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Bicycle Transport Infrastructure and the Challenge of Decarbonizing Road Transport in Polish Urban Centers

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Abstract:

Purpose: *The main objective of the study is to analyze whether bicycle transport within urban logistics could be one of the elements in response to the challenges associated with road transport decarbonization in the future.*
Design/Methodology/Approach: *The data sources used (CSO, bank of local data, CPB platform) allowed us to apply an analysis of the structure and dynamics of phenomena related to the development and condition of road infrastructure for bicycles in urban centers in Poland. In addition, an analysis and comparison of spatial needs for automobile and bicycle transportation in urban conditions was carried out, as well as a SWOT analysis for bicycle traffic.*
Findings: *ITF simulations have shown that, in the context of urban transport, it's already possible to achieve a reduction of CO2 and other pollutants, and thus realize the objectives related to decarbonization of road transport. Bicycles play a very important role in this context. By nature, they are environmentally friendly and emission-free (noise, pollution), thus, they seem to be an ideal response to the challenges associated with urban transportation in the face of decarbonization challenges.*
Practical Implications: *The problem is issues related to the transformational reorganization of transport networks in cities. Poland's large cities have some advantages over smaller cities in this regard. A partial bicycle infrastructure already exists in large urban centers. In large urban centers, there's already partial bicycle infrastructure, which can serve as an excel-lent skeleton for further expansion and the future transportation network of the city. To achieve decarbonization objectives means that vehicles should be eco-friendly and utilized as efficiently as possible – which from today's perspective means services like sharing platforms or taxi services.*
Originality/Value: *The conducted SWOT analysis for bicycles as a means of transportation in the city on a larger scale reveals that strengths outweigh weaknesses, while opportunities and threats are almost balanced. This argues for the creation of car-free zones in cities and zones with restricted motor vehicle traffic. Bicycle transportation has a large potential for utilization in the urban environment, mainly deriving from the inherent strengths of bicycles as a means of transport. However, external conditions pose a challenge.*

Keywords: *Decarbonization, road transport, bicycle transport, emission-free.*
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1. Introduction

In the face of escalating challenges associated with climate change, decarbonization of the transportation sector becomes a key element of global and local mitigation strategies (Lamb and Steinberger, 2017). Road transport, being a significant source of greenhouse gas emissions, is one of the areas where sustainable solutions can significantly contribute to emission reduction (Pyra, 2023). In this context, bicycle transportation as a form of low-emission mobility, gains importance, offering an alternative to traditional road transportation means (Oskarbski, Birr, and Żarski, 2021).

The development of bicycle transportation infrastructure is a key element of promoting sustainable urban mobility (Heinen, van Wee, and Maat, 2010). In Poland, investments in bicycle infrastructure, such as bike paths, bike racks, and bicycle repair stations, are gaining importance, as components of the transportation system promoting public health, sustainable development, and greenhouse gas emission reduction.

An analysis of bicycle infrastructure development in major urban centers in Poland, like Warsaw, Krakow, or Wroclaw, provides valuable information about the current state and future directions of bicycle transportation in an urban context.

Bicycle transportation, with its low emission level, can significantly contribute to the decarbonization of urban transport (Yao, Zhang, Tian, Zhou, and Li, 2019). Wang. Analysis of this potential in the context of Polish urban agglomerations provides essential data that can support local initiatives for sustainable mobility.

The evaluation of strengths and weaknesses, opportunities, and threats associated with the development of bicycle transportation in Poland, in the context of road transport decarbonization, provides a holistic view of challenges and possibilities facing Polish cities in striving to reduce greenhouse gas emissions in the transport sector.

Considering the above aspects, this article aims to research whether bicycle transport within urban logistics could be one of the elements in response to the challenges associated with road transport decarbonization in the future. The author posited the following hypotheses:

H1: It is possible to determine the theoretical degree of replacing personal car transport with personal bicycle transport in urban conditions, considering spatial constraints (availability of space designated for communication routes and accompanying elements) in heavily urbanized urban areas.

H2: The investment activity of urban centers related to the development of bicycle infrastructure over the last 10 years has increased, contributing to noticeable development of this infrastructure.

H3: Currently realized investments associated with bicycle infrastructure, particularly the development of road infrastructure for bicycles within urban centers in the country, are not satisfactory.

H4: Bicycle transport within large urban centers, given proper and adequately developed infrastructure, can provide an attractive alternative to personal road transport and public transport. Thus, it has the potential to become a significant element in response to the challenges associated with road transport decarbonization, in the context of urban logistics.

