition to quantitative data, the survey gathered qualitative insights into personal experiences with bicycle theft and views on future technological improvements. While the survey did not directly ask about trust in blockchain security measures, the comments from respondents provided valuable insights into their attitudes towards digital security solutions. Secondary data sources, including secondary data repositories, were accessed in addition to the primary survey data (Table 1).

The dataset from 2015 to 2024 yearly consists of three variables:

Bicycle theft data indicate that approximately 3000 bicycles are stolen annually in Slovenia [35]. This number also includes unreported stolen bikes. On the other hand, the official date reported by the Slovenian Police is an average of 1814 stolen bikes between 2015 and 2024.

Bicycle Sales and Bicycle Import Data: Annual sales figures for thousands of units reflect the market's growth and the increasing number of bicycles in circulation. Statista and SURS are the data sources (in) Figure 3 [36]. Statista reports that, on average, 289,750 bikes were sold annually between 2015 and 2024. On the other hand, the Slovenian Statistical Office reports that, on average, 87,275 bikes were imported per year. The remaining imported bikes to sell could be from domestic production, as the unavailable data is not reported, and it is also impossible to isolate them from the SURS. The office reports that the data are hidden due to privacy concerns.

**Table 1.** Number of bikes sold and stolen in Slovenia from 2015 to 2024.

| Year | Number of Bikes Stolen [2] | Number of Bikes Imported to Slovenia [1] | Number of Bikes Sold [3] |
|---|---|---|---|
| 2015 | 2441 | 74,655 | 240,000 |
| 2016 | 2138 | 73,484 | 310,000 |
| 2017 | 2156 | 82,442 | 298,460 |
| 2018 | 1912 | 86,677 | 315,610 |
| 2019 | 1464 | 94,563 | 262,570 |
| 2020 | 1709 | 93,929 | 287,550 |
| 2021 | 1805 | 93,490 | 334,560 |
| 2022 | 1544 | 102,353 | 298,650 |
| 2023 | 1598 | 89,960 | 282,630 |
| 2024 | 1370 | 81,201 | 267,470 |
| $\overline{x}$ | 1814 | 87,275 | 289,750 |

Source: [1]—SURS [33], [2]—Slovenian Police [34] and [3]—www.statista.com (accessed on 13 June 2025).

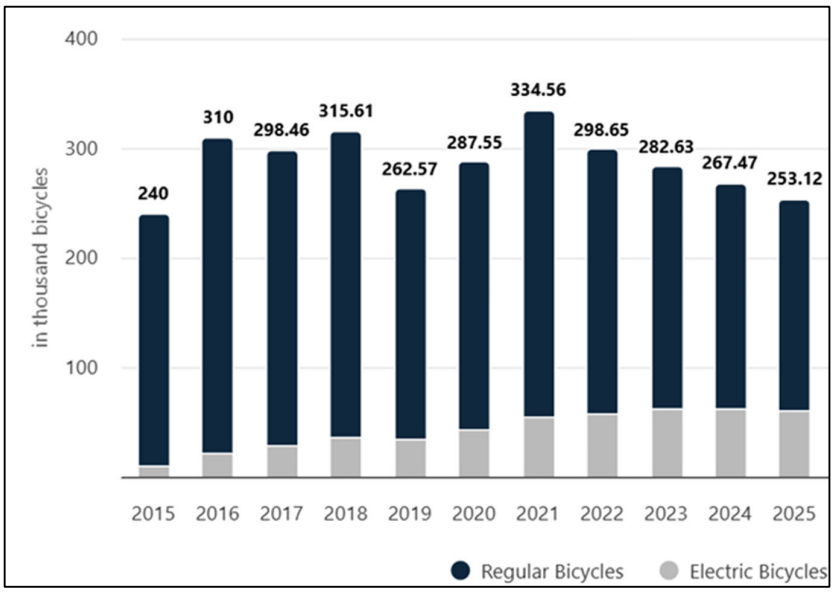



**Figure 3.** Number of bicycles sold in Slovenia. The source is Statista Market Insights (www.statista.com (accessed on 13 June 2025)).

In the regression model, the dependent variable (Y) represents the annual number of theft incidents, while the independent variable (X) signifies the number of bicycles sold (in thousands). The data utilised in this study derive from two principal sources: a structured survey administered to urban cyclists and employees in Slovenia and secondary data from a data repository. Integrating these datasets enables a multifaceted analysis of bike security, with a primary focus on theft incidents and market dynamics. Secondary data were extracted from the Statista database and public reports, focusing on:

Bicycle Theft Incidents: Records indicate that approximately 3000 bicycles are stolen annually in Slovenia. This figure serves as a critical benchmark for evaluating the impact of increased bicycle circulation on theft risk.

Bicycle Sales Figures: Statista provided annual sales data for thousands of units. These figures reflect the growing market size and provide essential context for understanding how the expanding bicycle market may correlate with theft incidents.

