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Sustainable Commuting: Active Transport Practices and Slovenian Data Analysis

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Abstract: This study examines the influence of transportation policies and urbanisation on cycling participation and environmental sustainability in Slovenia. Factor and regression analyses were employed. The yearly data from 2008 to 2021 were isolated. A modest increase in urban cycling frequency was observed, bolstered by investments in environmental protection and safety enhancements; however, additional evidence is needed to confirm the long-term effects (H1). Furthermore, while increased cycling was linked to a reduction in CO_2 emissions and improved air quality, the overall environmental benefits were found to be affected by other factors, such as motorisation and public transportation in summer (H2). The study revealed that the introduction of reduced urban speed limits and expanded cycling lanes significantly enhanced cycling safety and desirability, leading to a shift from car usage to bicycles (RQ). These findings indicate that cycling could play a vital role in advancing Slovenia's sustainable development goals, emphasising the need for continued investments and supportive urbanisation policies.

Keywords: climate data; cycling; econometrics; greenhouse gas emissions; Slovenia; urban commuting

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1. Introduction

The first air polluter globally is industry, and the second is transport. As a result, the turnover in the industry is increasing in terms of the transportation of goods and the daily transportation of employees to work. The daily transport to work of employees in industrial/urban cities is the focus of many researchers and discussions, as well as the 11th goal of sustainable development (sustainable cities). Means of transport to work can be (un)sustainable (cars) or sustainable (for example bicycles).

Cycling in urban environments offers numerous benefits, such as reducing traffic congestion and greenhouse gas emissions (GHG). Cities prioritising cycling infrastructure often see a decrease in motor vehicle reliance, leading to lower air pollution and improved public health [1,2]. Key initiatives like dedicated bike lanes and bike parking infrastructure enhance safety and encourage more people to cycle. Moreover, urban cycling fosters community engagement, allowing for direct interactions with local surroundings and boosting support for local businesses. It also promotes inclusive mobility, providing a cost-effective transportation option for all socio-economic groups. With climate change pressing, there is an urgent need for sustainable transportation solutions in urban areas. Transitioning from car-centric planning to cycling can address significant environmental issues. By examining successful cycling cultures in other nations, Slovenia can adopt effective strategies to enhance its sustainable commuting practices.

This research is motivated by Slovenia's urgent need for sustainable urban transportation to combat climate change, particularly in Ljubljana and Novo Mestoand, and to investigate the feasibility of cycling to enhance its status as a sustainable transportation system that has broad political support. The primary objective is to identify practical strategies for promoting cycling in urban areas. The specific objectives include investigating the primary factors that contribute to cycling's success, analysing Slovenian climate data with a focus on carbon dioxide (CO_2) levels, analysing the use of cars and bicycles in urban areas Ljubljana and Novo Mesto to assess the benefits of increased cycling adoption, conducting a comparative analysis of cycling practices, and offering policy recommendations for the integration of sustainable transportation practices in Slovenia. The economic factors support the active transport model (described below).

The research question explores the feasibility of Slovenia adopting successful cycling practices to encourage sustainable commuting and diminish GHG emissions. The following hypotheses accompany this investigation:

H1: *Slovenia will substantially increase the frequency of urban cycling commuters through new measures implemented in recent years.*

H2: *A surge in cycling participation in Slovenia will lead to a quantifiable decrease in CO_2 emissions and an enhancement in urban air quality.*

The proposed hypotheses and research questions will be examined through factor analysis. Furthermore, hypothesis 1 will be evaluated employing regression analysis techniques, while an assessment of the corresponding research question will utilise vector autoregression (VAR) methodologies.

RQ: Thoughtful urban planning and the implementation of reduced urban speed limits will bolster cycling's safety and desirability, prompting a significant number of individuals to transition from cars to bicycles.

This paper examines the current literature on sustainable commuting practices. It includes a comprehensive explanation of the research methods utilised, analysis of Slovenian data, and econometric time series methods, as well as presenting findings from the study and the impact assessment of increased cycling in Slovenia. By interpreting the results, the paper emphasises the potential benefits and challenges of implementing other national cycling practices in Slovenia. A summary of the essential findings and policy recommendations for promoting sustainable commuting in Slovenia are also presented.

2. Literature Review

The evolution of transportation technologies has significantly influenced social and economic development. It began around 8000 BC with animal domestication, followed by Egyptian sailing boats around 4000 BC, which enhanced trade in Mediterranean civilisations. The Sumerians invented the wheel in 3500 BC, and the fourth transportation revolution started in the 19th century with the steam engine, leading to locomotives and steamboats. The fifth revolution, marked by the invention of the internal combustion engine in 1886, led to the rise of automobiles and buses. Today, transportation emissions have risen faster than other sectors, averaging a 1.7% annual increase from 1990 to 2021. The sector accounted for 37% of CO_2 emissions from end-use sectors in 2021, with road transport responsible for about 75% of the total. This highlights the urgent need for a shift toward sustainable mobility [3].

The concept of sustainable mobility does not have a generally accepted definition. According to most researchers, sustainable mobility is represented by walking and cycling. To address this and other global challenges, the United Nations listed 17 Sustainable Development Goals (SDGs) in 2015 with corresponding targets [4–6]. Sustainable mobility is not explicitly listed among the Sustainable Development Goals; rather, it is included in Goal 11.2, which reflects its importance for sustainable cities and communities. In this context, the overarching ambition is to reduce GHG emissions significantly and, at the same time, promote a more livable urban environment/city/community. This goal should be achieved by implementing the concept of sustainable mobility and developing the "active transport" model, which is covered by three fundamental principles: avoidance/reduction, movement/conservation, and improvement. This model, conceptually upgraded with three basic tenets, prioritises eliminating unnecessary traffic, advocates the transition to environmentally friendly means of transport, and supports improvements in organisational frameworks and technological progress to optimise efficiency [6]. Optimisation or adaptation to the current climate situation is the basis of the model of "active transport" in urban areas; it is perceived as an eco-adaptive model for already existing state transport models.

Unveiled by the European Commission in 2019 as part of the European Green Deal, the sustainable and smart mobility strategy addresses these concerns comprehensively and indirectly suggests the introduction of the eco-adaptation model [7]. The Green Deal ambitiously targets a 90% reduction in transport-related GHG emissions by 2050, aligning with broader climate objectives. Within this framework, 'avoid/reduce' focuses on enhancing system efficiency by eliminating the need for travel through consolidation or minimising travel distances through route optimisation. Route optimisation, spatial connectivity, travel time, and strategically thought-out urbanisation are all well described in the articles [8,9]. Next, 'movement/conservation' emphasises improving trip efficiency by encouraging a transition to less energy-intensive and more environmentally benign modes of transportation, such as walking, cycling, rail, or public transport. You will find more in the article [7]. The 'improve' principle concentrates on vehicle efficiency, advocating for reducing energy consumption and emissions through advancements in fuel and vehicle technologies when motorised travel is indispensable [10,11].

Cities account for 70% of global carbon emissions and consume two-thirds of the world's energy, making them a critical focus for global carbon mitigation efforts. To align with the 2015 Paris Agreement, which aims to limit the global temperature increase to 1.5 °C or 2 °C, it is essential to consider how much change is needed in the current emissions trajectory. This requires evaluating efficiency improvements, technological substitutions, and demand-side solutions to reduce emissions. London's latest local transport strategy, outlined in the Mayor's Transport Strategy of 2018, aims to decrease car travel by 12% by 2041. However, achieving stringent carbon budgets will require aggressive and disruptive policies, given the current system's limitations [12,13].

