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Unlocking Sustainable Commuting: Exploring the Nexus of Macroeconomic Factors, Environmental Impact, and Daily Travel Patterns

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Abstract: This paper examines normality in time series econometrics for a sustainable energy transition. By analysing data from January 1997 to December 2021, this study integrates macroeconomic, environmental, and energy data to gain insights into the potential changes in daily commuting patterns among Slovenians. Various methods, including unit root tests such as the augmented Dickey–Fuller (ADF), Kwiatkowski–Phillips–Schmidt–Shin (KPSS), and Zivot–Andrews (Z-A), as well as other tests, are employed. Additionally, the vector autoregressive (VAR) model, Granger Causality and regression analysis determine the impact. This paper contributes to uncovering valuable information within data from macrovariables using macroeconometric techniques. It also provides insights that can support evidence-based decision-making for sustainable energy transition policies in Slovenia. The results of the normality tests indicate that most macro variables are integrated; there is a need for a careful analysis of integration levels and appropriate testing methods. These findings have implications for policymakers, researchers, and practitioners in economics, the environment, and energy supply. At the same time, this research highlights that gross domestic product, unemployment, inflation, and carbon dioxide positively impact car usage among Slovenians, while gasoline prices and commuters have a negative one. While the recently investigated development of sustainable commuting does not work, the study highlights an innovation: the connection of time series econometrics, which offers a better understanding of future commuting patterns on energy consumption and their causalities.

Keywords: case study; commuting; energy-saving; environmental impact; VAR model

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1. Introduction

Pursuing a sustainable energy transition has become a pressing global concern, driven by the need to address environmental challenges and mitigate climate change impacts. Daily commuting patterns play a crucial role in this context, as they significantly influence energy consumption, environmental emissions, and overall sustainability. Understanding the dynamics and patterns of daily commuting is essential for designing effective policies and strategies to promote sustainable transportation and reduce carbon footprints.

While several studies have explored the relationship between transportation and environmental sustainability [1,2], a comprehensive examination of daily commuting patterns within the framework of time series econometrics is still relatively limited [3]. This study aims to bridge this research gap by investigating normality in time series data and uncovering insights into the transition of daily commuting. We chose Slovenia as a case study, a country characterised by its unique socioeconomic context in terms of energy transition and potential for sustainable development into a low-carbon economy (part of the European Union (EU) Cohesion Policy for climate transition).

The primary goal of this study is to explore the relationship between the share of cars in daily commuting and sustainable daily commuting, specifically in the Slovenian context. The overarching aim is to better understand the underlying dynamics and patterns by analysing time series data. The objectives of this research are as follows: First, to analyse macroeconomic, environmental, and energy data integration using advanced econometric methods, such as unit root tests and vector autoregressive models. Second, to assess the potential impact of macroeconomic variables on daily commuting patterns in Slovenia, considering factors such as gross domestic product (GDP), number of bicycles, unemployment rate, price indices (inflation and gasoline prices), carbon dioxide (CO_2) emissions, and industry labour costs, as well as commuting allowances. Lastly, identifying potential structural breaks within the time series data allows for a more accurate understanding of temporal variations and their implications for daily commuting.

Two hypotheses could be developed based on literature review and supporting elements of the methodology.

H1. *Integrating macroeconomic, environmental, and energy data will reveal significant relationships and patterns that influence daily commuting behaviour in Slovenia. Specifically, variables such as GDP, unemployment rate, carbon dioxide emissions, and commuting allowance will significantly impact the share of cars among residents.*

H2. *The implementation of policies and interventions aimed at promoting sustainable commuting practices, such as incentivising public transportation use, developing cycling demand, and providing commuting allowances for energy-efficient modes of transportation, will contribute to a reduction in the share of cars among residents and facilitate the transition to a more sustainable commuting system and energy transition in transport in Slovenia.*

The motivation for this study stems from the desire to uncover valuable information within macrovariable data using macroeconometric techniques. By examining the integration, co-movement, and potential structural breaks in time series data, the research contribution of this paper is to provide insights that can support evidence-based decision-making for sustainable energy transition policies in Slovenia.

The paper is structured as follows: After the introduction section, a comprehensive literature review is presented to provide a theoretical framework for the study. Subsequently, the dataset and a summary of the econometric results are provided in the following section. The subsequent section outlines the methodology employed and presents the results of misspecification tests. The main results section reports the findings of the vector autoregressive (VAR) analysis. The penultimate section presents a discussion providing deeper insights and interpretations of the results. Finally, the last section concludes the paper and summarises the key findings and their implications.

2. Literature Review and Hypothesis Development

A review of the literature on exploring the daily commuting transition and sustainable energy transition is generally characterised by various studies investigating various aspects of this complex relationship. Scholars [4–6] have explored commuting patterns' economic, social, and environmental dimensions and their implications for sustainable development [7–9]. Recent studies [10–12] are mainly focused on reducing energy and carbon intensity, and on decarbonisation. An in-depth analysis of contemporary empirical literature [4–12] reveals critical insights into commuting patterns and their implications for sustainable development. Based on best practices, these nine scientific papers shed light on various aspects of sustainable transportation. The articles offer valuable insights into commuting patterns and sustainable transportation strategies. These research papers encompass a range of critical topics, such as tailored policies for sustainable commuting in

Californian cities, global urban ecological management models, and effective mechanisms to accelerate the adoption of electric vehicles in the Nordic region.

Additionally, they explore decoupling transport growth from emissions in EU-15 countries, promoting cycling as a sustainable mode of transportation in Canada and the USA, and comparing cycling levels in Melbourne and Sydney. The literature also provides a theoretical framework for decoupling transport volumes and CO_2 emissions from GDP and examines the adoption of the public service obligation (PSO) mechanism in European air transport. Finally, these studies delve into the significance of correctly pricing transport behaviour to account for external costs and discuss various countries' approaches and their success in achieving transportation demand management objectives. In summary, this collection of recent scientific research offers a comprehensive panorama of the multifaceted challenges and innovative solutions surrounding commuting and sustainable transportation. By addressing regional variations, urban ecological management, electric vehicle adoption, decoupling transport from emissions, and the promotion of cycling, these studies provide a holistic understanding of how societies can transition towards more sustainable mobility. Moreover, they highlight the importance of tailored policies, infrastructure development, pricing mechanisms, and international collaboration to create greener and more accessible transportation systems.

Within the broader literature [13], there is a recognition of the significant role that daily commuting plays in energy consumption and greenhouse gas emissions. Researchers have examined the potential of alternative transportation modes, such as public transit, cycling, and walking, to reduce the reliance on private vehicles and promote more sustainable commuting behaviours. They have investigated factors influencing mode choices, such as travel time, cost, accessibility, and individual preferences.

In Slovenia, specific studies have contributed to a better understanding of the unique challenges and opportunities related to commuting and sustainable energy transition in the country. Researchers [14–16] have examined the characteristics of commuting patterns in different regions of Slovenia, considering factors such as the urban–rural divide, population density, and the spatial distribution of employment centres. They have also investigated the impact of transportation infrastructure and land use planning on commuting behaviours and the potential for integrating sustainable mobility solutions into urban development strategies [17].

Furthermore, the literature review highlights the importance of policy interventions in promoting sustainable commuting practices. Scholars have assessed the effectiveness of measures such as carpooling programs [18], flexible work arrangements [19,20], and congestion pricing schemes [21] in influencing commuting choices and reducing energy consumption. Additionally, studies have emphasised the need for integrated policy frameworks that align transportation planning, land use policies, and environmental objectives to foster sustainable commuting practices. While the existing literature [22–25] provides valuable insights into the relationship between the daily commuting transition and sustainable energy transition, several research gaps remain. This compilation of recent empirical studies delves into various aspects of commuting patterns and their implications for sustainable transportation. Studies explore the impact of micromobility services on urban transit, revealing faster travel times during peak congestion and informing urban planning and policy decisions. Additionally, the research underscores the multifaceted factors influencing bicycle commuting decisions in small cycling-oriented cities, emphasising the need to address physical infrastructure and attitudes and perceptions to promote active transportation effectively.

Furthermore, a life cycle assessment of commuting modes demonstrates the importance of comprehensive approaches to transportation-related strategies to reduce environmental impacts. By comparing six transportation modes, the evaluation highlights the significance of policies targeting strategies that enhance the environmental performance of urban transportation, encompassing factors such as local emissions, life cycle impacts, and health effects. Lastly, examining the influence of traffic intensity on commuter cycling rates in Surrey underscores the harmful effects of high traffic speeds on cycling propensity, with separated cycle paths emerging as a positive influence. While the existing literature [22–25] provides valuable insights into the relationship between the daily commuting transition and sustainable energy transition, several research gaps remain.

These include the need for more longitudinal studies to capture temporal dynamics, a deeper understanding of the sociocultural factors influencing commuting behaviours, and the integration of emerging technologies and intelligent transportation solutions into the analysis. However, given the current research objectives, the utilisation of quantitative research methods using time series econometrics has not been applied and should be further developed and examined [26].

Overall, the literature review underscores the significance of the daily commuting transition in achieving sustainable energy goals. It highlights the importance of considering multiple economic, social, and environmental dimensions in designing effective policies and interventions. By building upon the existing knowledge base, this study aims to contribute further insights into the dynamics of daily commuting and its role in the broader context of the sustainable energy transition, specifically in Slovenia, supported by time series analysis [27].