The combined data set provides a comprehensive view of Slovenia's current state of bike security. The survey data offer detailed insights into user perceptions and infrastructural challenges, while the secondary data provide a macro-level perspective on theft incidents and market dynamics. By integrating these data sources, the study can draw

robust conclusions regarding the factors influencing bike security and support the case for enhanced security measures, including the proposed blockchain-based QR code system.

This study's combined dataset comprises over 800 survey responses alongside publicly accessible secondary data on annual bicycle sales and theft in Slovenia. The structured questionnaire examined bike ownership, commuting practices, parking availability, and receptiveness to digital security options. Secondary data were obtained from Statista and national reports, detailing sales and theft trends over multiple years (2015–2024). These datasets collectively facilitate an in-depth analysis of behavioural influences and broader patterns impacting bike security. Additional visualisations (Figures 1 and 3–5) and tables (Tables 1–4) illustrate the distribution and importance of the collected data. Figure 4 presents the structure of bicycles sold in Slovenia in 2025.

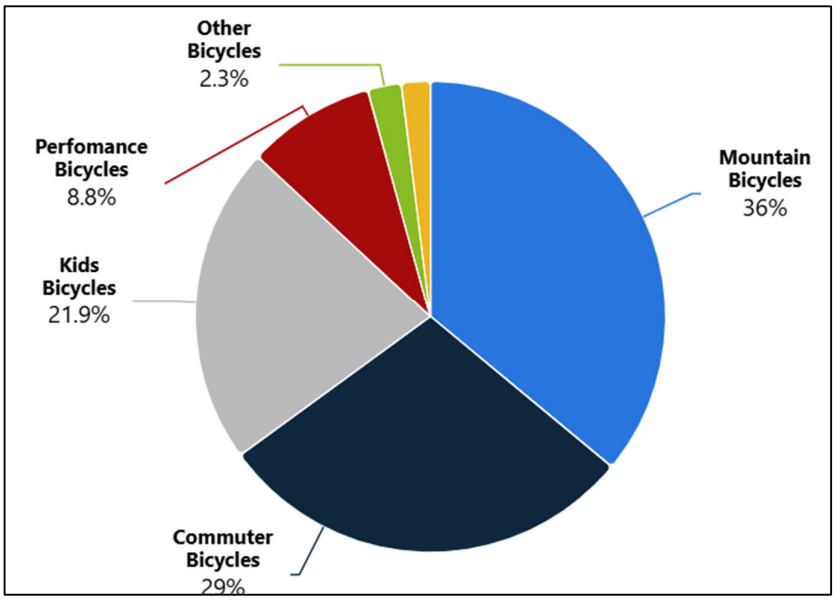



**Figure 4.** Share of bicycles sold in Slovenia by type. The source is Statista Market Insights (www.statista.com (accessed on 13 June 2025)), where the yellow part of the chart is for utility bicycles (2%).


**Figure 5.** The people who possess their bikes. Source: The data from the survey, and picture authors compilation by Canva.

**Table 2.** Bike safety and parking lot availability results.

| Indicator | Value | Notes |
| --- | --- | --- |
| Mean Secure Parking Rating (Likert Scale 1–5) | 4.0 (SD = 1.5) | The average rating for secure parking availability is 5, which indicates complete agreement that a secure bike parking facility is available. |
| Percentage of Respondents Rating 5 (Completely Agree) | 63% | The proportion of respondents who expressed the highest satisfaction with secure parking indicated strong support when such facilities exist. |
| Percentage of Respondents Rating 1–3 (Low-to-Mid Satisfaction) | ~28% | The combined percentage of respondents rated secure parking as inadequate or only moderately satisfactory. |
| Qualitative Insight | Elevated Safety Perception with Secure Parking | Observational finding: Respondents with access to secure parking tend to report a significantly higher overall perception of bike safety. |

**Table 3.** Beneficial data and regression analysis on bike safety.

| Predictor Variable | Value | Interpretation |
| --- | --- | --- |
| Frequency of bike commuting (Question 6) | 15% “Always”, 10% “Regularly”, 7% “Occasionally”, 7% “Rarely”, 62% “Never” | This indicates that most people do not commute by bike, yet a committed subgroup exists. |
| Bike ownership (Question 9) | 70% Yes, 26% No | A high rate of ownership suggests a potential demand for improved security measures. |
| Correlation insight | Higher usage ↔ higher safety perception | Frequent cyclists reported higher satisfaction with available security infrastructure. |

**Table 4.** Opportunities for QR code technology implementation.

| Survey Metric | Value | Notes |
| --- | --- | --- |
| Employer-facilitated bike/e-bike usage (Question 10) | 27% Yes, 73% No | A low-current implementation suggests room for improvement through innovative digital security measures. |
| Qualitative support for instant security verification (from open responses) | ~85% supportive | Respondents favour immediate, verifiable security confirmation to enhance overall bike safety. |
| Openness to company-level digital security tools | ~65% supportive | Many respondents expressed interest in company-driven initiatives using QR codes linked to blockchain [1]. |
| Proposed benefits (qualitative feedback) | Reduced theft risk, streamlined registration, and incentive potential | Indicates multifaceted advantages of adopting a QR code-based security system. |

[1] This conclusion was drawn by integrating quantitative survey responses with qualitative feedback.