In the face of the climate crisis, it is clear that economic changes are necessary to address the environmental damage caused by fossil capitalism. The European Green Deal represents a political commitment to environmentally friendly policies and practices to promote ecological modernisation. The social aspect of this transition encompasses societal dynamics, structures, outcomes, and baselines of 'green' economic change. Research studies have highlighted significant cross-country differences in eco-social interactions, but there is a need for theoretical concepts to guide their analytical approaches and interpretation of findings. It is widely argued that the historical development of a country's idea of state, administration, and democracy has fundamentally influenced the establishment of welfare institutions. In the context of a green transition, welfare states are vital for ensuring social inclusion, preventing widespread poverty, and stabilising economies by addressing green social risks and adapting to changing labour market demands. Different welfare systems exhibit variations in welfare culture and social divisions. It is apparent that these differences also shape the response of welfare systems to the green transition, as indicated by the limited empirical studies on cross-country differences in eco-social policies, politics, institutions, and outcomes [14].

In everyday situations, Germans use their cars more frequently for short distances than their neighbours in Switzerland or the Netherlands. This raises the question of why cycling for practical purposes in urban areas seems less popular in Germany. The city of Aachen exemplifies this trend, as the percentage of people cycling for transportation remains consistently low despite growing interest and advocacy for cycling within civil society. Authors [15,16] use the term utility cycling to describe everyday cycling as a mobility behaviour that mainly includes short distances such as commuting to and from work, visiting local shops, or visiting friends and family. In their study of Leipzig, Germany, Marquart et al. [17] found that improved integration of cyclists' perceptions in transport planning could enhance cycling infrastructure in the country. They observed that traffic and infrastructure were identified as more significant risks, contributing substantially to the overall perception of safety. Cyclists developed more strategies to mitigate traffic risks over time, likely due to the unpredictable nature and immediate consequences of such risks. The unsafe traffic conditions in the city have become ingrained in the local mobility culture. While infrastructure can influence people's mobility choices, cultural and social factors are crucial in shaping long-term cycling habits [18].

The field of sustainable urban freight is evolving rapidly, with particular emphasis on city logistics. It draws heavily from the discourse on sustainability transitions, primarily employing the multi-level perspective (MLP) and strategic niche management (SNM) frameworks. A notable ambition by the Swedish government to become the world's first fossil-free welfare state by 2045 has catalysed the target, which was solidified in a 2017 climate policy framework mandating zero net GHG emissions by 2045. Within this context, bicycle logistics emerged around 2012 as an innovative approach, with companies like MBB and Pling pioneering the development of specialised freight bicycles (e.g., Velove bikes). These endeavours highlighted the importance of financing strategies and business models in fostering niche developments. Interviews with Stockholm municipality officials revealed a supportive stance towards bicycle logistics, recognising its potential in advancing sustainable urban freight systems. The analysis underscores the significance of 'shielding' (protecting innovations from mainstream market pressures) and 'nurturing' (providing support to innovations) in the evolution of bicycle logistics. A central study inquiry focused on identifying the prerequisites for integrating bicycle logistics into the broader urban freight regime. The findings advocate for enhanced measures to empower this niche, specifically improving bicycle infrastructure and traffic management practices. Additionally, altering the perceptions, attitudes, and knowledge of policymakers, planners, and potential users towards bicycle logistics is crucial for its broader acceptance and implementation [19].

The high CO_2 emissions caused by congestion have prompted government agencies to implement highway tolls, high-occupancy vehicle lanes, public transit infrastructure investments, fuel economy standards, and voluntary information campaigns [20]. Another emerging solution to urban traffic congestion is adopting citywide bicycle-sharing systems, which are gaining popularity due to their cost-effectiveness, environmental-friendliness, and positive health impacts. While European cities like Amsterdam, Paris, Copenhagen, and London have embraced bicycle-sharing programs for some time, cities in the United States of America (USA) have only recently started to adopt these transportation systems. These systems are designed to promote short- to medium-distance rides, complement existing public transit, and provide an alternative to walking to and from major transit centres or connecting non-overlapping routes [21]. According to [22], potential benefits of bike-sharing include increased mobility, cost savings for consumers, reduced transportation infrastructure costs, decreased traffic congestion, lower fuel use, increased public transit usage, improved public health, and greater environmental awareness.

In various studies, it has been consistently observed that motorised traffic has a discouraging effect on cycling. Motorised traffic poses direct health hazards to cyclists through traffic accidents and air pollution. Considering the overall health benefits of cycling, motorised traffic indirectly impacts public health by discouraging cycling. The research focused on analysing how different traffic conditions along potential commuting routes influence the likelihood of an individual choosing cycling as their mode of transport. The analysis pertains explicitly to commuters working 2–5 km from their homes, where distance shows a negative correlation with the choice of cycling as a mode of transport.

In contrast, the presence of cycle paths shows a positive correlation. It is important to note that various traffic conditions do not uniformly deter commuters from cycling to work. The study also suggests that speed limits under 30 km/h may promote more cycling, as evidenced by the higher likelihood of an individual being a cyclist when their shortest route to work consists of a more significant proportion of roads with speeds under 29.3 km/h. Furthermore, cycle paths in appropriate locations will likely boost the cycling rate [23].

The recent surge in bicycling activity in Memphis has prompted essential discussions about the city's unique identity, urban development, and community building. Bicycling in particular has become a prominent driver of urban change, potentially contributing to social inequality. New approaches to governance have opened up possibilities for reshaping the character of urban spaces. Starting in 2009, a shift in the city's bicycling culture and a renewed focus on bicycling infrastructure brought about significant changes. A change in city leadership led to increased public discourse about bicycling infrastructure. This, combined with the support from creative class policies and the growing demand from residents, resulted in the development of nearly 100 km of new bicycle lanes. These lanes were successfully implemented despite initial opposition from businesses along a key city corridor. Additionally, plans for a pedestrian bridge across the Mississippi River to attract tourists have been proposed alongside other projects [24].

In the context of rapid urbanisation, sustainable mobility is increasingly viewed as essential for urban sustainability. Research indicates that business travel plays a significant role in urban travel demand and is influenced by sociodemographic factors, environmental considerations, and individual attitudes. Key determinants of mode choice include trip characteristics such as distance, travel time, and cost. Personal factors, including physical exertion, cycling proficiency, and safety concerns, also affect bicycle usage, with distinct gender differences in travel preferences noted. Greater educational attainment is often associated with increased walking. Moreover, comfort, convenience, travel satisfaction, cultural norms, and personal values significantly influence mode choice. The built environment and urban design—characterised by compact and polycentric layouts—are crucial for promoting sustainable transportation. Additionally, disparities between urban and suburban areas and various environmental factors heavily impact walking and cycling preferences across different cities [25]. Globally, the inclination towards walking and cycling varies significantly. These modes undertake a mere 1% of daily trips in the USA, in stark contrast to up to 18% in European nations. Predominantly, individuals holding bachelor's or professional degrees are more inclined to cycle, underscoring the link between educational levels and sustainable transportation mode choice [26].

Addressing climate change and promoting sustainable development, particularly in urban areas, is essential given that over half the global population resides in cities. This reality has prompted governments to prioritise urban management, resulting in various initiatives focused on low-carbon and green development. Urban management has evolved through four distinct phases: germination (1890–1970), transition (1970–1980), formation (1980–2000), and prosperity (2000–present). The foundations of urban eco-management can be traced back to Ebenezer Howard's Garden City concept and Patrick Geddes's contributions to town planning. The eco-city concept emerged under the United Nations Educational, Scientific and Cultural Organisation "Man and Biosphere" initiative in 1971, marking a significant shift towards integrating ecological principles into urban planning. This transformation underscores the need to transition to low-carbon infrastructures and enhance urban spaces' environmental and ethical dimensions [27,28].