Table 1 presents a comprehensive review investigating various aspects of transportation and mobility with their implications on energy transition. It explores factors influencing residents' travel behaviour. The studies examine the effects of sociodemographic characteristics, residential built environments, personality traits, attitudes, and car ownership on the willingness to use car sharing. Additionally, one study analyses the relationship between urban characteristics and residents' commuting behaviour, considering income groups and the influence of urbanisation and population density. Furthermore, another study explores the provision of commuting-related fringe benefits by employers in the Netherlands and their correlation with company, employee, and location subsidies and characteristics. One study also highlights the relationship between gasoline tax rates and commuting patterns, emphasising the importance of fuel taxes in promoting environmentally friendly modes of transport. Lastly, one study investigates per-trip commuting CO_2 emissions and proposes reduction policies for sustainable commuting practices. Using a spatial panel approach for Great Britain [28], one study employs an econometric modelling structure to analyse the relationship between commuting, unemployment, and economic growth. Overall, these studies contribute to a deeper understanding of transportation choices, policy implications, and the promotion of sustainable mobility and energy transition.

A hint of specific policy measures is discussed following the ideas and findings from the literature review section in Table 1 and before the data presentation. The discrepancy in salary allowances related to commuting in Slovenia presents an intriguing aspect that can significantly impact the energy consumption associated with daily commuting. In this research, it becomes crucial to investigate and analyse the commuting allowance and its potential implications for energy reduction [12].

One notable feature of Slovenia is that all employees are eligible for a commuting allowance, an essential yo-yo in the research. However, the structure of these allowances differs depending on whether the employee works in the public or private sector. Since 2021, in the public sector, employees are often reimbursed based on a fixed percentage of the gasoline price per litre per kilometre. This approach incentivises employees to consider fuel-full modes of transportation, as they are directly reimbursed based on the distance covered and fuel consumption. Conversely, the private sector takes a slightly different approach, providing employees with options for commuting allowance reimbursement. These options may include rebates per kilometre or subsidies towards the cheapest ticket for public transportation from home to the workplace [29–31]. In this research, we used data from the bus ticket price index and costs per kilometre when using a car to/from work.

Table 1. Variables and data selection for an overview of modelling process literature.

Study Highlights
Study [32] explores the relationship between immigrant status and the use of emerging transportation modes. The researchers used regression models.
Study [33] examines the effects of pro-environmental and self-interested motivations, government measures, and demographic characteristics on urban residents' travel mode choices in Jiangsu Province, China.
The authors of study [34] investigate factors influencing the willingness to use car sharing in Norway, focusing on sociodemographic and residential built environments, personality traits, attitudes, and car ownership in 2414 people.
By analysing survey data, study [35] identifies connections between telework, flexitime, and various commuting allowances and highlights sustainable commuting measures.
In study [36], the relationship between gasoline tax rates and commuting behaviour in the USA is examined, revealing that higher gasoline taxes are associated with a reduced commuting time and a shift towards public transport and other physical modes of transportation.
Study [37] examines commuting CO_2 emissions at the Technical University of Madrid, finding that although public transport is widely used, private modes of transport contribute significantly to total emissions.
Study [28] reveals commuting, unemployment, and economic growth in an econometric modelling structure to examine Okun's Law using a spatial panel approach for Great Britain from 1985 to 2011.

Source: Authors' compilations.

This disparity in commuting allowances between the public and private sectors opens up an interesting avenue for research. Examining the effects of these different reimbursement schemes on commuting patterns and energy consumption can offer valuable insights into the potential for reducing energy usage in daily commuting.

In summary, Slovenia's commuting allowances present a compelling investigation area. By analysing the impact of these commuting allowances and other independent variables on patterns and energy consumption, this research aims to provide valuable insights that can inform policy decisions and contribute to the transition towards more sustainable and energy-efficient daily commuting practices.

3. Materials and Methods

Juselius [38] emphasises that data, a reflection of past events and occurrences, contain valuable information that can be extracted and utilised for predicting and shaping future events. This notion holds particular significance in daily commuting and policy decisions. The data used in this study encompass various variables related to commuting patterns, such as the share of cars among residents, CO_2 emissions, GDP, and the unemployment rate. They contain a wealth of information that can guide policy decisions and inform sustainable energy transition strategies.

Moreover, recognising the relevance of historical data for future predictions is crucial. By analysing past trends and patterns, policymakers can anticipate the potential impacts of policy decisions on commuting patterns and assess their effectiveness in achieving sustainable energy transition goals. The data provide a valuable foundation for evidence-based policy formulation, offering insights into the potential consequences of different policy scenarios and informing decision-making processes.

Overall, Juselius highlights the significance of extracting information from data to guide policy decisions on daily commuting. By utilising appropriate econometric techniques and methods, policymakers and researchers can harness the rich information in data to understand past events, predict future trends, and devise effective strategies for the sustainable energy transition in commuting [39–41].

3.1. Methods

The analysis in this study employs various methods to explore the relationship between the daily commuting transition and sustainable energy transition in Slovenia. These methods include unit root tests, normality tests, regression analysis, and descriptives from summary statistics. Some theoretical issues can be further investigated, such as the impact of macroeconomic factors (macroeconomic stability, policy failures, macroeconomic policies and variables) on the environment. This study examines the intricate relationship between macroeconomic factors, environmental impact, and daily travel patterns. It acknowledges that commuting behaviours are interconnected with broader economic and environmental trends. By exploring these distinct aspects, the research illuminates how individual decisions collectively impact ecological outcomes and economic stability. The analysis goes beyond sample examination by making sustainability a central focus. As the world confronts environmental challenges, comprehending the dynamics of daily travel and its effect on emissions and energy consumption becomes vital. To strengthen the study's ability to draw nuanced conclusions and provide a robust foundation for future research, diverse research methodologies such as unit root tests, normality tests, regression analysis, and descriptive statistics are employed. The potential exists to expand the scope of the study limitations outside Slovenia and include the entirety of the Western Balkans. Slovenia has successfully implemented strategies like environmental neutrality by adopting best practices from Western European countries like Austria and Italy. Expanding the sample limitations to include the capitals of former Yugoslav republics would encompass approximately 30 million individuals.

Unit root tests such as the augmented Dickey–Fuller (ADF) test, Zivot–Andrews (Z-A), and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test are utilised to assess the stationarity properties of the time series variables. These tests help determine the order of integration and the presence of long-term trends or structural breaks in the data. The vector autoregressive model (VAR) with the Johansen test is applied to investigate the existence of long-term relationships. This technique helps identify whether there are stable equilibrium relationships among the variables over time, indicating a long-run association between commuting patterns. Besides that, the impulse response function (IRF) has been used. This function is designed to solve conceptual problems: the history, shocks, and dependence of composition. Nevertheless, the results of the methods mentioned above are compared with the Granger Causality test and Johansen cointegration, accompanied by the augmented autoregressive distributed lag (ARDL).

Furthermore, descriptive statistics provide an overview of the variables' central tendency, dispersion, and distribution. These descriptive measures offer insights into the variability and characteristics of the data, allowing for a better understanding of the patterns and trends in daily commuting and the selected macrovariables.

3.2. Data

Data for this study were sourced from the following datasets: the Statistical Office of the Republic of Slovenia (SISTAT) [42], the Employment Service of Slovenia (ESS) [43], the Statistical Office of the European Commission (Eurostat) [44], the Collective Agreement for Non-commercial Activities in the Republic of Slovenia (CANAS) [45], and the National Oceanic and Atmospheric Administration (NOAA) [46]. The data cover the period from January 1997 to December 2021, providing a substantial timeframe for analysis. December 2021 is the last reported date from the NOAA, and January 1997 is the first declared value for gasoline prices provided by SISTAT.

On top of that, the dependent variable of interest in this study is the share of cars among Slovenian residents. This variable serves as a proxy for daily commuting patterns and reflects the prevalence of private vehicles used for transportation. The aim is to examine the factors that influence the choice of commuting modes and understand the potential impact of the sustainable energy transition on commuting behaviour. The proxy variable is gained from the equation:

$$Y_t \vdots CAR_t = CAR/POP, \tag{1}$$

where the number of cars residents own is obtained by dividing the number of cars by the population; the source variables are not treated for the initial analysis and are only provided for the calculation. Our research specifically focuses on the number of cars residents own, emphasising the impact of bicycle usage as one of the independent variables. While our approach provides valuable insights into the relationship between these two modes of transport, it is important to note certain limitations within its scope. The same econometric procedure is followed for the commuting allowance independent variable:

$$X_{t,7} \vdots CA_t = \overline{KM} \cdot TC_t, \tag{2}$$

therefore, we gain real variables, which are crucial steps for econometric analysis in the time series approach.

The independent variables are crucial in understanding the economic and environmental dimensions of daily commuting and their relationship with sustainable energy transition. They provide insights into the broader macroeconomic context, potential factors influencing commuting patterns, and their details. They are presented in Table 2, accompanied by descriptives of summary statistics. The examined variables include the share of cars among residents, GDP at constant prices, unemployment rate, carbon dioxide emissions, inflation rate, gas prices, reimbursement of transportation costs to work (collective agreement), number of bicycles, and commuting allowance.

Overall, the data section of this study incorporates diverse datasets from secondary sources, covering the period from January 1997 to December 2001, where January 1997 is the base year (1997 = 100). The chosen dependent variable, the share of cars among Slovenian residents, is complemented by independent variables. This comprehensive dataset provides a foundation for analysing daily commuting patterns and their relationship with the sustainable energy transition in Slovenia.