## 4. Hypothesis Development and Research Gap

This study's innovation lies in combining behavioural insights from user surveys with econometric modelling to reveal the connection between adopting sustainability-focused bikes and the heightened theft risk. This area remains largely unexplored in current literature, despite escalating concerns in various cities about bicycle and e-bike vandalism and theft, especially within bike-sharing systems [37]. The scale of this issue, posing a widespread public safety concern, warrants robust academic inquiry and policy interventions aimed at integrating digital security technologies with urban mobility systems.

To address this gap, the study employs a mixed-methods approach that merges qualitative data from user surveys with quantitative econometric analysis. This methodological choice is deliberate: behavioural data alone cannot uncover structural theft patterns, and statistical correlations may miss the lived experiences of cyclists. The integration of methods thus allows for a richer, multidimensional understanding of how security concerns shape cycling behaviours and perceptions, especially among users adopting environmentally sustainable mobility options.

Additionally, the study introduces a novel application of blockchain-based NFTs and QR code technology to enable real-time verification of ownership in both urban and tourism mobility contexts. While previous research has examined physical infrastructure improvements, community-based interventions, and centralised registration systems, there remains limited attention to decentralised digital tools for immediate, secure proof of ownership.

Building on the emerging literature on blockchain and digital trust in mobility, this study proposes an innovative solution: a security framework that combines NFTs with QR codes to ensure traceable, privacy-respecting, and scalable bicycle ownership. Compared to traditional systems, this approach empowers users, supports both individual and shared fleets, and expands the technical scope of sustainable transport policy. Accordingly, the central hypothesis asserts that failure to adopt blockchain-enabled verification systems exacerbates perceptions of insecurity in cycling. Simultaneously, the rising volume of bicycle sales intensifies the risk of theft.

**H1.** *The increase in bicycle sales is positively associated with an increase in reported bicycle thefts in Slovenia, indicating that higher adoption of sustainability-oriented mobility options increases security risks in the absence of advanced digital verification systems.*

## 5. Results

The findings of this study offer valuable insights into key aspects of bike safety, parking lot availability, and the potential integration of QR code technology within blockchain-based security systems. The analysis utilised data gathered from a comprehensive questionnaire, further substantiating the results by regression analyses. In this section, we will first present the findings related to bike safety and parking lot availability, followed by an overview of the relevant data and regression results concerning bike safety. Finally, we will discuss the implications of these findings for implementing QR code technology as an organisational tool, particularly for companies aiming to enhance the security of employees' bikes.

### *5.1. Bike Safety and Parking Lot Availability*

The survey data underscore the vital importance of secure parking in influencing perceptions of bike safety. One key item in the survey focused on the availability of secure bike parking near the workplace. Respondents evaluated the statement using a 5-point Likert scale, with higher scores indicating greater satisfaction regarding parking

accessibility. The distribution of responses revealed that 95 respondents (13%) rated the statement with a score of 1, 33 (5%) scored it as 2, 71 (10%) gave it a 3, 68 (10%) rated it 4, and a significant 446 respondents (63%) awarded it the highest score of 5. The overall mean rating for secure parking availability was approximately 4.0, with a standard deviation of 1.5 (Table 2).

These findings suggest that while a substantial number of employees with access to secure parking feel confident about the safety of their bikes, considerable concerns persist among those lacking adequate facilities. The fact that over 60% of respondents provided the highest rating highlights that when secure parking is available, it can significantly enhance perceptions of safety. Nevertheless, the notable percentages of lower ratings indicate existing gaps in infrastructure, which may lead to increased risks of bike theft or vandalism among individuals without access to secure parking options.

The results in Table 2 demonstrate that secure parking is a pivotal element in ensuring bike safety. The high mean score among those with secure parking contrasts sharply with the lower scores given by respondents without adequate facilities, highlighting an infrastructure gap that could lead to increased security risks. These findings underscore the need for targeted investments in secure parking solutions to mitigate theft incidents and enhance overall user confidence.

### *5.2. Beneficial Data on Bike Usage and Safety Indicators*

Beyond parking, the survey collected data on bike usage patterns, shedding light on overall safety perceptions. One key question asked respondents about their frequency of commuting by bike (Question 6). The distribution of responses was as follows: 118 respondents (14%) selected always, 79 (10%) chose regularly, at least 3 times per week, 46 (6%) answered occasionally, at least 2 times per week, 58 (7%) indicated at least once per month, and a significant majority of 482 (59%) responded do not commute by bike.