Today, the sustainable mobility model is based on fair mediation between environmental protection, economy, and technology towards achieving sustainable development goals. Sustainable mobility as we know it needs to be adapted or conceptually supplemented (avoidance/reduction, movement/conservation, and improvement) to current climate problems/needs to achieve the 11th Sustainable Goal—sustainable cities. Cycling is becoming the centre of the model of (eco) active mobility in the European Union (EU) because it has the potential to adapt to current models and achieve climate needs such as climate neutrality.

The EU is committed to achieving climate neutrality by 2050, with a strong emphasis on promoting cycling as a critical mode of transportation. In pursuit of this goal, the EU aims to expand high-quality cycling infrastructure by 5000 km by 2030. Social innovation plays a crucial role in driving changes in individual mobility behaviours, and embracing cycling on a larger scale can improve public health, the local environment, and climate change mitigation [29,30]. Efforts are being made to improve air quality and promote cycling as a primary transport mode by expanding cycling infrastructure. Challenges remain in incentivising this shift, influenced by personal norms, infrastructure quality, and environmental factors. The Netherlands, Sweden, and Denmark lead in bicycle ridership, while Cyprus, Malta, and Portugal have the lowest rates. Investing in cycling infrastructure can enhance health and local environmental quality, combat climate change, and foster a strong cycling culture [31–34].

3. Materials and Methods

This study encompasses a series of variables intricately connected to the hypotheses and the central research question. To bridge the research gap identified within the existing body of literature, which has notably failed to amalgamate certain variables within a single study, this research posits that several determinants could influence cycling culture. To comprehensively analyse the factors influencing cycling decisions, this study employs factor analysis accompanied by regression analysis and the VAR model [35,36]. These methodologies facilitate a holistic overview and underscore the significance of these decisions within the broader context of a green transition economy and urbanisation. In this study, factor analysis was conducted using principal component analysis (PCA) to identify underlying patterns among the variables. Key factors were selected based on the Kaiser criterion, retaining only those with eigenvalues greater than 1, which explained a significant portion of the total variance in the dataset.

Data for this study have been collected from various sources, with the aggregated information being systematically presented in Table 1. The dataset for Slovenia encompasses yearly data spanning from 2008 to 2021. This longitudinal approach allows for a detailed examination of trends over time. It enhances the robustness of the analysis, thereby contributing significantly to the extant literature on sustainable urban transportation and its pivotal role in promoting environmental stewardship and economic sustainability. First, the summary statistics are presented. Afterwards, data were transformed using MS Excel to the base indices, where 2008 equals 100. This step is essential for further analysis. The workload chart is presented in Figure A1.

This study provides a comprehensive statistical analysis of various sustainability metrics in Slovenia between 2008 and 2021. The data include indicators of pollution, aura (environment), motor (motorisation), safety, urban (urbanisation), education, meteo (weather), and public (commuting).

The dataset tracks CO_2 emissions from both residents and non-residents across the period. In 2008, total CO_2 emissions peaked at 20,116.2 milligrams (mg), while the lowest point was recorded in 2014, with emissions dropping to 15,451.6 mg. Over the entire period, CO_2 emissions declined, with the average annual CO_2 emissions at 17,464.11 mg. This reduction is likely attributed to increased awareness and efforts towards environmental protection, as reflected by other variables in the dataset, such as increased investments in environmental protection.

Notably, emissions from non-residents were significantly lower than those from residents throughout the years, peaking at 1325.50 mg in 2018 and reaching a low of 600.68 mg in 2012. The average contribution of non-residents to CO_2 emissions was 816.65 mg. The data suggest that the reduction in CO_2 emissions was consistent, although 2018 marked a slight increase in total emissions to 17,368.7 mg, possibly reflecting a temporary rise in economic or transportation activities.

Carbon monoxide (CO) emissions reflect another critical aspect of urban air quality. CO emissions declined significantly from 213.4 mg in 2008 to 98.6 mg in 2021. The sharpest reduction occurred between 2020 and 2021, coinciding with the global COVID-19 pandemic, which likely reduced transportation and industrial activities. On average, CO emissions were 167.02 mg annually, with a minimum of 97.5 mg in 2020. This downward trend reflects Slovenia's positive strides in improving air quality.

Table 1. Data Overview and Descriptions from the Summary Statistics.

Variable		Abbreviation	Measurement	Minimum	Maximum	Average
CO_2_residents	Pollution	CO2R_BI	Gg	12,543.96	16,716.68	14,310.38
CO_2_nonresidents		CO2NR_BI	Gg	600.68	1325.50	816.65
CO_2 in the air		CO2_BI	tones	15,451.60	20,116.20	17,464.11
CO		CO_BI	/	97.50	213.40	167.02
N_2O		N2O_BI	mg	2360.19	2611.70	2471.77
CH_4		CH4_BI	mg	7446.83	91,519.80	81,815.52
Investments in environmental protection	Aura	IEP_BI	EUR	38,809.00	211,147.00	102,691.86
State investments in environmental protection		IEPP_BI	million EUR	74.56	294.15	146.61
Investments in environment protection/GDP		IEP_GDP_BI	%	0.50	1.15	0.84
Motorisation	Motor	CAR_BI	cars/10^3 inhabi.	514.00	564.00	531.35
Motorisation (Ljubljana)		CAR_LJ_BI	cars/10^3 inhabi.	492.00	531.00	514.29
Motorisation (Novo mesto)		CAR_NM_BI	cars/10^3 inhabi.	533.00	585.00	557.14
The oldness of the cars		OLDC_BI	years	7.80	10.60	9.32
Number of deaths on the road	Safety	DE_BI	by 10^4 inhabi.	0.40	1.10	0.61
Number of deaths on the road (Middle)		DE_MR_BI	by 10^4 inhabi.	508.00	546.00	525.07
Number of deaths on the road (SouthEast)		DE_SE_BI	by 10^4 inhabi.	502.00	580.00	535.14
Number of inhabitants in the cities	Urban	URB_BI	people	963,055.00	1,002,704.00	983,747.21
GDP real		GDPR_BI	EUR	34,877.00	50,660.00	40,014.21
Number of bikes		BIK_BI	piece	64,998.00	109,600.00	82,122.07
Not finished primary school	Education	NPRI_BI	people	48,863.00	115,556.00	67,391.14
Primary school		PRI_BI	people	349,528.00	435,108.00	39,6491.43
Secondary school		SEC_BI	people	899,341.00	945,704.00	930,575.00
University first cycle		1C_BI	graduates	142,133.00	214,364.00	174,446.57
University second cycle		2C_BI	graduates	143,029.00	195,541.00	168,636.57
University third cycle		3C_BI	graduates	22,188.00	37,397.00	29,686.71
Average temperature	Meteo	T_BI	°C	10.70	12.60	11.89
Precipitation		PRE_BI	mm	998.10	1840.50	1415.45
Sun		SUN_BI	hours	1695.90	2259.90	1985.15
Snow		SN_BI	days	14.00	88.00	34.14
Bus rides	Public	BUS_BI	passengers $\times 10^3$	13,350.00	38,751.00	27,223.21
City bus rides		BUSC_BI	passengers $\times 10^3$	24,238.00	61,776.00	46,727.50
Rides by train		TRA_BI	passengers $\times 10^3$	8151.00	16,661.00	14,372.07

Notes: BI—base index, inhabi.—inhabitants, CO_2—carbon dioxide, CO—carbon monoxide, GDP—gross domestic product, N_2O—Nitrous oxide, CH_4—methane, Gg—gigagram, °C—the degree Celsius, mg—milligrams, 10^3—1000, 10^4—10,000. Source: Authors calculations, SORS [37,38], ARSO [39].