One limitation is the exclusivity of our analysis, which primarily examines the dynamics between cars and bicycles. This narrow focus may not encompass the entirety of commuting behaviours, as various other modes of transportation exist, each with unique patterns and implications. However, this limitation is partly due to data availability constraints, as comprehensive time series data for other modes, except for the number of public transport passengers, may not have been readily accessible. Technological changes were not included in the analysis as they were absent in the time series data. However, the results emphasised specific long-term issues.

Table 2. Data overview (January 1997–December 2021, January 1997 = 100) and descriptives of summary statistics.

Variable	Abbreviation	Frequency	T	Min	Max	Skewness	Kurtosis	Data Structure	Source
Cars/residents	$Y_t \vdots CAR_t$	M	300	63.36	409.18	0.90	3.10	CAR/POP	Equation (1)
Number of cars	CAR	M	300					Number of first registrations—all vehicles used	SISTAT
Population in SI	POP	HY→M	50					Population	SISTAT
Gross domestic product	$X_{t,1} \vdots GDP_t$	Q→M	100	100.00	1337.70	0.52	–0.42	GDP at constant prices	SISTAT
Unemployment	$X_{t,2} \vdots UNEMP_t$	M	300	46.95	103.07	−0.16	−0.89	Number of people registered	ESS
Carbon dioxide	$X_{t,3} \vdots CO_{2\,t}$	M	300	89.33	110.42	0.06	−0.81	Parts per million (ppm)	NOAA
Inflation	$X_{t,4} \vdots HICP_t$	M	300	100.00	230.17	−0.78	−0.63	Month-over-month	SISTAT
Bus ticket price	$X_{t,5} \vdots BTP_t$	M	300	100.00	259.90	–1.49	0.94	Month-over-month	SISTAT
Gasoline prices [1]	$X_{t,6} \vdots GP_t$	M	300	100.00	481.35	−0.46	−0.83	Price in EUR per litre	SISTAT
Gasoline prices [2]	$X_{t,6} \vdots GP_t$	M						Price in EUR per litre	Accounting
Costs [3]	TC	M	300					Month-over-month	CANAS
Comm. allowance	$X_{t,7} \vdots CA_t$	M	300	100.00	467.28	0.47	−0.04	$\overline{KM}$ [4]$\cdot TC_t$	Equation (2) [47]
Commuters	$X_{t,8} \vdots CO_t$	M	300	0.03	312.97	0.57	−0.86	Number of passengers	SISTAT
Gross salary [5]	$X_{t,9} \vdots GS_t$	M	168	100.00	388.51	−0.35	−0.94	Month-over-month	SISTAT
Gross salary [6]	$X_{t,9} \vdots GS_t$	Q→M	44					Quarter-over-quarter	EUROSTAT
No. of bicycles	$X_{t,10} \vdots B_t$	Y→M	25	96.69	344.77	0.48	0.59	Number of bicycles [7]	SISTAT

Notes: T—number of time series observations, SI—Slovenia, M—monthly frequencies, HY—one half of a year, Q—quarterly frequencies, Y—yearly data, costs—reimbursement of transportation costs to work. Sources: SISTAT—Statistical Office of the Republic of Slovenia, NOAA—National Oceanic and Atmospheric Administration, ESS—Employment Service of Slovenia, CANAS—Collective Agreement for Non-commercial Activities in the Republic of Slovenia, and authors' compilations. [1] Different source: Gasoline price from January 1997 to December 2017. [2] Different source: Gasoline price from January 2018. [3] Explanation: Subsidies regarding the Collective Agreement for Non-commercial Activities in the Republic of Slovenia are 15% per kilometre per litre of gasoline prices per litre. Nevertheless, some changes have occurred temporarily; therefore, this percentage changes in June 2012 to 8% and in July 2021 to 10%. [4] Data from SISTAT: In Slovenia, the average commuting distance for work purposes by car per person per day is: (1) 9.51 km up to 2017 and (2) 10.13 km from 2017. [5] Different source: Index from January 2008. [6] Different source: Index from first quarter of 1997 to last quarter of 2007. [7] Number of bicycles is from 2017 onwards and includes electric bicycles.

4. Results

The results section presents the findings of our analysis, highlighting the relationships and dynamics among various variables related to the daily commuting and sustainable energy transition in Slovenia.

Overall, the results section comprehensively analyses the various variables related to daily commuting and sustainable energy transition. It provides valuable insights into the intricate dynamics among these factors and their implications for policy-making, aiming to inform evidence-based decision-making in promoting energy-conserving transportation practices in Slovenia.

4.1. Summary Statistics

The study focuses on ten variables, with the share of cars among residents (CAR) as the dependent variable. The summaries of this variable indicate a frequency (T) of 300, a minimum value (min) of 63.36, and a maximum value (max) of 409.18. The data exhibit a slight deviation from the normal distribution, with skewness at 0.90 and kurtosis at 3.10. The data structure and source are represented by Equation (1) CAR/POP, which combines registered cars and population.

Moving on to the independent variables, their dispersion varies depending on the data structure. For example, GDP is measured in constant prices in EUR in the previous year and obtained by quarters, with a T of 100, a min of 100.00, and a max of 1337.70. The data exhibit significant deviation from the normal distribution, with a skewness of 0.52 and kurtosis of −0.42. The data structure was transformed using the EViews software (version 10) to align with the monthly frequency.

The unemployment (UNEMP) variable is observed monthly, with a frequency of 300, a min of 46.95, and a max of 103.07. Similar to GDP, it shows a significant deviation from the normal distribution, with a skewness of −0.16 and kurtosis of −0.89. The CO_2 variable, also observed monthly, exhibits a min of 89.33 and a max of 110.42, with skewness at 0.06 and kurtosis at −0.81. The harmonised consumer price index (HICP), measured in months, has a minimum of 100.00 and a max of 230.17, with skewness at −0.78 and kurtosis at −0.63. Bus ticket price (BTP) as a monthly variable has a min of 100.00 and a max of 259.90, with skewness at −1.49 and kurtosis at 0.94.

The GP variable represents the petrol price in EUR per litre and is based on 300 observations. It ranges from a minimum base index of 100.00 to a max of 481.35, with skewness at −0.46 and kurtosis at −0.83. The commuting allowance (CA) variable, calculated from Equation (2) from the average commuting distance by car per person per day divided by employer subsidies, consists of 300 observations. The commuter (CO) and gross salary (GS) variables, both observed monthly, exhibit min values of 0.03 and 100.00 and max values of 312.97 and 388.51, respectively. Their skewness and kurtosis values are 0.57 and −0.86 for CO_2 and −0.35 and −0.94 for GS.

Overall, a detailed explanation of the variables and their summary statistics provide valuable insights into the data structure and characteristics, paving the way for further analysis and modelling in the study. Additional testing on the misspecification test is presented in the next section. Before that, the following figures show an overview of the dispersion of the data in levels: Figure 1 for economic variables and Figure 2 for environmental variables.

Upon observing Figures 1 and 2, it is evident that all variables exhibit substantial volatility [48], posing a challenge for time series analysis. However, the subsequent section of the research provides further insights. Notably, GDP and CA demonstrate the highest levels of volatility, with GDP experiencing a significant upsurge in recent years and CA declining sharply following a major financial crash in 2009 in Slovenia.

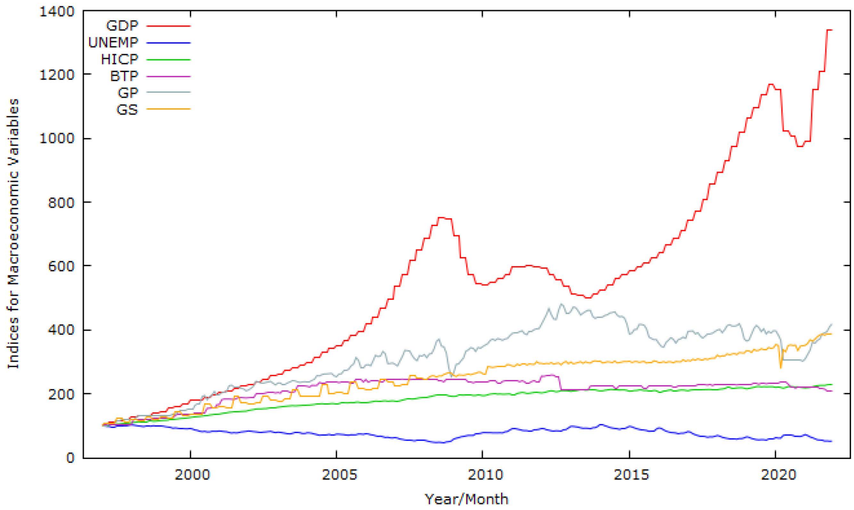

Figure 1. Dispersion of data for economic variables.