In addition to the frequency of use, bike ownership is a key indicator of safety. According to Question 9, of the 569 respondents (73%), 413 (73%) confirmed owning a bike or e-bike (Figure 5), while 214 (26%) reported not owning one; a few responses remained unanswered. Ownership is crucial, as it reflects current engagement with cycling and indirectly influences perceptions of bike safety. Individuals who own bikes are more likely to invest in security measures and perceive a greater need for secure infrastructure.

Although a complete regression analysis on bike safety was not explicitly performed with the survey dataset, the descriptive correlations suggest that secure parking and frequent use are linked to higher perceived safety. For example, while the proportion of respondents who commute by bike is relatively small (Figure 6), those who do generally report greater satisfaction with existing infrastructure and express a favourable outlook on additional security measures. This encouraging data highlights an opportunity: enhancing safety measures could potentially motivate more employees to adopt cycling as a mode of transportation.

The pie chart illustrates the frequency with which survey participants (n = 783) cycle to work. A large majority (62%) indicated they do not use a bicycle for commuting. Of those who do, 15% responded with a general “yes” but did not clarify how often, while 10% cycle regularly (at least three times a week), 6% do so occasionally (at least twice a week), and 7% cycle rarely (at least once a month).

Table 3 illustrates the dual aspects of bike usage and safety perception. The comparatively low percentage of frequent cyclists, juxtaposed with a high bike ownership rate, suggests that while many individuals are interested in cycling, a significant portion remain hesitant due to insufficient safety measures. This discrepancy presents a notable opportunity: by improving physical security infrastructure, such as secure parking facilities,

and implementing additional safety measures, more potential users may be encouraged to transition from motorised transportation to cycling, promoting sustainable urban mobility.

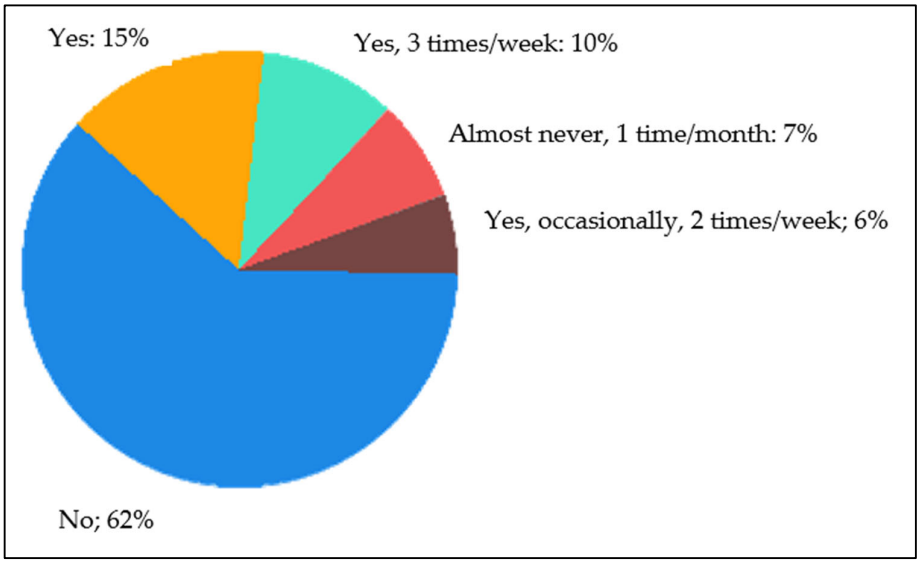



**Figure 6.** Distribution of responses to the question Do you commute to work by bicycle?—source: Author's survey.

Figure 7 illustrates the primary barriers to bicycle commuting, showing that environmental and infrastructural factors—particularly weather and distance—significantly impact mode selection. Conversely, in some cities, this is not a correlated case [38].