Investments in environmental protection are critical to reducing pollution and improving sustainability. Slovenia's investments in this area saw substantial variation over the period. The highest investment level was observed in 2012, with EUR 211,147 million directed towards environmental protection, while the lowest was EUR 38,809 million in 2016. The average investment per year was EUR 102,691 million. Notably, the years following the economic crisis in 2008–2009 saw increased investments, potentially reflecting policy initiatives to promote green recovery strategies. These investments represent approximately 0.84% of Slovenia's gross domestic product (GDP) on average, with the highest percentage recorded in 2010 (1.15%) and the lowest in 2017 (0.50%).

Motorisation, measured as the number of cars per 1000 inhabitants, provides insight into transportation habits and the reliance on personal vehicles in Slovenia. The motorisation rate increased steadily from 514 cars per 1000 inhabitants in 2008 to 564 in 2021, indicating a growing reliance on private transportation. Ljubljana, the capital city, exhibited slightly lower motorisation rates than the national average, while Novo Mesto, an industrial town, showed higher rates, suggesting regional differences in transportation dynamics. Despite increased motorisation, road deaths per 10,000 inhabitants generally declined during the period. The highest number of road fatalities was recorded in 2008 (1.1 per 10,000 inhabitants) and the lowest was in 2018 (0.4 per 10,000 inhabitants). Reducing road fatalities may reflect improved safety measures and enhanced awareness of safe driving practices. The Southeast region consistently reported higher road fatality rates than other regions, possibly reflecting different road infrastructure challenges in more rural or industrial areas.

Nitrous oxide (N_2O) and methane (CH_4) emissions significantly contribute to global warming. N_2O emissions remained relatively stable during the study period, ranging from 2360.19 mg in 2013 to 2611.7 Mg in 2019. The average annual N_2O emissions were 2471.77 mg. Methane emissions, however, showed a slight but steady decrease from 91,519.80 mg in 2008 to 74,468.83 Mg in 2021. The average annual CH_4 emissions were 81,815.52 mg. The reductions in N_2O and CH_4 emissions suggest that Slovenia has made progress in addressing GHG emissions through improved agricultural practices, waste management, and transportation policies.

The data reveal a gradual increase in the average age of cars in Slovenia, rising from 7.8 years in 2008 to 10.6 years in 2021. The ageing vehicle fleet poses challenges for sustainability, as older cars tend to be less fuel-efficient and more polluting. This trend underscores the need for policies promoting the adoption of newer, more environmentally friendly vehicles, including electric or hybrid models.

The analysis of climate variables, such as temperature, precipitation, and sunshine hours, provides essential context for understanding the environmental conditions under which transportation and urban sustainability strategies are implemented. The average annual temperature over the period was 11.89 °C, with a low of 10.7 °C in 2010 and a high of 12.6 °C in 2014. The temperature data indicate relatively stable but slightly warming conditions, consistent with broader global climate change trends. Precipitation levels showed notable variability, averaging 1415.45 mm per year. The wettest year was 2010, with 1797.9 mm of rainfall, while the driest was 2011, with only 998.1 mm. Sunshine hours followed a similar pattern, averaging 1985.15 per year. These climate factors influence urban transportation patterns, as extreme weather conditions can affect cycling and public transportation usage.

Public transportation is a critical component of sustainable urban mobility. Bus and train usage in Slovenia showed varying trends throughout the period. The number of bus rides peaked in 2008 with 38,751,000 rides, gradually declining to 14,896,000 in 2021. This decline could be attributed to the increasing motorisation rate and the convenience of private vehicle ownership. Train rides followed a similar trend, with the highest number recorded in 2008 (16,661,000) and the lowest in 2020 (8,151,000). The sharp decline in 2020 and 2021 can be attributed to the COVID-19 pandemic, which reduced travel and public transportation usage. Despite these declines, the data underscore the importance of maintaining robust and efficient public transportation systems to reduce reliance on private vehicles and support sustainable commuting.

The dataset also includes information on education levels, which can influence transportation choices and sustainability attitudes. Over the period, most of Slovenia's population had completed secondary school education. However, the number of people with primary or lower levels of education declined, while the number of individuals with tertiary education increased, reflecting overall improvements in educational attainment. These changes in education levels could be linked to a growing awareness of environmental issues and a higher propensity to adopt sustainable transportation options, such as cycling or public transit, especially among younger, more educated populations.

This analysis of summary statistics highlights several key trends in Slovenia's sustainability metrics over the 2008–2021 period. While motorisation rates have increased, there has been a noticeable decline in CO_2 and other harmful emissions, likely driven by increased investments in environmental protection and improvements in public transportation infrastructure. However, challenges remain, particularly regarding vehicle age and the declining use of public transportation. Climate data (favourable climate for cyclists), alongside socio-economic factors such as education, further contextualise Slovenia's progress towards sustainable urban development.

4. Results

This section shows the study's results, starting with the merged data of cycling practices, followed by factor analysis and regression analysis. The research will conclude with vector autoregression analysis.

4.1. Active Transport Practice

This section analyses a strategic document intended to enhance results in factor analysis. Active transport—such as walking and cycling—is vital for sustainable urban mobility in the EU, bringing benefits beyond personal health to environmental, social, and economic aspects. European cities aiming to reduce carbon emissions should assess the costs and benefits of active transport infrastructure and policies. Litman's report offers a framework for evaluating active transport initiatives, emphasising their role in a multi-modal, equitable, and efficient transportation system [40].

The EU's push to reduce GHG emissions aligns with the benefits of active city transport. Replacing motor vehicle trips with walking and cycling can significantly lower CO_2 emissions and energy consumption. Investing in active transportation also leads to lower air pollution, reduced fossil fuel dependency, and more sustainable land use. Increasing active transport improves public health by addressing physical inactivity, obesity, and lifestyle-related diseases. Even moderate increases in walking and cycling can lower the risk of heart disease, diabetes, and mental health disorders. This approach fosters local businesses and reduces traffic congestion, aiding post-COVID-19 economic growth. Active transport also promotes social equity by providing accessible options for all citizens, including low-income individuals and those with disabilities. While costs for developing infrastructure like cycling lanes and pedestrian paths exist, they are significantly lower than maintaining car-centric roads. As active transport grows, initial increases in traffic accidents may occur, but implementing traffic-calming measures can help mitigate these risks. A challenge is the potential for slower travel times, which can be offset by more efficient land use and denser urban designs common in EU cities.

Section 4.1 acknowledges that several modern studies from countries with highly developed cycling infrastructure, such as the Netherlands and Denmark, show a strong correlation between infrastructure and increased cycling participation. These studies highlight the importance of continuous development and maintenance of cycling networks to sustain and grow cycling as a primary mode of urban transportation [41–43].

4.2. Factor Analysis

All variables have been included in the factor analysis. Factor analysis reduces observed variables to smaller latent ones, revealing patterns and hidden structures in the data. The results of using PCA to identify three main factors are in Table 2.

Table 2. Factor Analysis.