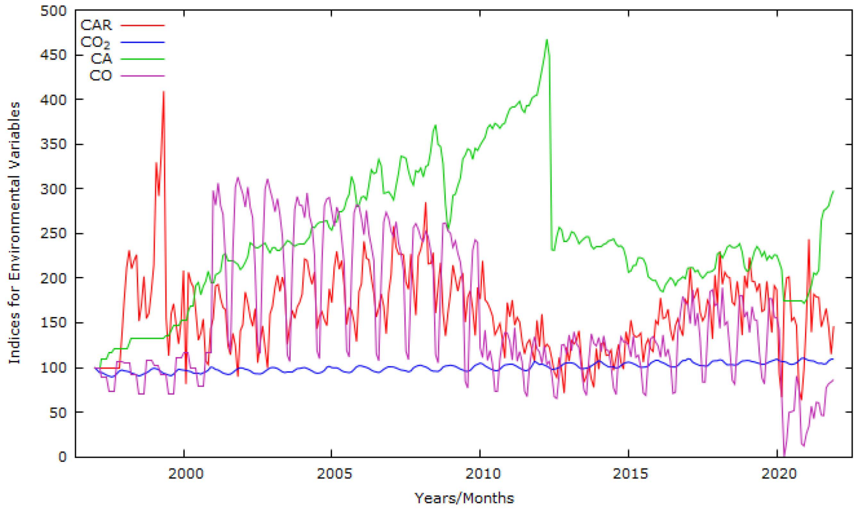

Figure 2. Dispersion of data for environmental variables.

An additional noteworthy observation is the constant upward trend of CO_2, indicating a concerning issue for policymakers and management in companies seeking effective solutions to reduce energy consumption in commuting. Interestingly, CAR does not align with the patterns exhibited by CO in the recent period, particularly from 2020 onwards, highlighting the need for the focused development of alternative and sustainable commuting strategies.

On the other hand, it is observed that HICP and GS exhibit an increasing trend, suggesting potential challenges for individuals and the economy. In contrast, BTP and UNEMP show a decreasing trend, indicating possible positive developments in commuting behaviour and labour market conditions. These contrasting trends in the variables highlight the complex dynamics and interplay of various factors influencing commuting patterns and economic conditions.

4.2. Results of Misspecification Tests and Regression Analysis

The next step in the analysis is to become familiar with the data; therefore, a regression analysis based on ordinary least squares (OLS) is conducted. The result on the data vector:

$$ {}^{SI}_{I(0)}[CAR]^T_t \ {}^{SI}_{I(0)}[GDP\ UNEMP\ CO_2\ HICP\ BTP\ GP\ CA\ CO\ GS\ B]^T_t, \tag{3}$$

where the abbreviations are cars/residents—CAR, gross domestic product—GDP, unemployment—$UNEMP$, carbon dioxide—CO_2, inflation—$HICP$, bus ticket price—BTP, gasoline prices—GP, commuter allowance—CA, commuters—CO, gross salary—GS, number of bicycles—B, T—number of monthly observations, $I(0)$—data in levels, SI—Slovenia and t—time series of allowed set T, is as follows:

$$\begin{aligned} CAR_t = \underset{(0.52)}{45.43_{\alpha}} + \underset{(2.71)}{0.12 \cdot GDP_t} - \underset{(-0.77)}{0.38 \cdot UNEMP_t} + \underset{(1.38)}{1.60 \cdot CO_{2,\,t}} + \underset{(0.92)}{0.63 \cdot HICP_t} + \underset{(1.65)}{0.43 \cdot BTP_t} \\ - \underset{(-1.28)}{0.12 \cdot GP_t} + \underset{(0.56)}{0.03 \cdot CA_t} - \underset{(-0.64)}{CO_t} - \underset{(4.02)}{1.00 \cdot GS_t} + \underset{(0.91)}{0.06 \cdot B_t} + \varepsilon_t, \end{aligned} \tag{4}$$

which represents the problems of robust testing and modelling, and ε_t is a normally distributed error term. t statistics are in parenthesis. Therefore, the relatively low F test (13.25) and low results of the deterministic coefficient (0.29) do not necessarily indicate spurious results. Nevertheless, data should be tested first to the order of integration in Table 3. The Durbin–Watson statistic is 0.89, which indicates a high positive autocorrelation.

Table 3. Misspecification tests (January 1997–December 2021, January 1997 = 100).

Variables	ADF with a Constant		KPSS with a Trend		Z-A with a Constant (TB)	
	Levels	$I(0)$	Levels	$I(0)$	Levels	$I(0)$
CAR_t	−2.42	−4.67 ***	0.21 ***	0.02	−6.31 ** (2010M3)	−16.62 *** (2012M12)
GDP_t	0.68	−3.43 ***	4.34 ***	−0.14 **	−2.98 (2009M1)	−5.35 ** (2008M7)
$UNEMP_t$	−1.93	−3.23 ***	0.49 ***	0.12 *	−4.57 (2008M12)	−10.94 *** (2008M10)
$CO_{2\,t}$	−0.04	−14.43 ***	0.03	0.01	−21.28 *** (2015M10)	−12.55 *** (2017M2)
$HICP_t$	−1.97	−2.39 *	1.20 ***	0.10	−3.26 (2013M10)	−11.79 *** (2008M8)
BTP_t	−3.05 **	−17.76 ***	1.09 ***	0.06	−3.22 (2000M12)	−18.50 *** (2013M9)
GP_t	−1.77	−10.48 ***	0.91 ***	0.04	−4.00 (2004M11)	−10.75 *** (2012M10)
CA_t	−2.31	−12.86 ***	1.00 ***	0.07	−7.24 *** (2012M6)	−13.23 *** (2012M5)
CO_t	−1.79	−3.38 ***	0.54 ***	0.02	−5.71 *** (2002M3)	−11.08 *** (2002M4)
GS_t	−0.26	−4.07 ***	0.90 ***	0.04	−4.85 *** (2014M2)	−11.26 *** (2018M1)
B_t	−2.26	−17.23 ***	0.49 ***	0.06	−3.65 (2002M1)	−17.65 *** (2004M2)

Notes: ADF—augmented Dickey–Fuller test, KPSS—Kwiatkowski–Phillips–Schmidt–Shin test, Z-A—Zivot–Andrews test, TB—time break, ***, **, *—1, 5, 10% statistical significance. Sources: SISTAT, NOAA, ESS, CANAS, and authors' compilations.

The regression analysis provides two statistically significant variables that influence or impact CAR. These two are GDP and GS. Therefore, the use of cars throughout the population, supported by OLS, only exists because of the country's transformation from emerging developing to developed. Thus, the first impression is that the policy has not any effort, up to now, towards the zero-emission United Nations and Slovenian goal strategies.

The misspecification test results (Table 3) provide valuable insights into the integration properties of the variables under analysis. The ADF test reveals that all variables exhibit first-order integration, indicating that they follow a trend and are not stationary in levels. However, it is worth noting that the inflation variable (HICP) shows a higher degree of persistence, approaching second-order integration. This finding aligns with the Juselius theory, which suggests that inflation exhibits slower mean reversion. Interestingly, the bus ticket price (BTP) variable displays a different pattern, being stationary in levels. This observation contradicts the theoretical expectations and raises questions about the factors influencing bus ticket pricing. It implies that the bus ticket price does not exhibit a persistent trend over time, which may lead to potential misinterpretations or ineffective policy strategies related to public transportation pricing.

The KPSS test results indicate that almost all researched variables are trend-stationary in differences. While they may exhibit short-term fluctuations and deviations from the mean, they tend to revert to a stable long-term trend over time. The presence of a trend component in the variables suggests that they are influenced by persistent factors that impact their behaviour. While most variables exhibit trend-stationarity in differences according to the KPSS test, there are a few exceptions worth noting. One such exception is CO_2, which shows insignificance in both levels and first-order integration. This suggests that long-term trends or persistent factors may not have strongly influenced CO_2 emissions in the observed period.

On the other hand, variables such as GDP and UNEMP demonstrate marginal significance in first-order integration. This implies that while these variables may have some short-term fluctuations and deviations from their mean values, they still exhibit a degree of persistence or sensitivity to economic conditions. Their marginal significance suggests that changes in GDP and unemployment rates can impact other variables in the analysis, although the strength of these relationships may not be extreme.

Univariate unit root tests with structural breaks have recently become very popular. The Z-A methodology, proposed by Zivot and Andrews, is based on the assumption of an unknown break point in the deterministic trend function. The finding from Table 3 shows that time series have different orders of integration. CAR, CO_2, CA, CO, and GS are stationary at the level when an endogenously determined structural break is included. On the other hand, GDP, UNEMP, HICP, BTP, GP, and B are stationary after converting into the first difference, i.e., $I(1)$ variables. Generally, the combined results of the traditional and structural tests are not identical.

These findings provide insights into the dynamics of the variables and their relationships. The insignificant behaviour of CO_2 emissions in levels and first-order integration suggests that other factors beyond the scope of the analysed variables may significantly influence carbon dioxide levels. Additionally, the marginal significance of GDP and unemployment indicates that these economic indicators can play a role in shaping the behaviour of other variables, albeit to a limited extent.

4.3. Cointegration and VAR Model Results

Considering these ADF, KPSS, and Z-A results, the data vector, where the transformation of variables is integrated and the integration is approved, should be written as follows:

$$ {}^{SI}_{I(i)}[car]^{T}_{t-1} \; {}^{SI}_{I(i)}[gdp\ unemp\ co_2\ hicp\ btp\ gp\ ca\ co\ gs\ b]^{T}_{t-1}, \tag{5} $$

where the lowercase letters signal the real variable, i is a specific order of integration based on Table 3, and $t-1$ is the differentiation of the lagged variable.

Testing the Johansen cointegration on the six ranks of the restricted variable CAR calls for five cointegrated relations (Table 4). The VAR allows us to examine the interrelationships and dynamic interactions among the variables under study. By applying the VAR model to our dataset, we can present the results of this analysis and gain insights into the relationships between the variables. The VAR model provides a comprehensive framework to assess how changes in one variable impact the others over time.