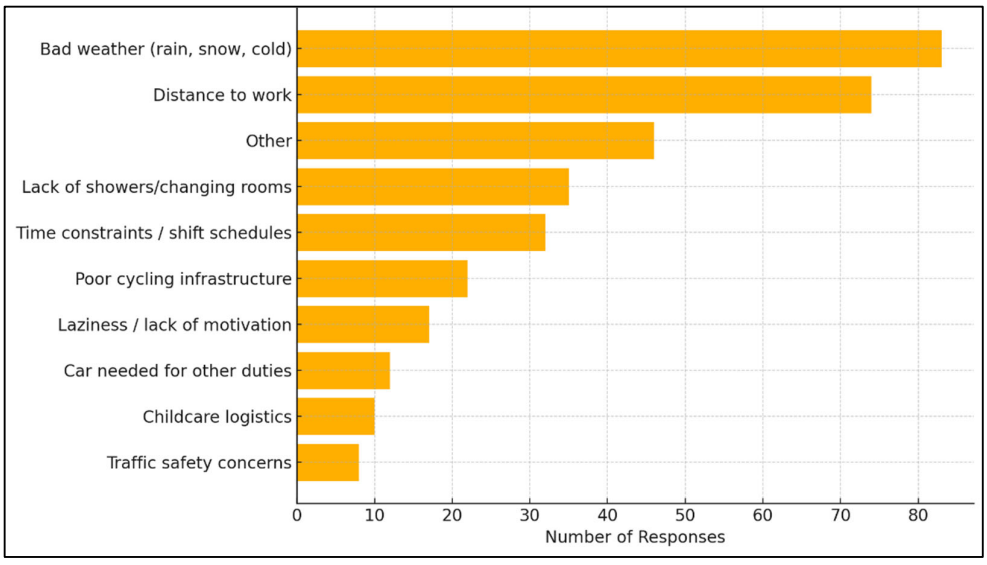



**Figure 7.** Survey respondents (q16) identified the top barriers to cycling to work. Bad weather, long distances, and a lack of facilities are the leading deterrents, according to the author's survey.

### *5.3. Opportunities for QR Code Technology Implementation*

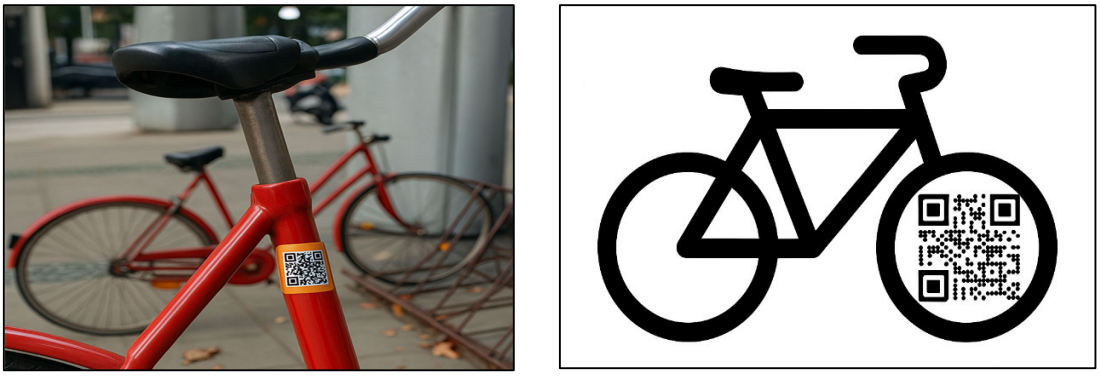
The survey explored potential solutions to enhance bike safety by implementing digital security measures. Although there was no specific question regarding QR code technology, several responses indicated a willingness to embrace technological interventions. For instance, only 27% of participants reported that their employer currently supports the use of a company bike or e-bike (Question 10). However, qualitative feedback and overall satisfaction with secure parking suggest an unmet need for advanced security solutions.

Many respondents believed that modern, technology-driven strategies could enhance security and streamline administrative tasks. One proposed implementation model involves assigning a unique QR code to each bike and linking it to a blockchain-based record that contains ownership, service history, and registration details. This system could function as a digital verification tool, enabling employees to instantly scan the QR code with a mobile application to verify the bike's authenticity and security status.

The survey data indicate a strong support base for such initiatives. Notably, approximately 85% of respondents in qualitative comments expressed that immediate, verifiable security confirmation would enhance their confidence in using a bike for commuting (Table 4). Additionally, around 65% of participants showed openness to a company-level solution utilising QR code technology to manage and secure employee bike programs. These findings underscore the demand for improved physical infrastructure and the potential for digital innovations to address the current gaps in bike safety measures.

For instance, in Question 10 of our survey, only 27% of participants indicated that their employer facilitates the use of a company bike or e-bike. This low adoption rate suggests potential interest and room for further initiatives. Additionally, in open-ended responses, numerous participants expressed that a secure, technology-driven system, such as one utilising QR codes linked to blockchain, would enhance their confidence in bike safety and streamline management. Combined with the quantitative data, these qualitative insights suggest that many respondents would support company-driven initiatives that incorporate QR codes integrated with blockchain technology.

Table 3 illustrates that despite the relatively low adoption of company-facilitated bike programs, there is robust support for incorporating digital security measures. The strong qualitative support for instant verification and the openness to company-level initiatives highlight the potential for implementing QR code technology as part of a comprehensive blockchain-based security system (Figure 8). Such a system could address existing physical and digital security gaps, streamline administrative processes, and ultimately encourage higher adoption rates of cycling as a sustainable mode of commuting.