Variable	Factor 1	Factor 2	Factor 3
CO2R_BI	−0.662	0.674	−0.202
CO2NR_BI	0.377	0.492	0.714
CO2_BI	−0.681	0.657	−0.221
CO_BI	−0.874	0.146	0.422
IEP_BI	0.024	−0.401	−0.700
IEPP_BI	−0.055	−0.623	0.048
CAR_BI	0.944	0.290	−0.012
DE_BI	−0.737	0.478	−0.257
N2O_BI	0.780	0.309	−0.160
CH4_BI	−0.923	0.293	−0.152
IEP_GDP_BI	0.964	−0.126	0.176
CAR_LJ_BI	0.078	0.903	−0.332
CAR_NM_BI	0.409	0.845	−0.180
DE_MR_BI	0.587	0.729	−0.277
DE_SE_BI	0.977	0.153	0.067
URB_BI	0.936	−0.171	−0.200
GDPR_BI	0.937	0.291	−0.025
BIK_BI	0.290	0.851	−0.108
NPRI_BI	−0.856	0.334	−0.140
PRI_VI	−0.972	−0.086	−0.193
SEC_BI	0.292	−0.471	−0.591
1C_BI	0.747	0.497	0.163
2C_BI	0.959	−0.045	0.196
3C_BI	0.961	0.027	0.241
T_BI	0.440	−0.275	0.513
PRE_BI	−0.194	−0.008	0.251
SUN_BI	0.359	0.003	−0.441
SN_BI	−0.419	−0.037	0.047
BUS_VI	−0.697	0.391	0.525
BUSC_BI	−0.323	0.208	0.866
TRA_BI	−0.896	−0.018	0.194
OLDC_BI	−0.991	−0.100	−0.054

Notes: CO_2_residents—CO2R_BI, CO_2_nonresidents—CO2NR_BI, CO_2 in the air—CO2_BI, CO—CO_BI, N2O—N2O_BI, CH4—CH4_BI, Investments in environmental protection—IEP_BI, State investments in environmental protection—IEPP_BI, Investments in environment protection/GDP—IEP_GDP_BI, Motorisation—CAR_BI, Motorisation (Ljubljana)—CAR_LJ_BI, Motorisation (Novo mesto)—CAR_NM_BI, The oldness of the cars—OLDC_BI, Number of deaths on the road—DE_BI. Number of deaths on the road (Middle)—DE_MR_BI, Number of deaths on the road (SouthEast)—DE_SE_BI, Number of inhabitants in the cities—URB_BI, GDP real—GDPR_BI, Number of bikes—BIK_BI, Not finished primary school—NPRI_BI, Primary school—PRI_BI, Secondary school—SEC_BI, University first cycle—1C_BI, University second cycle—2C_BI, University third cycle—3C_BI, Average temperature—T_BI, Precipitation—PRE_BI, Sun—SUN_BI, Snow—SN_BI, BUS rides—BUS_VI, City bus rides—BUSC_BI, Rides by train—TRA_BI. Source: Authors calculations.

4.2.1. Factor 1: Environmental and Economic Impact

Within the comprehensive framework of the analysis, Factor 1 emerges as a predominant element, characterised by its significant correlation with a spectrum of variables pertinent to environmental stewardship, economic metrics, and emission levels. This factor elucidates the most substantial portion of variance within the dataset, warranting its conceptualisation as the Environmental and Economic Impact Factor. A discernible pattern is observed wherein high positive loadings on specific variables underscore their robust association with Factor 1. In contrast, negative loadings delineate an inverse correlation, demarcating this factor’s multifaceted nature.

Notably, the variable IEP_GDP_BI, representing investments in environmental protection as a percentage of GDP, exhibits the most pronounced positive loading (0.964) on Factor 1. This correlation underscores the pivotal role of fiscal allocations towards environmental protection in articulating this factor, thereby bridging economic resource allocation with tangible environmental outcomes. Furthermore, the URB_BI variable, indicative of urban population figures, boasts a substantial positive loading (0.936), suggesting a significant linkage between urbanisation processes and the economic-environmental nexus, potentially attributed to the agglomeration of resources and infrastructural developments within urban locales.

Additionally, the CAR_BI variable, reflecting motorisation rates or the per capita number of automobiles, is closely associated with Factor 1 through a favourable loading of 0.944. This association accentuates the interplay between economic advancement, escalated vehicle ownership, and its consequent environmental ramifications, mainly through heightened emission levels. The variable N2O_BI, nitrous oxide emissions, further corroborates the environmental dimension of Factor 1 through a moderately high positive loading (0.780).

Conversely, Factor 1 manifests significant negative loadings on several variables, notably CO_BI and CO2_BI, which register strong inverse correlations (−0.874 and −0.681, respectively). These findings suggest that CO and CO2 emissions elevations are inversely proportional to the investments in environmental protection and the degree of urbanisation, insinuating that regions or epochs characterised by heightened emissions might exhibit diminished environmental protection efforts or underdeveloped urban infrastructures. The variable TRA_BI, symbolising train ridership, also displays a negative loading (−0.896) on this factor, potentially indicating that locales with increased emissions and motorisation rates may concurrently experience a decline in public transportation utilisation.

Factor 1 encapsulates the dynamic interrelations between economic growth, urban development, environmental protection investments, and emission outputs. It postulates that an upsurge in motorisation and a reduction in public transportation usage is intertwined with elevated emission levels. In contrast, investments in environmental protection are instrumental in ameliorating these effects.

4.2.2. Factor 2: Urban Transportation Dynamics

Factor 2 is predominantly influenced by variables associated with motorisation in specific cities and educational achievement. It can be interpreted as an urban transportation dynamics factor, reflecting regional transportation dynamics and the impact of education on these outcomes. Strong Positive Loadings are inside three variables: (1) CAR_LJ_BI (0.903) and CAR_NM_BI (0.845). These variables measure motorisation levels in Ljubljana and Novo Mesto, respectively. Both variables exhibit significant positive loadings on Factor 2, indicating that motorisation in these cities plays a crucial role in this factor; (2) BIK_BI (0.851). The number of bikes is also strongly linked to this factor, suggesting a correlation between motorisation and cycling, particularly in urban areas; (3) Educational Variables: Variables related to educational attainment, such as 1C_BI (0.497) (university first cycle) and 2C_BI (0.959) (university second cycle), are positively associated with this factor. This implies a connection between higher levels of education and transportation dynamics, possibly due to the influence of education on mobility choices and awareness of sustainable practices.

Contrarily, there is strong negative loading for the variable PRI_VI (−0.972). This variable, representing individuals with only primary school education, significantly negatively affects Factor 2. This indicates a reverse relationship between lower educational attainment and the transportation patterns captured by this factor, such as motorisation and cycling in urban areas.

Factor 2 underscores the significance of regional disparities in transportation infrastructure and the influence of education on transportation choices. It suggests that cities with higher motorisation rates also tend to have higher cycling rates and that these patterns are associated with educational attainment.

4.2.3. Factor 3: Climate and Public Transportation

Factor 3 captures the influence of climate and public transportation on the dataset. It can be interpreted as a Climate and Public Transportation Factor, reflecting how weather conditions and transportation infrastructure interact to influence sustainability outcomes. Three factors have high positive loadings: (1) CO2NR_BI (0.714). CO_2 emissions from non-residents have a high positive loading on Factor 3. This may suggest that non-residents, possibly tourists or commuters, contribute significantly to emissions in regions where this factor is strong; (2) BUSC_BI (0.866): City bus rides are strongly associated with this factor, indicating public transportation's role in areas where non-residents' emissions are significant; (3) T_BI (0.513): Temperature also shows a moderately high positive loading, suggesting that warmer climates may be associated with higher bus usage and emissions from non-residents, possibly due to seasonal tourism or other factors.

On the other hand, two variables recognise high negative loadings: (1) SUN_BI (−0.441). Sunshine shows a negative loading on Factor 3, suggesting that areas with higher sunshine hours may not rely as heavily on public transportation or experience lower emissions from non-residents; (2) SEC_BI (−0.591): Secondary school attainment shows a moderate negative loading, indicating an inverse relationship between this level of education and the variables in Factor 3.

Factor 3 illustrates the influence of climate conditions and public transportation on emissions, particularly from non-residents. It suggests warmer regions with higher public transportation use, such as city buses, experience higher emissions from non-residents.

4.3. Answering the Hypotheses and Research Question

4.3.1. Hypothesis 1

Based on the factor analysis results, there is evidence to partially support hypothesis 1: New measures implemented in recent years will substantially increase the frequency of urban cycling commutes in Slovenia.