The presence of cointegration indicates a long-term relationship among variables. In the case of the dependent variable CAR, the analysis reveals the existence of six cointegration relations with the observed variables. This suggests that these variables jointly influence the share of cars among residents, highlighting their interconnectedness and the potential for a collective impact on car usage patterns. Understanding and analysing these cointegration relations can provide valuable insights to promote sustainable transportation alternatives and reduce car reliance. Therefore, additional research is now supplied by VAR(2) analysis in Table 5. The Akaike information criterion prose lag is two, which is consistent with the Juselius theory, where the optimal lag is two. The optimum lag was selected based on the VAR model setting, characterised by the absence of autocorrelation, heteroscedasticity, and the distribution of residuals that have tendencies to normal.

Table 4. Johansen cointegration rank test.

Rank	Trace Test	*p*-Value
0	478.86	0.00
1	335.33	0.00
2	231.99	0.00
3	169.51	0.00
4	118.30	0.00
5	71.52	0.04
6	45.78	0.09
7	22.10	0.31
8	7.90	0.49
9	2.82	0.10

Table 5. VAR model restricted on CAR, lag = 2, first cointegration relation.

Time Series	Coefficient	*t*-Value
CAR_{t-1}		
GDP_{t-2}	0.16 *	1.55
$UNEMP_{t-2-}$	3.23 ***	2.56
$CO_{2\ t-2}$	9.08 ***	5.02
$HICP_{t-2}$	3.48 *	1.52
BTP_{t-2}	0.35	0.76
GP_{t-2}	−0.54 ***	−2.18
CA_{t-2}	−0.24	−0.17
CO_{t-2}	−0.16 ***	−2.43
GS_{t-2}	−0.33	−1.39
B_{t-2}	−0.02	−0.15

Note: ***, *—1, 10% statistical significance.

In the first lagged period, there are no significant relations. Therefore, we do not present the results. In Table 4, six cointegration significant relations are presented between the dependent variable CAR and restrictions on GDP, UNEMP, CO_2, HICP, GP, and CO. The results indicate that rising development with increases in GDP and inflation produces higher demand for car usage among residents. In contrast, the same is true when unemployment rises, which is a bit surprising but still connected to previous research with similar findings [49]. On the other hand, sustainability is not an issue among Slovenians. While higher CO_2 produces a boom in car demand, the only declining factors, but at much smaller coefficients, are gasoline prices and commuters. Although there is substantial talk about micromobility, bicycles do not significantly impact car demand among Slovenians. Results indicate that policymakers and managers have much work towards sustainability and a strategy of zero emissions, which is also seen in Figure 3, where dashed lines forecast the prediction.

The Granger cointegrating relationship confirms our findings that GDP positively impacts car ownership and wages. Conversely, unemployment hurts car ownership among Slovenians. The cointegrating relationship is provided below.

$$car_{t-1} = \underset{(0.52)}{1.20_{\alpha}} - \underset{(-1.84)}{0.20 \cdot gdp_{t-1}} + \underset{(1.83)}{2.41 \cdot UNEMP_{t-1}} - \underset{(-1.65)}{0.40 \cdot gs_{t-1}} + \varepsilon_t, \quad (6)$$

t statistics are in parentheses. The Johansen cointegrating relationship is presented in Table 6 when the beta is normalised on the CAR variable for the short and long run.

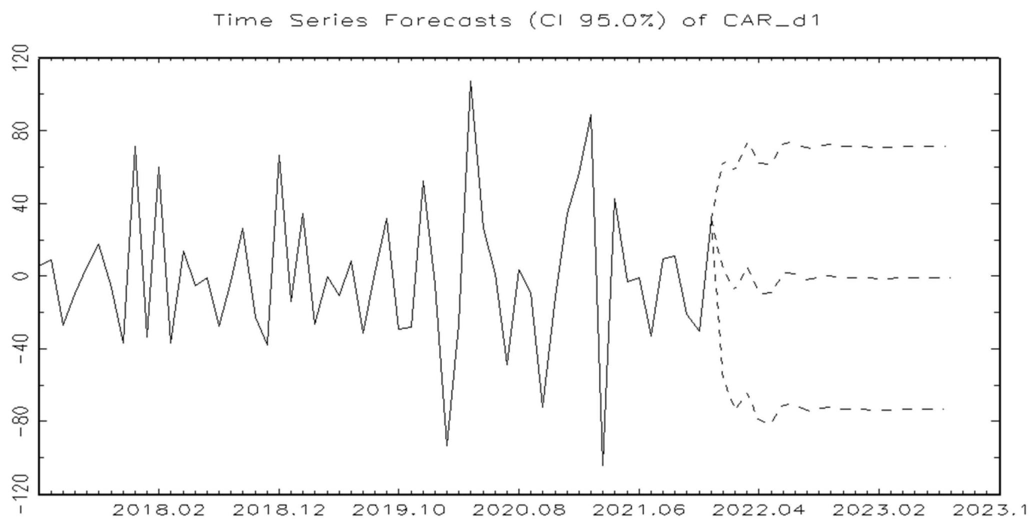

Figure 3. Time series forecast of CAR.

Table 6. Cointegration.

Variable	Short Run	Long Run
car_{t-1}	1.00	−2.53
gdp_{t-1}	−1.39	0.61
$unemp_{t-1}$	−10.06	−0.03
$co_{2\ t}$	−15.29	0.01
$hicp_{t-1}$	−13.65	0.00
btp_{t-1}	−0.88	−0.03
gp_{t-1}	−0.74	−0.04
ca_{t-1}	−2.19	0.01
co_{t-1}	0.05	0.15
gs_{t-1}	23.97	0.10
b_{t-1}	−0.63	0.33

Additionally, Table 7 shows the ARDL test, performed using EViews software. The ARDL (bounds testing approach) model tests the variables' dependence. During the application of ARDL, the connection of variables is tested independently from whether all variables $I(1)$, $I(0)$ or perhaps have different order of integration. The only condition is that the observed time series are not of integration order two or more. This model was developed by Pesaran et al. (2001) [50].

Table 7. ARDL test.

ARDL	Specification Tests				
Estimated model	Optimal lag length	F-statistics	X^2_{ARCH}	X^2_{RAMSEY}	X^2_{SERIAL}
F(CAR/GDP, UNEMP, CO_2, HICP, BTP, GP, CA, CO, GS, B)	3, 0, 4, 4, 0, 1, 0, 0, 4, 1, 0	4.08 *	8.69	0.003	5.44

Note: * Shows significant at 1% level. Critical values are available in the paper by Pesaran et al. (2001) [50], asymptotic n = 1000. Source: Author's calculation.

Determining the optimal size of lag is necessary before the test application since the value F of statistics is very sensitive to the choice of lag. Akaike information criteria for selecting the optimal structure of lags in the model was applied in the research (Pesaran et al. (2001) [50]). The empirical results of the used model are shown in Table 7. Calculated value F of statistics is larger than the upper bound at a test significance of 1% (which means cointegration between variables exists). Specification tests confirm the quality of evaluated model stability of long-term considered connection.

These results support our hypotheses for the study regarding energy consumption systems among car users and the causalities of the selected variables. The accumulated impulse response function (IRF) examines shock effects on CAR. The IRF presents the impact of a simultaneous positive, innovative shock in one variable on present and future values of endogenous indicators (in this case, just CAR). IRF indicates a positive response in CAR due to standard shocks stemming from GDP, UNEMP, and CO_2. GDP, UNEMP, and CO_2 contribute to CAR (Figure 4). On the other hand, Figure 4 indicates a negative response in CAR due to standard shocks stemming from GP and CO. CAR does not react to standard shocks in other observed variables. These results support our hypotheses in this study regarding energy consumption systems among car users.

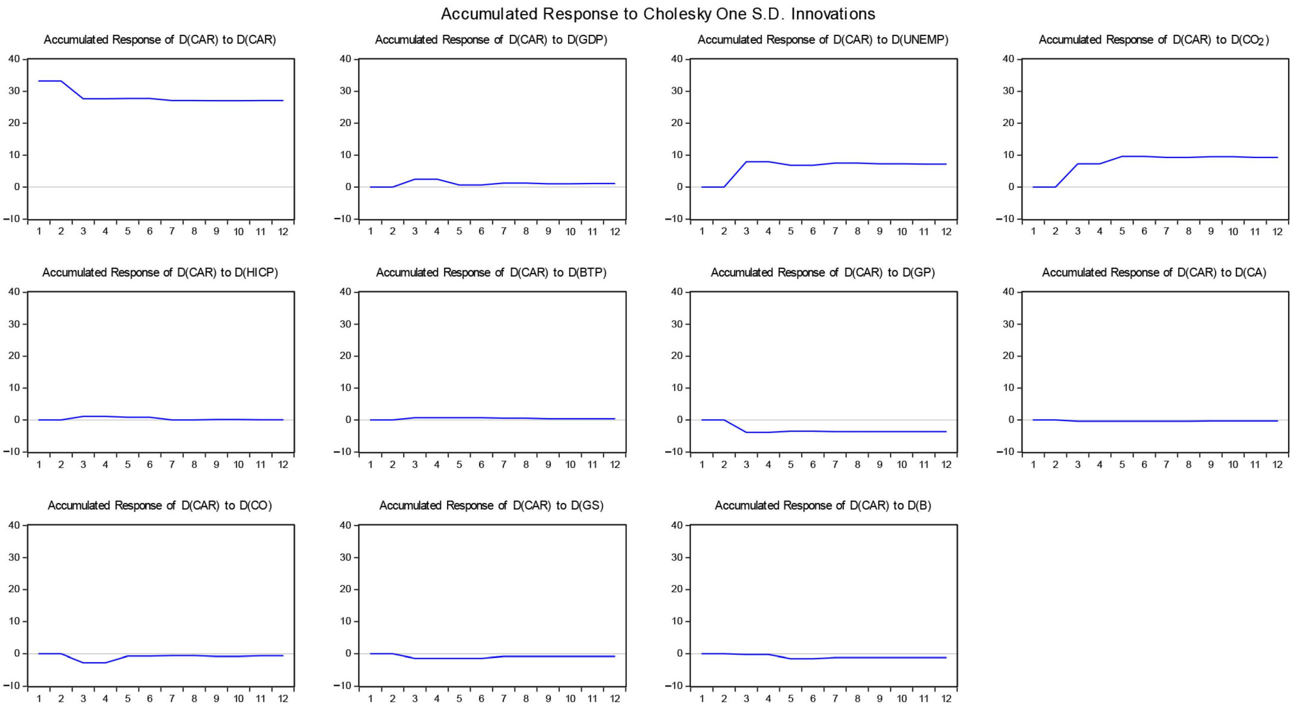

Figure 4. Impulse response function results.