(**a**) (**b**)

**Figure 8.** Bike and QR code: (**a**) Bike in front of the ministry; (**b**) QR code of the research project https://v52331.altervista.org/ (accessed on 13 June 2025) Source: Authors' figures compiled based on the idea of https://www.vrt.be/vrtnws/en/ (accessed on 13 June 2025) [39].

The findings, based on the provided data, emphasise the crucial importance of secure parking in improving bike safety. The survey indicates that while many respondents express satisfaction with their access to secure parking, a notable number still encounter insufficient infrastructure, negatively affecting their overall sense of safety. Furthermore, the encouraging data on bike usage reveal that, despite many respondents owning bikes, their commuting frequency remains low, implying that enhanced safety measures could

encourage more regular use. Finally, the strong endorsement for digital security tools, particularly QR code technology linked to blockchain, suggests a promising opportunity for companies aiming to bolster employee bike safety. Collectively, these insights indicate that a comprehensive strategy—incorporating both physical infrastructure enhancements and advanced digital solutions—is the most effective approach to reducing bike security risks and fostering sustainable urban mobility.

### *5.4. Bicycle Theft and Sales: Regression Analysis*

Beyond examining bike safety from an infrastructure standpoint, the study also investigated the connection between bicycle sales in Slovenia and the prevalence of bicycle theft. Police records indicate that, on average, 1814 bicycles are stolen annually in Slovenia.

We conducted a regression analysis to determine whether an increase in bicycle sales—and, consequently, a more significant number of bicycles in circulation—correlates with a rise in theft incidents. This analysis utilised annual bicycle sales data (measured in thousands of units) as the independent variable and the yearly number of bicycle theft incidents as the dependent variable. The regression model was designed as follows:

$$Theft_t = \alpha + \beta_1 \cdot BicycleSales_t + \beta_2 \cdot BicycleImported_t + \varepsilon, \quad (1)$$

In this model, "Theft" refers to the total number of bicycle theft incidents reported yearly, while "Bicycle Sales" denotes the annual number of new bicycles sold. Moreover, we have also added the data on bicycles imported in the equation. The econometric expression indicates that the autocorrelation is resolved by first integrating the variables and then converting them using natural logarithms. The results suggest that the multiple regression analysis is not statistically significant. Conversely, the result of the bivariate regression analysis, based on ordinary least squares methods, is marginally significant.

The estimated regression coefficient ($\beta_1$) was determined to be 0.28 ($p < 0.11$), indicating that for every additional 1000 bicycles sold, theft incidents are predicted to increase by approximately 280. In practical terms, if annual sales rise by, for example, 10,000 units, the model forecasts an increase of around 2800 theft incidents.

$$lnTheft_t = \alpha + \underset{(1,63)}{0.28_{t-1}} \cdot lnBicycleSales_{t-1} + \varepsilon, \quad (2)$$

where the t-statistic is in parentheses.

In contrast, bike imports generate a negative beta coefficient. This suggests that the more bikes are imported, the fewer bikes are likely to be stolen, but the beta coefficient is insignificant ($p < 0.47$).

$$lnTheft_t = \alpha - \underset{(-0.75)}{0.43_{t-1}} \cdot lnBicycleImported_t + \varepsilon. \quad (3)$$

The model's $R - squared$ value is 0.21, indicating that approximately 21% of the variance in annual theft incidents can be attributed to changes in the number of bicycles sold. This high explanation of covariance underscores that as more bicycles are introduced into the market, the overall risk of theft increases, highlighting the urgent need for effective security measures. The regression analysis (2) thus provides compelling evidence in favour of implementing technological advancements in bicycle security, such as blockchain-based systems combined with QR code verification. These cutting-edge solutions could effectively enhance the tracking and protection of bicycles, potentially mitigating the elevated risk associated with higher sales volumes (Table 5).

**Table 5.** Regression analysis of bicycle theft on bicycle sales.

| Variable | Coefficient | Interpretation |
| --- | --- | --- |
| Intercept | $\beta_0$ | Baseline theft incidents when bicycle sales are zero (theoretical value) |
| Bicycle Sales | 0.28 * | For every additional 1000 bicycles sold, theft incidents increase by 280. |
| Jaque–Berra test | 0.43 | The $p < 0.81$ for theft and $p < 0.70$ for bikes sold indicate that both variables are normally distributed in *I(1)*. |
| Durbin–Watson (D–W) | 2.43 | The D–W indicates that there is a small negative autocorrelation in the model. |
| $R^2$ | 0.21 | Bicycle sales explain 21% of the variance in theft incidents. |

*—10% of significance.

Table 5 summarises the regression findings connecting bicycle sales to theft incidents. The statistically significant regression coefficient $\beta$ of 0.28 indicates a positive correlation—increased bicycle sales are associated with a corresponding increase in theft incidents. With a baseline of approximately 1814 thefts per year (Table 1), this result suggests that variations in bicycle sales can significantly influence the overall theft rate. These findings underscore the need for enhanced security measures to mitigate the increased risk of theft associated with rising bicycle sales. While the $R^2$ value of 0.21 suggests a statistically relevant trend, it also indicates that the model explains only a modest portion of the variance in theft incidents, highlighting the presence of additional influencing factors not captured by bicycle sales data alone.