Please remember the following information: The analysis reveals a positive correlation between motorisation and cycling, as indicated by Factor 2. Within this factor, the presence of bikes (BIK_BI) is closely linked to motorisation in cities like Ljubljana (CAR_LJ_BI) and Novo Mesto (CAR_NM_BI). This suggests that cycling is becoming a viable mode of transport in regions with higher car ownership. The increased investments in urban infrastructure (as indicated by the strong positive association of IEP_GDP_BI with Factor 1) likely enhance cycling infrastructure and safety, thus encouraging cycling as a sustainable commuting option.

However, to fully confirm this hypothesis, the effectiveness of recent measures such as cycling lane expansions or incentive programs would need to be directly examined, and additional longitudinal data on cycling frequency would be necessary. Nevertheless, the factor analysis suggests that regions with higher urbanisation and infrastructure investments will likely experience increased cycling. This supports the hypothesis that Slovenia's efforts have contributed to the growth of urban cycling commutes. Moreover, a regression analysis has been conducted with BIK_BI as the dependent variable and component factors as independent variables:

$$BIK\_BI_t = 74.83 + 3.82 \cdot K1_{(2.16)} + 10.63 \cdot K2_{(6.33)} - 1.35 \cdot K3_{(-0.80)} + \varepsilon, \quad (1)$$

where ε is white noise and factor, K3 is not statistically significant. The model suggests that K2 (Urban Transportation Dynamics) has the strongest positive impact on the frequency of urban cycling commutes, with a coefficient of 10.63, which is statistically significant ($t\text{-}value = 6.33$). The results suggest that regions with higher levels of motorisation and better education are likely to experience a significant increase in cycling. Moreover, the coefficient of 3.82 for K1 indicates that investments in environmental protection and urban planning also contribute to the rise in urban cycling commutes. However, the statistical insignificance of K3 (Climate and Public Transportation Factor) implies that climate conditions and public transportation do not directly impact cycling frequency in this case. While infrastructure improvements and socio-economic factors positively influence urban cycling, the results indicate that further measures may be necessary to sustain or enhance this growth. Therefore, while the data largely support Hypothesis 1, additional efforts, particularly in public transportation integration, could further promote urban cycling. Overall, Hypothesis 1 is partially confirmed.

4.3.2. Hypothesis 2

Based on the factor analysis results, we find partial support for Hypothesis 2, which suggests that increased cycling participation in Slovenia will result in a measurable decrease in CO_2 emissions and an improvement in urban air quality. The factor analysis reveals that Factor 1 (Environmental and Economic Impact) demonstrates strong negative loadings for CO_2 emissions from residents and non-residents, as well as for total CO_2 emissions and CO emissions. This indicates that higher CO_2 emissions are linked to weaker environmental and economic performance and that reducing emissions through increased cycling would have a positive environmental impact. Furthermore, a moderate positive correlation between cycling participation and environmental outcomes suggests that areas with higher cycling rates tend to have better environmental results.

However, the analysis does not explicitly demonstrate a robust direct link between increased cycling and a significant reduction in CO_2 emissions, as this impact is influenced by broader factors such as motorisation rates, environmental protection investments, and public transportation usage. Factor 3 (Climate and Public Transportation), which could impact urban air quality, does not strongly correlate with cycling participation. While the factor analysis implies that increased cycling may contribute to lower emissions and improved air quality, the relationship is intricate and indirect. To fully confirm Hypothesis 2, further evidence is needed to quantify the specific impact of cycling on CO_2 reduction. Therefore, Hypothesis 2 is partially supported, with the potential for cycling to enhance air quality, but other factors such as motorisation and public transport use must also be considered.

4.3.3. Research Question

The findings derived from the factor analysis substantiate the research inquiry posited at the outset of this study: "Thoughtful urban planning and the implementation of reduced urban speed limits will bolster cycling's safety and desirability, prompting a more significant number of individuals to transition from cars to bicycles?" The analysis elucidates a positive correlation between the variables BIK_BI (quantifying the number of bicycles) and Factor 1 (0.290), underscoring the premise that urban planning initiatives to ameliorate environmental conditions—specifically through infrastructural investment—positively influence cycling participation rates.

Furthermore, Factor 2, designated as Urban Transportation Dynamics, delineates a robust relationship between urban motorisation rates (CAR_LJ_BI = 0.903, CAR_NM_BI = 0.845) and cycling participation (BIK_BI = 0.851). This relationship intimates that notwithstanding high levels of automobile ownership, implementing thoughtful urban planning measures, such as expanding cycling lanes and promoting safety through reducing urban speed limits, can augment cycling rates. Additionally, a positive association with educational levels within this factor suggests an enhanced consciousness regarding cycling as a safer and more desirable mode of transportation. While Factor 3 (Climate and Public Transportation) did not exhibit a significant association between climatic conditions and cycling.

In sum, the results from the factor analysis lend empirical support to the research question that urban planning—manifested through proactive urban infrastructure investments and the judicious management of motorisation—and the potential implementation of reduced urban speed limits can indeed foster cycling. By enhancing cycling infrastructure and safety measures, urban planning policies can render cycling more attractive and incentivise a modal shift from automobiles to bicycles. This paradigm shift holds particular resonance in highly motorised urban contexts, where the effective implementation of measures to augment cycling safety could significantly elevate participation levels.

Therefore, the research question is empirically validated by the analysis, affirming that urban planning and speed reduction policies are likely to enhance the safety and appeal of cycling, thereby contributing to increased adoption rates of cycling as a mode of transportation. As such, let us see this in the regression analysis where URB_BI is a dependent variable and component 2 and deaths are independent variables:

$$URB\_BI_t = 52.88 - 0.84 \cdot K2_{(-5.49)} + 0.003 \cdot \underset{(0.29)}{DE\_BI_t} + 0.37 \cdot \underset{(3.49)}{DE\_MR\_BI_t} + 0.11 \cdot \underset{(2.539)}{DE\_SE\_BI_t} + \varepsilon, \quad (2)$$

where t statistics is written in parenthesis, the coefficient for K2 is −0.84, with a statistically significant t-value of −5.49. This indicates a strong and negative relationship between motorisation/education (Component 2) and urban population growth. In cities with higher motorisation rates and better educational outcomes, there seems to be a reduction in population growth or urbanisation. This could suggest that high levels of motorisation make urban areas less attractive or sustainable, leading to slower population growth.

The coefficient for DE_BI is 0.003, with a t-value of 0.29, which is not statistically significant. This suggests that the overall number of road deaths does not meaningfully impact the urban population size. This implies that general road fatalities may not be the primary factor influencing urbanisation trends. The coefficient for DE_MR_BI is 0.37, with a t-value of 3.49, which is statistically significant. This suggests that road deaths in the Middle region positively correlate with urban population growth. One possible interpretation is that in this region, other factors (such as economic opportunities or infrastructure development) may offset the negative impact of road safety issues, leading to continued urban growth despite a higher rate of fatalities. The coefficient for DE_SE_BI is 0.11, with a t-value of 2.539, which is also statistically significant. This indicates a more minor but positive impact of road fatalities in the Southeast region on urban population size. Similar to the Middle region, this suggests that despite road safety concerns, urban population growth continues, possibly driven by other socio-economic factors.