5. Discussion

5.1. Discussion of Previous Research

When analysing previous manuscripts, the research path undertaken in this study encompassed a diverse range of transportation-related topics, contributing to a comprehensive understanding of urban mobility and spare energy consumption transportation systems. The primary goals of the research were to investigate various aspects of transportation behaviour, assess the impact of different variables on commuting patterns, and propose strategies for promoting sustainable modes of transportation. The specific objectives of the previous studies included examining the effects of sociodemographic factors, built environments, and personality traits on the adoption of car-sharing, analysing the relationship between urban characteristics and commuting behaviour, evaluating the role of fringe benefits in encouraging sustainable transport choices, exploring the relationship between gasoline tax rates and commuting time, understanding the factors influencing decisions to commute by bicycle, assessing the life cycle impacts of commuting alternatives, investigating the influence of traffic intensity on commuter cycling rates, and addressing challenges in dealing with massive bike-sharing system data.

The discussions generated from these studies have significant implications for urban planning, transportation policy, and the design of interventions to promote sustainable and efficient transportation systems with more rational energy consumption. The findings support the development of strategies such as car-sharing programs, traffic management measures, infrastructure improvements, and awareness campaigns to encourage sustainable transport modes. Additionally, the research highlights the potential for leveraging data-driven approaches, advanced modelling techniques, and innovative technologies to enhance efficiency, accessibility, and environmental and energy-safe practices in the performance of urban transportation systems.

In conclusion, the collective findings presented in this study contribute to a more comprehensive understanding of urban transportation and offer valuable insights into the complexities of commuting behaviour, the impact of various factors on mode choice, and the potential strategies for promoting sustainable mobility and energy systems. The interdisciplinary nature of the research, combining quantitative analysis, econometric modelling, life-cycle assessments, and spatial analysis, provides a robust foundation for evidence-based decision-making and the development of effective policies and interventions in sustainable transportation and sustainable energy transition.

5.2. Discussion of Recent Research

5.2.1. Summary of Descriptives and OLS

An analysis of Figures 1 and 2 reveals significant findings about the variables under study. The share of cars among residents has not closely aligned with CO in recent years, indicating a challenge for policymakers and companies in finding energy-efficient solutions. HICP and GS have increased, while BTP and UNEMP have decreased. OLS analysis conducted in this study reveals some significant findings regarding the variables' influence on CAR. Despite the relatively low *F*-test value of 13.25 and a deterministic coefficient of 0.29, which may not suggest potential spurious results, it is crucial to examine the data and the order of integration, as shown in Table 3.

Upon further examination, regression analysis identifies two variables significantly impacting CAR: GDP and GS. This implies that the prevalence of car usage in the population is primarily driven by the country's transition from an emerging, developing nation to a developed one [51]. However, it is worth noting that the current policies in place do not appear to align with the global and national strategies aiming for zero-emission transportation [52,53], as advocated by the United Nations and Slovenian strategy [54], but maybe with some exceptions, as noted by Sofuoğlu and Kirikkaleli [55].

In conclusion, summary statistics and OLS results shed light on the characteristics and relationships of the analysed variables. The deviations from normal distribution patterns and the wide range of values observed emphasise the intricate nature of factors influencing the share of cars among residents. These findings underscore the importance of further exploration and modelling [56] to better understand the dynamics of car ownership and develop effective policies and strategies for sustainable transportation in urban areas.

5.2.2. Discussion of the Main Results

The ADF and KPSS tests provide valuable insights into the stationarity properties of the variables under analysis. The ADF test suggests that most variables are integrated in the first order, indicating the presence of trends or persistent factors. However, the KPSS test shows that the variables are stationary in levels, suggesting a different perspective on their behaviour. The bus ticket price (BTP) variable, as determined by the ADF test, shows a distinct pattern compared to other variables. It is stationary in levels, indicating that it does not possess a unit root and exhibits stability over time. Unlike other variables requiring differencing or adjustments to achieve stationarity, BTP does not display a trend or persistent behaviour. If we observe only the Z-A test results, it is evident that variables have a mixed order of integration $I(0)$ or $I(1)$, and no one variable is $I(2)$.

When analysed using the KPSS test, most variables demonstrate stationarity in the first order. However, CO_2 is an exception, showing insignificance in both levels and first-order integration. This suggests that long-term trends or persistent factors may not have strongly influenced CO_2 emissions during the observed period. GDP and UNEMP exhibit marginal significance in first-order integration, indicating a certain degree of persistence or sensitivity to economic conditions.

VAR(2) analysis results reveal exciting insights into the relationships among the variables. No significant relations were found in the first lagged period; thus, those results are not presented. However, Table 4 shows six significant cointegrating relationships between the dependent variable CAR and the restrictions on GDP, UNEMP, CO_2, HICP, GP, and CO. Additionally, the comparison of additional methodologies is presented in Appendix A. The results are compared to a previous study by Pachiyappan et al. [56]. This study explores the link between CO_2 emissions, GDP, energy usage, and population growth in India from 1980 to 2018 using statistical methods. The results of study [57] show a long-term balance between these variables, with Granger causality indicating causal links. Energy usage had a significant impact on future CO_2 emissions. Population growth led to a 1.4% increase in CO_2 emissions, which has important policy implications. On the other hand, observations from the Granger causality analysis in Tables A1–A4 isolate one-way causal relationships between the variables researched, specifically between the number of cars among residents (CAR) and variables such as GDP, UNEMP, BTP, and CO. Furthermore, it was found that gross salaries lead to an increase in the number of cars among residents among almost all lags, exhibiting a reverse causality. The ARLD test also confirms the cointegration relations.

The findings suggest that economic development, as reflected by GDP, wages (GS), and increasing inflation levels (HICP), contributes to higher demand for car usage among Slovenians. This result aligns with previous research showing a positive association between economic growth and car usage. Surprisingly, the results indicate that higher unemployment rates are associated with an increased car demand. This may be counterintuitive but could be attributed to limited public transportation options or to individuals relying on vehicles for job search and commuting.

Regarding sustainability, it is noteworthy that higher carbon dioxide emissions (CO_2) lead to a surge in car demand, indicating a disconnect between environmental concerns and consumer behaviour. Conversely, gasoline prices and the availability of alternative modes of transportation, such as public transport (CO), show a more minor, but still negative, impact on car demand. This highlights the challenges in promoting sustainable mobility and achieving zero-emission goals in Slovenia.

The findings emphasise the need for policymakers and managers to address the sustainability issues associated with car usage. Despite the growing discourse around micromobility and the potential benefits of bicycles, the results indicate that bikes do not significantly impact car demand among Slovenians. This suggests that additional efforts are required to promote cycling as a viable alternative for commuting and reduce reliance on cars.

Predicting future car demand, as depicted in Figure 3 by the dashed lines, further underscores the importance of sustainability strategies and zero-emission targets. The study's motivation lies in exploring the energy consumption patterns among car users and understanding the causalities between the selected variables.

5.2.3. Hypothesis Testing

Based on the results obtained, we can evaluate the hypotheses as follows.

H3. *The integration of macroeconomic, environmental, and energy data revealed significant relationships and patterns that influence daily commuting behaviour in Slovenia. The variables examined, such as GDP, unemployment rate, carbon dioxide emissions, and inflation, exhibited significant positive impacts on the share of cars among residents. These findings indicate that economic factors like GDP and unemployment rate affect car usage patterns. Additionally, carbon dioxide emissions* *were found to have a positive relationship with car demand, suggesting a need for further attention to sustainability in commuting behaviour. On the other hand, gasoline prices and commuters in public transportation provide an incentive negative effect.*

H4. *The results provide valuable insights for policymakers and interventions promoting sustainable commuting practices in Slovenia. While the study did not directly analyse the effectiveness of policies or interventions, the findings highlight the importance of implementing strategies to reduce car usage and facilitate a transition to a more sustainable commuting system. Incentivising public transportation use (measured by commuters (CO)), developing cycling infrastructure and demand (for example, measured by the number of bicycles), and providing commuting allowances (measured by commuting allowances (CA)) for energy-efficient modes of transportation are potential interventions that can contribute to a reduction in the share of cars among residents. These measures align to promote sustainability and reduce emissions in daily commuting.*

However, it is important to note that the study's findings suggest complexities and challenges associated with influencing commuting behaviour. For instance, the limited impact of bicycles on car demand indicates the need for more comprehensive and targeted measures to promote cycling as a viable alternative. Therefore, while the results support the hypothesis that implementing sustainable commuting policies and interventions can contribute to reducing car usage, it is crucial to carefully design and implement such measures to effectively address the specific patterns and factors influencing commuting behaviour in Slovenia.