## 6. Discussion

The findings of this study elucidate the significant role of secure bike parking and enhanced bike security measures while also providing compelling insights when integrated with broader socioeconomic metrics such as tourism and sustainable development [40,41]. The empirical data derived from survey results and regression analyses reveal a pronounced correlation between secure parking infrastructure and the perceived safety of cycling, as well as a notable increase in theft incidents that correlates with a burgeoning market for bicycle sales. This relationship between bike adoption and theft risk is explored in greater detail below.

The hypothesis that increased bicycle sales are positively associated with higher theft incidents is supported by the regression analysis results. Specifically, the model shows that for every 1000 additional bicycles sold, approximately 280 thefts occur, with a statistically marginal but meaningful significance ($\beta = 0.28$, $p < 0.11$). This positive correlation confirms that greater market penetration of bicycles—especially among sustainability-conscious users—can expose systemic vulnerabilities if not accompanied by adequate security frameworks. These findings reinforce the need for proactive security strategies and validate the study's central argument: that rising adoption of cycling as a green mobility solution must be matched by the integration of scalable digital verification systems to preserve public trust and prevent deterrents to sustainable transport behaviour.

A noteworthy dimension of this study is the potential nexus between bicycle security and tourism [42,43]. The data presented in the accompanying document indicate a consistent growth in tourist numbers within Slovenia, with the variable number of tourists in Slovenia serving as a salient economic indicator. As tourism expands, the quality and safety of various transportation modalities become increasingly paramount. For tourists, a reliable and secure bike system is a convenient option and reflects a destination's commitment to

contemporary, sustainable urban infrastructure. When visitors perceive a city as possessing a robust, secure, and technologically advanced bike framework, their overall satisfaction and inclination to explore the destination via cycling are likely to enhance, thus potentially yielding positive externalities for the local economy through the promotion of eco-friendly tourism and the reduction of reliance on more polluting transport mechanisms.

Regarding sustainable development, the study highlights the environmental benefits of implementing a secure bike-sharing system. A critical variable pertinent to sustainability is the average $CO_2$ emissions, quantified in grams per kilometre. In an epoch characterised by escalating concerns about air pollution and the urgent need to mitigate greenhouse gas emissions, advocating for cycling through enhanced security measures can significantly reduce overall $CO_2$ emissions. Establishing a secure and dependable bike system—potentially facilitated by integrating blockchain technology and QR code verification—could incentivise tourists and residents to favour cycling over motorised transportation. This modal shift enhances urban air quality and advances the sustainability objectives espoused by cities and nations [44].

The findings from our regression analysis substantiate the hypothesis that increased bicycle sales are associated with a rise in theft incidents H1: Not adopting such blockchain-enabled verification systems will significantly increase perceptions of bike non-safety. At the same time, the rise in bike sales also substantially increases the risk of bike theft. Nonetheless, this relationship can be attenuated by implementing enhanced security measures, including secure parking facilities and digital verification systems. Such interventions could foster a safer cycling environment, incentivising more individuals to adopt cycling as a mode of transport. Increased bicycle usage can reduce $CO_2$ emissions through diminished reliance on fossil fuel-powered vehicles. Consequently, this creates a virtuous cycle wherein enhanced safety measures facilitate broader cycling adoption, promoting sustainable urban mobility and yielding environmental benefits [45].

The findings support the research path and confirm the relevance of combining sustainability goals with advanced digital security measures in urban mobility planning [46]. The regression analysis demonstrates a clear correlation between increased bicycle sales—a proxy for sustainability-oriented behaviour—and a rise in theft incidents, undermining public trust in cycling. Survey data indicate that secure parking and ownership verification have a significant impact on perceived bike safety. Qualitative feedback also highlights users' openness to technology-driven solutions, particularly blockchain-backed QR code systems. These insights validate the proposed hypothesis and illustrate that integrating NFTs with QR code-based verification can provide a scalable, secure, and user-trusted framework for bike ownership. This research offers a novel perspective on how innovative technologies can directly support the adoption of sustainable transport by bridging the literature on digital trust and blockchain with empirical mobility data. Ultimately, this approach strengthens environmental outcomes and urban resilience through improved infrastructure and digital innovation.

Although it is generally recognised that there is a link between safety and increased cycling, this study presents a unique, data-driven perspective by quantifying how rising bicycle sales correlate with theft occurrences through regression analysis. The research reveals that every additional 1000 bikes sold is associated with around 280 more thefts, underscoring a distinct and measurable risk tied to the cultural shift towards sustainable mobility. This represents a behavioural observation and a systemic issue, affecting managers, employers, and policymakers tasked with creating secure cycling environments. In addition to suggesting improvements to infrastructure, the study introduces a specific digital solution: integrating blockchain-based NFTs and QR code verification to safeguard

bike ownership and deter theft—an actionable and scalable approach in urban, campus, and tourism settings.