The regression analysis provides mixed results regarding the relationship between urban planning measures (concerning motorisation and road safety) and urban population growth. Motorisation (K2) has a significant negative impact on urban growth, suggesting that high levels of car ownership could discourage urbanisation by making cities less desirable or livable. Road fatalities in specific regions (DE_MR_BI and DE_SE_BI) have a positive relationship with urban growth, which could indicate that, in certain areas, urbanisation continues despite road safety concerns, possibly due to other attractive factors such as employment opportunities or infrastructure development. These results imply that reducing motorisation and improving road safety could enhance urban growth (and consequently higher GDP [44]) and promote more livable cities, supporting the broader context of the research question related to urban planning and the shift from cars to bicycles. Therefore, a VAR analysis needs to have a more straightforward meaning. Let us mention that all variables could not be observed in VAR because of the degrees of freedom.

$$\begin{aligned} URB\_BI_t = {} & 45.69 + 0.93 \cdot \underset{(2.15)}{DE\_MR\_BI_t} - 0.07 \cdot \underset{(-1.23)}{DE\_SE\_BI_t} + 0.33 \cdot \underset{(2.05)}{URB\_BI_t} + 0.01 \cdot \underset{(0.57)}{BIK\_BI_t} \\ & -0.69 \cdot \underset{(-2.75)}{CAR\_LJ\_BI_t} + 0.05 \cdot \underset{(0.61)}{CAR\_NM\_BI_t} + \varepsilon, \end{aligned} \quad (3)$$

where t statistics is in parenthesis, the results of the VAR analysis provide insights into the relationship between the number of inhabitants in the cities (URB_BI) and several independent variables, including road deaths in different regions, urban motorisation, and the number of bikes. Let us analyse the key findings. The constant is 45.6891, with a significant p-value (0.0070), indicating that urban population growth has a baseline positive effect even without the other variables.

The coefficient DE_MR_BI is 0.928473, with a marginally significant p-value (0.0750). This suggests that an increase in road deaths in the Middle region has a positive relationship with the urban population size, which may be counterintuitive but could imply that despite higher fatalities, urban growth continues due to other attractive factors (like economic development). This relationship is statistically significant at the 10% level. The coefficient

DE_SE_BI is −0.069, with a non-significant *p*-value. This indicates that road deaths in the Southeast region do not significantly impact urban population growth. The negative coefficient suggests a potential inverse relationship but is not statistically robust enough to draw firm conclusions. The coefficient URB_BI is 0.33, with a significance level of 10%. This positive relationship suggests that past urban population levels influence future urban growth, indicating some degree of persistence or momentum in urbanisation trends.

The coefficient for CAR_LJ_BI is −0.69, with a significant *p*-value, indicating a strong negative relationship between motorisation in Ljubljana and urban population growth. This suggests that higher car ownership in Ljubljana may discourage urbanisation, potentially due to congestion, environmental degradation, or reduced livability associated with high motorisation rates.

The coefficient is 0.05, with a non-significant *p*-value, indicating that motorisation in Novo Mesto does not significantly affect urban population growth in this model.

The coefficient for BIK_BI is 0.01, with a non-significant *p*-value. This indicates that the number of bikes does not statistically affect urban population growth. This could imply that while cycling infrastructure is important for urban mobility, it does not directly drive urban population increases in this model. Therefore, regarding the research question and hypotheses, the last VAR model excludes cars. The results show that bikes could also have a significant implication of the coefficient 0.02, where Durbin—Watson (D-W) statistics is 2.07, which indicates no severe autocorrelation in the model.

Nevertheless, the initial VAR model has a model performance as follows. The R-squared value is 0.98, indicating that the model explains approximately 98.5% of the variance in the dependent variable (urban population). This is an excellent fit, suggesting that the independent variables included in the model provide a comprehensive explanation of urban population dynamics. The F-statistic is 65.06 with a significant *p*-value (0.01), meaning that the overall model is statistically significant and explains a substantial amount of the variance in urban population growth. The D-W value is 2.80, which suggests no severe autocorrelation of the model's residuals (as values close to 2 indicate little to no autocorrelation).

Overall, the VAR analysis highlights several significant findings related to urban population growth in Slovenia. Motorisation in Ljubljana (CAR_LJ_BI) significantly negatively impacts urban population growth, suggesting that reducing motorisation and promoting alternative transportation modes like cycling could enhance urban livability and attract more residents. Road deaths in the Middle Region (DE_MR_BI) have a positive and marginally significant relationship with urban growth. This might indicate other compensatory factors, such as economic opportunities or infrastructure development, despite safety concerns. Cycling participation (BIK_BI) has significant effect on urban growth in the alternative model. It indicates that while it may play a role in urban mobility, it does not directly influence urban population size if cars are associated.

5. Discussion

The study's findings support the idea that investing in cycling infrastructure can substantially decrease GHG emissions in urban areas, which aligns with previous research on the environmental benefits of active transport. Successful integration of cycling into transportation networks in cities like Copenhagen and Amsterdam serves as a model for Slovenia, emphasising the role of well-planned infrastructure in reducing reliance on cars and lowering emissions. Furthermore, promoting cycling in urban areas such as Ljubljana and Novo Mesto could lead to lower CO_2 levels. The study also establishes a strong correlation between the number of bicycles and reductions in urban CO_2 emissions, confirming the potential environmental benefits of increased cycling adoption.

In Slovenia, the potential health benefits of cycling are particularly noteworthy, given the increasing levels of motorisation in cities such as Novo Mesto. The study's econometric analysis indicates that higher motorisation rates are associated with elevated CO_2 emissions and traffic congestion, adversely impacting air quality. Despite the clear ideas of cycling, the study identifies several challenges that could hinder the widespread adoption of cycling in Slovenian cities. High motorisation rates in industrial areas, such as Novo Mesto, present a significant obstacle as the reliance on cars grows. This aligns with previous research, indicating that areas with higher levels of car ownership are less likely to adopt cycling as a primary mode of transport [45]. This may also be influenced by the geographic location of the area. Additionally, the study's analysis suggests that urban planning strategies, such as reducing speed limits and creating dedicated cycling lanes, are crucial for making cycling safer and more appealing to the public. This finding is consistent with the literature and emphasises the importance of infrastructure and traffic calming measures in promoting cycling [46]. Nevertheless, the results of the third factor and regression (URB_BI and CAR_LJ_BI) show that while cycling rates are moderately influenced by weather conditions, such as temperature and precipitation, the availability of public transportation plays a more significant role.

The study highlights the role of education in influencing transportation choices and the benefits of cycling. It finds a positive link between education levels and cycling participation, particularly in urban areas like Ljubljana. However, Ljubljana faces a critical challenge with high motorisation rates, which hinder urban growth and could lead to slower GDP growth. As residents opt for cars over sustainable transport, the city risks becoming less appealing to new residents and businesses, potentially stalling economic development and reducing the advantages of a well-connected urban environment [47].

Overall, we can answer the hypotheses and research question based on the study results as follows. Hypothesis 1 is partially confirmed: Slovenia has seen an increase in cycling frequency, but more direct evidence on the impact of recent measures is needed. Hypothesis 2 is partially supported: Cycling contributes to lower CO_2 emissions, but the relationship is complex and influenced by other factors like motorisation and education. The research question is supported: Thoughtful urban planning, including traffic-calming measures and cycling infrastructure, increases cycling's safety and desirability, encouraging a shift from cars to bicycles.

6. Conclusions

The study highlights the role of cycling in reducing CO_2 emissions in urban areas of Slovenia, particularly in cities like Ljubljana and Novo Mesto, which face rising motorisation and pollution. Reducing dependence on cars is critical for improving air quality and fostering sustainable urban growth, which could positively impact Slovenia's GDP. Novo Mesto's high reliance on cars has led to traffic congestion and poor quality of life, making significant transportation interventions necessary. Promoting cycling and integrating public transportation is vital for creating a more sustainable urban environment. Higher education levels correlate with increased cycling, indicating that educational initiatives could encourage active transport. Air pollution in Slovenian cities is closely linked to vehicle emissions, and investments in cycling could improve urban air quality. Tourism exacerbates pollution through increased traffic, especially in peak season, and weather patterns affect tourist numbers and pollution levels. Slovenia must promote cycling alongside public transport improvements and speed reductions to achieve sustainability goals.