5.2.4. The Contribution of the Research

This research presented in this compilation of recent empirical studies makes several noteworthy contributions to the existing body of research on commuting patterns and their implications for sustainable transportation. These studies delve into critical aspects of urban mobility, offering insights into micromobility services, promoting bicycle commuting, conducting comprehensive environmental assessments, and addressing traffic management for cycling promotion.

Additionally, Slovenia's unique position as a central European country, with its capital Ljubljana, is indexed in the Copenhagenize index, adding a distinctive dimension to this research. As a European nation, Slovenia is a relevant case study examining commuting patterns in a region that bridges Western and Eastern Europe. Furthermore, Ljubljana's inclusion in the Copenhagenize index highlights its commitment to promoting cycling and sustainable transportation. This index reflects Slovenia's efforts to prioritise bicycle-friendly urban planning and underscores its potential as a model for other cities seeking to enhance sustainable commuting practices. The research findings and Slovenia's inclusion in the Copenhagenize index highlight the importance of adopting a holistic approach to urban transportation planning.

Furthermore, this research's distinctive variable selection and methodological approach constitute a valuable contribution to the fields of economic and environmental science. By introducing the selection of variables from past investigations accompanied by a research path and methodology, this study expands the toolkit available to researchers and policymakers when analysing commuting behaviour and its impacts. These novel approaches offer fresh perspectives and insights, enhancing our ability to comprehend the complex dynamics of transportation choices and their environmental consequences. As such, this research advances our understanding of commuting patterns and fosters sustainability and informed decision-making in urban mobility and environmental management.

6. Conclusions

6.1. Highlights of Study Findings

The study highlights innovation in connecting time series econometrics to understand future commuting patterns and energy consumption while acknowledging the recent lack of success in sustainable commuting. First, descriptive statistics highlight the volatility and variation in the data, indicating the complex nature of the variables under examination. GDP and gross salary change significantly over time, reflecting the country's economic dynamics.

Regression analysis further demonstrates that GDP and gross salary statistically impact the share of cars among residents (CAR). These results suggest that economic factors play a significant role in shaping car ownership and usage patterns. As the economy grows and individuals' salaries increase, there is a corresponding increase in the share of cars among residents.

However, it is crucial to recognise the implications of these findings for sustainable transportation goals and environmental and energy concerns. A heavy reliance on cars for daily commuting raises challenges in terms of carbon emissions and traffic congestion. Policymakers must prioritise alternative transportation modes and invest in infrastructure supporting public transportation, cycling, and walking.

The results of the VAR analysis demonstrated the significant impact of variables such as GDP, unemployment rate, carbon dioxide emissions, and inflation on the share of cars among residents, emphasising the need for targeted policies and interventions to foster sustainable commuting practices in the country. A decline is visible only in gasoline prices and commuters on public transport. Granger causality confirms five bivariate relations for the dependent variable CAR.

In conclusion, the VAR model employed in this study provided valuable insights into the time series patterns and measures taken over the past 25 years (i.e., from 1997 to 2021), highlighting significant steps forward while also revealing substantial opportunities for further improvements in addressing commuting behaviour and promoting sustainable transportation and energy practices in Slovenia, visible in Figure 3.

6.2. Limitations and Delimitations

The limitations of the study are foreseen as follows. First, the study relies on available statistical data, which may have restricted coverage, accuracy, or granularity. The availability of data for specific variables or periods could impact the comprehensiveness and generalisability of the findings. Second, while efforts were made to utilise reliable and accurate data sources, the study is subject to potential data quality issues, such as measurement errors, reporting biases, or inconsistencies. These limitations may introduce uncertainties or preferences in the analysis and subsequent interpretations. Lastly, the econometric analysis and modelling techniques employed in the study involve assumptions and simplifications to make the analysis manageable. These simplifications may not capture all the complexities and nuances of real-world dynamics, potentially limiting the accuracy and completeness of the findings.

The highlighted delimitations underline the other motivation of the research. First, the study focuses explicitly on Slovenia and its commuting patterns. The study's scope is delimited to Slovenia's unique features and circumstances. Second, the study includes specific variables related to the daily commuting and sustainable energy transition. While these variables offer valuable insights, other variables or factors that could potentially influence commuting patterns and sustainable energy transition may not have been considered. Lastly, the adopted quantitative approach is based solely on econometric analysis. The delimitation to a quantitative methodology may have restricted exploring subjective experiences, attitudes, or behavioural factors that could influence commuting choices.

Overall, this research faces some long-term limitations due to the limited number of innovative ideas implemented in architectural design and sustainable urban planning. This may make it challenging to forecast future trends based on historical data alone, especially given the rapid pace of technological changes. While our study employs a rigorous quantitative methodology that provides a comprehensive analytical framework, it primarily focuses on quantitative research. However, a limitation of our current approach is that it lacks qualitative research with significant scientific implications. On the one hand, the absence of qualitative research limits our ability to capture the nuanced, context-specific factors that influence commuting patterns and sustainable transportation decisions. Qualitative research can delve into the "human" aspect of these decisions, shedding light on the underlying motivations, perceptions, and cultural factors that quantitative data alone may not fully elucidate.

On the other hand, the absence of qualitative research highlights the need for future investigations that combine quantitative and qualitative methodologies. By complementing our quantitative findings with qualitative research, we can gain a more comprehensive and nuanced understanding of commuting patterns. This approach can bridge the gap between data-driven analysis, the lived experiences of commuters, and the transformative impact of evolving technologies. Such a fusion of techniques presents an exciting avenue for future research and can contribute significantly to our knowledge of sustainable transportation, urban planning, and the integration of emerging technologies.

6.3. Policy and Managerial Implications

This study shows the importance of implementing policies and initiatives for sustainable commuting and energy-saving practices. Policymakers can consider introducing or enhancing commuting allowances that prioritise energy-efficient modes of transportation, such as public transit, cycling, carpooling, bicycles, and e-scooters. Governments and employers can enable individuals to opt for ecologically and energy-friendly transportation options by offering financial incentives and subsidies tailored to promote sustainable commuting.

Moreover, this study underscores the need for integrated transportation planning that considers the interplay between macroeconomic factors, energy consumption, and commuting patterns. Policymakers should strive to develop comprehensive strategies that address transportation infrastructure development and sustainability goals. This can involve investments in public transportation systems, establishing cycling-friendly infrastructure, and implementing measures that reduce the reliance on private vehicles, such as congestion pricing or car-sharing programs. This would also be in line with the decrease in GHG emissions.

Third, employers have a crucial role in promoting sustainable commuting practices. By offering flexible work arrangements, such as telecommuting or flexible work hours, employers can reduce the need for daily commuting and alleviate traffic congestion. Additionally, employers can actively support and promote sustainable transportation options by providing incentives for public transit use, offering bicycle facilities and storage, and partnering with ridesharing platforms to facilitate carpooling among employees.

Nevertheless, increasing awareness and understanding of the environmental, energy-saving and health benefits of sustainable commuting is essential. Government agencies and organisations can collaborate to develop education and awareness campaigns highlighting the advantages of energy-conserving transportation and providing practical tips and resources for individuals to make sustainable commuting choices. These initiatives include promoting public transit, organising cycling events, and disseminating information on carpooling and ridesharing options.

Lastly, regular monitoring and evaluation of commuting patterns, energy consumption, and the effectiveness of implemented policies are crucial for evidence-based decision-making. Governments and relevant stakeholders should establish mechanisms (for example, CO_2 mapping) to collect and analyse data on commuting behaviours, energy usage, and the impact of policy interventions. This data-driven approach will enable policymakers and managers to assess the effectiveness of implemented measures, identify areas for improvement, and make informed decisions to enhance sustainable commuting practices further. It is advisable to consider implementing measures after completing the given task. For instance, service- and knowledge-based employers could introduce flexible work hours or allow employees to work from home.

Additionally, designing a workplace that is bicycle- and pedestrian-friendly, complete with showers, wardrobes, and other amenities, would be helpful. Other measures that could be considered include tax deductions for environmentally friendly commuters, speed limits on all streets and roads to provide slower vehicles with more space and reduce accident risks, and building bicycle garages, rest stations, and pump stations with washing facilities. Not only should these be considered as policy implications, but they should also be taken into consideration as managerial implications in companies.

Urban planners and policymakers are advised to prioritise sustainable transportation options by revamping urban landscapes as part of their policy initiatives. This could limit car access in specific areas while enhancing infrastructure and accessibility for pedestrians, cyclists, and public transport users. Promoting the development of mixed-use urban zones that minimise the necessity for lengthy commutes and encourage active transportation is crucial. Additionally, exploring the potential for transitioning from dual carriageways to multifunctional transportation corridors could improve urban mobility and curtail the environmental consequences of car-dominated commuting. This shift towards urban planning that prioritises alternative transportation would promote sustainability and result in shorter daily commutes.