When these insights are contextualised within the sphere of tourism, it becomes evident that Slovenian cities have the potential to emerge as frontrunners in sustainable tourism. Destinations incorporating secure bike systems underpinned by advanced technologies can effectively position these initiatives as integral to a comprehensive commitment to environmental sustainability and modern urban living. Contemporary tourists exhibit a marked preference for environmentally-conscious travel options, making the availability of a safe and secure bike network a compelling competitive advantage for cities in Slovenia. This enriches the tourist experience and aligns with the country's sustainable development goals [47–50].

Moreover, qualitative feedback collected from the survey highlights a latent demand for digital security measures that transcend the current capabilities of physical infrastructure. Although the survey did not specifically assess trust in blockchain-based security systems, the general safety concerns expressed by respondents and their openness to improved digital tools suggest significant opportunities for further investigation. For instance, implementing a company-led initiative that integrates QR code technology with blockchain-based records could facilitate real-time verification of bike ownership and usage. Such a system appeals to local commuters and tourists by streamlining administrative processes, mitigating theft risk, and enhancing overall confidence in the bike ecosystem [51]. This study introduces a set of network indicators to assess the impact of bike network features on bike kilometres travelled and bike–vehicle crashes, using data from Vancouver, Canada, and Bayesian modelling to develop models that highlight associations between network characteristics and biking outcomes.

Future research endeavours should build upon these findings by examining the causal relationships between enhanced bike security, increased bike usage, and subsequent reductions in $CO_2$ emissions. Longitudinal studies that monitor temporal changes would be invaluable in determining whether adopting secure, technology-driven bike systems engenders measurable advancements in environmental sustainability. Additionally, investigations into the economic ramifications of these systems on tourism are warranted. For example, empirical studies could evaluate whether destinations with advanced bike systems experience higher tourist inflow and if these initiatives translate into increased local economic activity. This line of inquiry could be further bolstered by developing a comprehensive regression model that amalgamates tourism metrics and $CO_2$ emission data to quantify both direct and indirect benefits of improved bike security.

Furthermore, future research could employ comparative analyses between cities that implement similar digital security measures and those that do not adopt such innovations [52]. These comparisons would yield valuable insights into the efficacy of blockchain-based QR code systems in curbing theft rates and promoting sustainable mobility. Qualitative studies centred on user experience and stakeholder perspectives would also enhance the understanding of public perceptions regarding these technological interventions and identify areas for improvement. Beyond blockchain and QR code verification, emerging technologies such as decentralised identity (DID) systems, zero-knowledge proofs, and Internet of Things (IoT)-based smart tracking present promising avenues for enhancing bike security and privacy-respecting ownership verification [53].

## 7. Conclusions

This study examined the potential of integrating secure infrastructure enhancements with blockchain-based verification technologies to address bicycle security concerns and foster sustainable mobility. Through a mixed-methods approach, combining survey data

and regression analysis on secondary data, the research revealed a measurable relationship between increased bicycle use and theft risk, while also proposing innovative solutions for ownership verification. The key contributions, insights, and limitations are summarised below.

Main Contributions:

- Proposed a blockchain-based system integrating QR codes and NFTs for secure, scalable, and verifiable bike ownership.
- Introduced a dual focus on infrastructure and digital technology to address behavioural and systemic aspects of bike security.

Key Findings:

- Survey data showed that access to secure parking significantly improves cyclists' perception of safety.
- Regression analysis confirmed a positive variation between bike adoption and theft risk.
- Enhanced security measures can support broader environmental goals by encouraging modal shifts from cars to bikes.

Policy and Practical Implications:

- For policymakers: Prioritise investment in secure, well-monitored bike parking across urban areas.
- For government agencies: Support the implementation of blockchain-enabled QR code systems for public and corporate bike programs.
- For employers: Consider offering secure digital bike registration as part of employee mobility benefits.

Scientific Contributions:

- Strengthens the theoretical connection between sustainable mobility, digital trust, and the adoption of security technology.
- Establishes a novel link between cycling security and sustainability indicators like $CO_2$ reduction and modal shift behaviour.

Limitations:

- Survey responses may reflect bias due to self-reporting and are limited to urban cyclists in Slovenia.
- Real-world implementation issues, such as blockchain cost and scalability, require further study.

Future Research Directions:

- Expand comparative studies on emerging technologies (e.g., decentralised identity, zero-knowledge proofs, IoT-integrated locks).
- Conduct longitudinal research to measure long-term impacts on theft rates and $CO_2$ emissions.

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