6.1. Implications

The research recommends that policymakers in Slovenia prioritise investments in cycling infrastructure and implement measures to reduce motorisation, particularly in urban areas like Ljubljana and Novo Mesto. The country can improve air quality, public health, and urban livability by implementing traffic calming measures, such as speed reductions, and promoting cycling through education and public awareness campaigns. Policy incentives to encourage cycling over car usage can also help prevent negative impacts on urban growth and GDP.

This study reinforces the understanding that sustainable transportation, especially cycling, is crucial in reducing GHG emissions and preventing deaths. It emphasises the importance of integrating urban planning with transportation, economic, and environmental policies to achieve long-term sustainability goals.

6.2. Policy Recommendations

For the further development of cycling in Ljubljana and Nove Mesto, the development of local cycling models as local cycling plans is recommended by local goals for commuting to work, the current mobility strategy at the state level, and the goals of the Green Agreement at the EU level, and Sustainable Development Goals at the international level.

According to the Copenhagenize group's proposals, activities in this area should focus on space, communication, and ambitions within the best practices of Copenhagen and Amsterdam. This will contribute to transforming current political thinking, changing culture, and accepting sustainable values as EU identity.

The Slovenian legislature needs to create a theoretical basis for transport changes. Implementing sustainable mobility in national programs/strategies/laws is necessary. Based on this, an active transport model should be developed based on the principle of route optimisation, transition to bicycles, and reduction of energy consumption. To optimise the route, it is necessary to plan the further urbanisation of the city with the model of "active mobility" and adapt the current space. Safety proved to be a turning point for increasing the number of cyclists.

For this reason, safety measures are proposed: widening the paths, placing cycle paths, better road connectivity, space connectivity, adding signalling, etc. Companies should strongly encourage the transition to bicycles. The state should implement tax measures to subsidise coming and going to work by bicycle, subsidising the purchase of a bike, promoting bicycle logistics, overcoming cultural limitations (survey of public opinion and the primary limits for bicycle acceptance), and promoting equality, carrying out surveys for the exact number of cyclists before and after the implemented measures related to monitoring greenhouse gases in the same area, etc. Reducing energy consumption should be based on maintaining public transport that would provide the possibility of combined mobility. Policymakers should monitor population movement routes and, based on them, create circular modal mobility plans (bus/train + bicycle), more thoughtfully encourage bicycle sharing, invest in education and awareness of the environmental impacts of transport, etc.

6.3. Limitations and Furter Research

The study has several limitations related to the dataset and the analysis. First, the dataset predominantly focuses on urban areas, specifically Ljubljana and Novo Mesto, which restricts its representativeness to rural or less industrialised regions in Slovenia. The analysis does not account for regional variations that could influence cycling adoption across different geographic contexts. Furthermore, while the study underscores the positive environmental impacts of cycling, it does not adequately consider other influential factors, such as social and cultural resistance to cycling or the economic costs associated with infrastructure implementation, which could affect the feasibility of policies. The econometric models rely on historical data, potentially constraining their ability to predict future technological advancements or shifts in transportation behaviour. This reliance on past trends may also overlook emerging mobility solutions, such as e-bikes or shared transportation systems. Further research with a broader dataset and dynamic, long-term factors is essential to address these gaps and fully assess the long-term impact of cycling policies.

Therefore, future research should delve into the long-term effects of cycling infrastructure on economic growth and public health in urban and rural areas. Additionally, examining cultural and societal attitudes towards cycling, alongside technological advancements in transportation on the uptake of cycling, cost of living, and average income in urban areas, could yield more profound insights into the sustainability and success of active transport policies in Slovenia.

Some parts of Slovenia are industrial, so many new residents come from nearby countries. Cycling culture varies a lot. Slovenians love cycling, but this is mostly not the case for people from nearby countries who currently live in Slovenia. This can have various impacts on the results, which are highlighted as:

- Urban cycling in Slovenia has increased with infrastructure investment.
- Motorisation and urbanisation trends influence cycling participation rates.
- Increased cycling correlates with reductions in CO_2 emissions and CO levels.
- Reduced urban speed limits enhance cycling safety and desirability.
- Public transportation usage and climate conditions moderately impact cycling.

To conclude, our findings align with trends observed in other highly motorised countries, where the combination of increased cycling infrastructure and supportive urban policies has led to a notable rise in cycling participation, even in regions with high levels of car ownership.

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Appendix A

The flow chart of the research is presented in Figure A1.

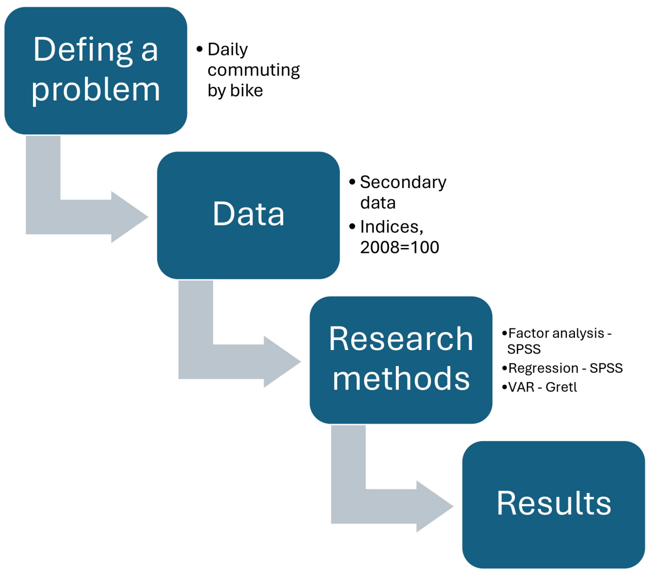

Figure A1. Flowchart of the research.

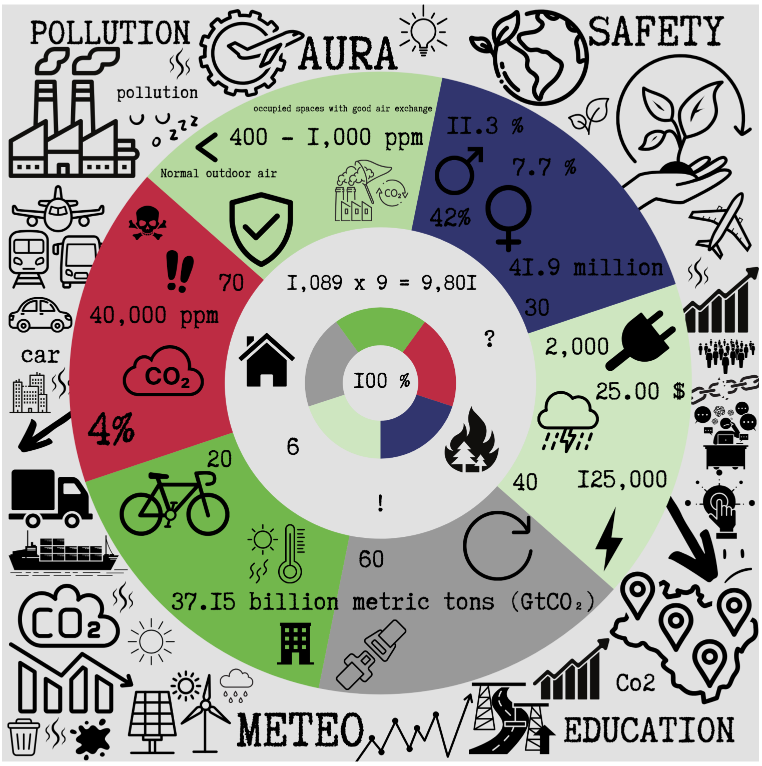

Figure A2. Flowchart of the research. Source: Author's calculations based on the research dataset and [48].

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