6.4. Proposals for Future Research

Future research directions are way brighter than one could think because most countries are stepping forward to zero-emissions policies. Therefore, the ideas are first, longitudinal analysis over an extended period; second, behavioural analysis of qualitative research methods; third, economic analysis of costs and benefits associated with different commuting and energy modes; fourth, a comparative study with other countries or regions; and lastly, an investigation of the potential of emerging technologies as innovations of transport and energy modes [58]. Due to data unavailability during the observed period, the analysis did not include the number of micro-, smart, and innovative vehicles. However, future research incorporating these variables could provide a more comprehensive understanding of their influence on car ownership and energy consumption patterns and contribute to a more robust model. By pursuing these future research directions, scholars can contribute to a deeper understanding of commuting dynamics, sustainable energy transition, and the effectiveness of policy interventions. The findings of such research can inform evidence-based decision-making, facilitate the development of more targeted and practical strategies, and ultimately contribute to a more sustainable and energy-efficient computing landscape.

As technology and transportation continue to advance, there is significant potential for future research in various areas. Many countries are committed to achieving zero emissions, which presents opportunities for exploration. We can gain insights into behavioural aspects by analysing long-term trends and employing qualitative research methods. Economic analyses can also help inform policy decisions by examining the costs and benefits of different commuting and energy modes. Comparative studies with other countries or regions can also provide valuable cross-cultural perspectives. Another exciting area for future research is exploring emerging technologies such as transport and energy innovations. The current analysis did not include data on micro-, intelligent, and innovative vehicles due to their unavailability during the observed period. However, including these variables in future research can provide a more comprehensive picture of their impact on car ownership and energy consumption patterns. This investigation will help scholars develop a more robust and holistic model, enhancing our understanding of the dynamics between commuting, the sustainable energy transition, and the effectiveness of policy interventions.

To enhance urban transportation, upcoming studies could investigate inventive urban planning techniques. A possible approach is to assess the consequences of shutting down streets for vehicular traffic and instead allocating them for dedicated lanes for eco-friendly modes of commuting, like biking or electric scooters, alongside efficient public transit systems. Another option is to analyse the impacts of transforming current dual carriageways, where one lane is reserved for cars and the other for alternative transportation modes. These explorations can offer valuable insights into the practicality and efficacy of decreasing car reliance and encouraging sustainable transportation.

The extended Granger causality approach, as presented in Tables A1–A4 in Appendix A, offers an opportunity to gain further insights into the direction of causalities of the variables under investigation. Therefore, conducting a comprehensive study of this approach is recommended to extract crucial facts about the causal relationships among the rest of the studied variables.

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Appendix A

Table A1. Results of pairwise Granger causality for the dependent variable, lag = 12.

Direction of Causality Variables $I(1)$		F-Statistics	Existence of Causality [A]	Existence of Return Causality
$CAR_t \rightarrow$	GDP_t	2.14 ***	Yes	No
	$UNEMP_t$	2.54 ***	Yes	No
	$CO_{2\,t}$	1.08	No	No
	$HICP_t$	0.99	No	No
	BTP_t	1.46 *	Partially (marginally significant)	No
	GP_t	1.11	No	No
	CA_t	0.93	No	No
	CO_t	3.58 ***	Yes	No
	GS_t	1.38	No	Yes
	B_t	0.39	No	No

Note: [A]—In each case, the null hypothesis is that the dependent variable (CAR) does not (Granger) cause the independent variable and vice versa (return causality); $I(1)$—first order of integration; CAR—cars/residents; GDP—gross domestic product, UNEMP—unemployment, CO_2—carbon dioxide, HICP—inflation; BTP—bus ticket price, GP—gasoline prices, CA—comm. allowance, CO—commuters; GS—gross salary, B—no. of bicycles; ***, *—1, 10% statistical significance; $\rightarrow$—direction of causality.

Table A2. Results of pairwise Granger causality dependent variables 1, lag = 12.

Direction of Causality Variables $I(1)$		F-Statistics	Existence of Causality [A]
$GDP_t \rightarrow$	CAR_t	1.39	No
	$UNEMP_t$	1.06	No
	$CO_{2\ t}$	1.28	No
	$HICP_t$	0.38	No
	BTP_t	2.01 **	Yes
	GP_t	0.68	No
	CA_t	1.53 *	Partially (marginally significant)
	CO_t	1.11	No
	GS_t	2.62 ***	Yes
	B_t	0.59	No
$UNEMP_t \rightarrow$	CAR_t	1.33	No
	GDP_t	2.73 ***	Yes
	$CO_{2\ t}$	1.07	No
	$HICP_t$	1.13	No
	BTP_t	1.91 **	Yes
	GP_t	0.74	No
	CA_t	1.53 *	Partially (marginally significant)
	CO_t	1.25	No
	GS_t	1.24	No
	B_t	0.43	No
$CO_{2\ t} \rightarrow$	CAR_t	1.53	No
	GDP_t	1.11	No
	$UNEMP_t$	2.08 ***	Yes
	$HICP_t$	1.69 **	Yes
	BTP_t	1.84 **	Yes
	GP_t	1.00	No
	CA_t	2.46 **	Yes
	CO_t	2.26 ***	Yes
	GS_t	1.50 *	Partially (marginally significant)
	B_t	1.51 *	Partially (marginally significant)
$HICP_t \rightarrow$	CAR_t	0.70	No
	GDP_t	1.26	No
	$UNEMP_t$	2.34 ***	Yes
	$CO_{2\ t}$	0.76	No
	BTP_t	1.66 *	Yes
	GP_t	1.18	No
	CA_t	1.26	No
	CO_t	0.80	No
	GS_t	1.53 *	Partially (marginally significant)
	B_t	1.24	No

Note: [A]—In each case, the null hypothesis is that the dependent variable does not (Granger) cause the independent variable; $I(1)$—first order of integration; CAR—cars/residents; GDP—gross domestic product, UNEMP—unemployment, CO_2—carbon dioxide, HICP—inflation; BTP—bus ticket price, GP—gasoline prices, CA—comm. allowance, CO—commuters; GS—gross salary, B—no. of bicycles; ***, **, *—1, 5, 10% statistical significance; $\rightarrow$—direction of causality.

Table A3. Results of pairwise Granger causality dependent variables 2, lag = 12.

Direction of Causality Variables $I(1)$		F-Statistics	Existence of Causality [A]
$BTP_t \rightarrow$	CAR_t	0.57	No
	GDP_t	0.45	No
	$UNEMP_t$	1.20	No
	$CO_{2\,t}$	0.92	No
	$HICP_t$	0.26	No
	GP_t	0.59	No
	CA_t	1.15	No
	CO_t	1.71 **	Yes
	GS_t	0.65	No
	B_t	0.88	No
$GP_t \rightarrow$	CAR_t	0.85	No
	GDP_t	2.20 ***	Yes
	$UNEMP_t$	0.99	No
	$CO_{2\,t}$	0.76	No
	$HICP_t$	0.79	No
	BTP_t	1.92 **	Yes
	CA_t	1.74 **	Yes
	CO_t	0.91	No
	GS_t	1.19	No
	B_t	1.00	No
$CA_t \rightarrow$	CAR_t	0.86	No
	GDP_t	0.87	No
	$UNEMP_t$	1.77 **	Yes
	$CO_{2\,t}$	0.38	No
	$HICP_t$	0.66	No
	BTP_t	9.20	Yes
	GP_t	1.11	No
	CO_t	0.81	No
	GS_t	0.80	No
	B_t	0.53	No
$CO_t \rightarrow$	CAR_t	1.57	No
	GDP_t	1.66 **	Yes
	$UNEMP_t$	2.36 ***	Yes
	$CO_{2\,t}$	0.59	No
	$HICP_t$	0.93	No
	BTP_t	1.18	No
	GP_t	0.88	No
	CA_t	0.85	No
	GS_t	1.75 **	Yes
	B_t	1.12	No

Note: [A]—In each case, the null hypothesis is that the dependent variable does not (Granger) cause the independent variable; $I(1)$—first order of integration; CAR—cars/residents; GDP—gross domestic product, UNEMP—unemployment, CO_2—carbon dioxide, HICP—inflation; BTP—bus ticket price, GP—gasoline prices, CA—comm. allowance, CO—commuters; GS—gross salary, B—no. of bicycles; ***, **—1, 5% statistical significance; $\rightarrow$—direction of causality.

Table A4. Results of pairwise Granger causality dependent variables 3, lag = 12.

Direction of Causality Variables $I(1)$		F-Statistics	Existence of Causality [A]
$GS_t \rightarrow$	CAR_t	1.79 **	Yes
	GDP_t	7.92 ***	Yes
	$UNEMP_t$	3.42 ***	Yes
	$CO_{2\ t}$	0.81	No
	$HICP_t$	2.49 ***	Yes
	BTP_t	1.37	No
	GP_t	2.74 ***	Yes
	CA_t	0.51	No
	CO_t	3.24	Yes
	B_t	0.42	No
$B_t \rightarrow$	CAR_t	0.56	No
	GDP_t	0.99	No
	$UNEMP_t$	1.91 **	Yes
	$CO_{2\ t}$	0.54	No
	$HICP_t$	0.66	No
	BTP_t	0.84	No
	GP_t	0.80	No
	CA_t	0.97	No
	CO_t	0.72	No
	GS_t	0.36	No

Note: [A]—In each case, the null hypothesis is that the dependent variable does not (Granger) cause the independent variable; $I(1)$—first order of integration; CAR—cars/residents; GDP—gross domestic product, UNEMP—unemployment, CO_2—carbon dioxide, HICP—inflation; BTP—bus ticket price, GP—gasoline prices, CA—comm. allowance, CO—commuters; GS—gross salary, B—no. of bicycles; ***, **—1, 5% statistical significance; →—direction of causality.

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