The article analyzes the significance of bicycle transportation infrastructure in the context of road transport decarbonization in Polish urban centers. This analysis aims to provide knowledge that will support local initiatives associated with promoting sustainable urban mobility and reducing greenhouse gas emissions in the transport sector.

2. Materials and Methods

The study utilized data from various sources. Among the most important are data from public statistics, specifically from the Central Statistical Office of the Republic of Poland (CSO) - the official and central statistical institution in Poland characterized by the reliability and objectivity of the presented data. CSO is responsible for collecting, analyzing, and publishing statistics concerning the broadly understood social and economic activity of the country.

Data from the Local Data Bank (BDL), which is one of the basic tools provided by CSO, was utilized. It allows access to statistical data at various territorial levels of the country. This tool is an important source of information for researchers, analysts, and all interested in the specificity and diversity of socio-economic processes on the territory of Poland.

The next source comprised official domestic and foreign documents. The European Cyclist's Federation provides valuable resources and data that can be utilized by scientists, urban planners, and political decision-makers. They concern bicycle mobility, the impact of cycling on the environment, and the quality and availability of bicycle infrastructure in different regions.

An essential source was the platform Corporate Partnership Board of the International Transport Forum which gathers enterprises from various transport sectors and related sectors, wanting to cooperate with political decision-makers to find solutions for transport challenges. Materials available on it focus on the issue of street space in cities, which is a scarce resource.

The above-mentioned data sources allowed for the application of the analysis of structure and dynamics of phenomena associated with the development and state of road infrastructure for bicycles in urban centers in Poland. Additionally, an analysis and comparison of spatial needs for car and bicycle transport in urban conditions (selected methodology) were conducted, as well as a SWOT analysis for bicycle movement as a way to carry out transportation tasks within urban agglomerations.

3. Results

3.1 Bicycle Road Infrastructure in the Country

The bicycle infrastructure present in the country falls into one of the main categories - transport routes or recreational tourist routes or mixed. This classification is utilitarian in nature and is simple and clear in practical application, as reflected in official documents or other public administration documents (Brzeziński, Jesionkiewicz-Niedzińska, Rezwow-Mosakowska, and Włodarek, 2022).

Simultaneously, there exists a functional-technical classification, which distinguishes three main categories of bicycle roads, as presented in Table 1.

Table 1. *Functional-technical classification of bicycle roads in the country.*

Category	*Description*	*Notes*
Bike Highways (V), Projected V = 40 km/h	They serve as so-called bicycle highways. They are designed primarily as roads for bicycles, with occasional bicycle lanes on priority roads; they should characterize the highest functional-technical standard.	On bike highways, it is recommended to have non-collision crossings over roads with a permissible speed of more than 30 km/h. In the case of crossings over roads with a permissible speed of no more than 30 km/h, raised crossings are allowed.
Primary Routes (P), Projected V = 30 km/h	They create the most important connections within a given area and between areas. They are an element of the basic skeleton of the transport system in a given area, ensuring connections between localities, access to major traffic generators and public transport nodes, as well as servicing attractive tourist spots; they should characterize a high functional-technical standard.	Within cities, they constitute major inter-district connections, important intra-district connections, and service major traffic generators (areas of work, service, school/higher education concentration, residential concentration areas, public transport nodes, healthcare facilities, sports, culture, and recreation areas).
Supplementary Routes (U),	These are all other bicycle routes, intended for short trips, commutes	The function of supplementary routes is to complement the

Projected V = 20-30 km/h	to less significant public transport nodes, and other intra-district routes.	network of primary routes and distribute bicycle traffic within smaller areas (e.g., districts and neighborhoods in the city) as well as to increase the cohesion and range of influence of the entire network of bicycle routes.

***Source:** Own elaboration based on 22. Brzeziński, A.; Jesionkiewicz-Niedzińska, K.; Rezwow-Mosakowska, M.; Włodarek, P. Wytyczne projektowania infrastruktury dla rowerów. Część 1: Planowanie tras dla rowerów. WR-D-42-1 ver. 1.0, Ministerstwo Infrastruktury, Warszawa 2022.*

The cited classification (Dąbrowska-Loranc, Cielecki, Jasiński, Skoczyński, Zalewski, and Zielińska, 2019) is mainly applicable at the stage of designing bicycle road infrastructure, as to date it does not find reflection in the CSO public statistics. CSO data regarding the length of bicycle roads are available on a general level and with a division into provinces and manager (not city size).

Thus, they reflect the general state and changes of the phenomenon, not allowing, however, for conducting analyses using the above classification. It can, however, be assumed that roads under the management of the Marshal's Office are veloroutes and primary roads.

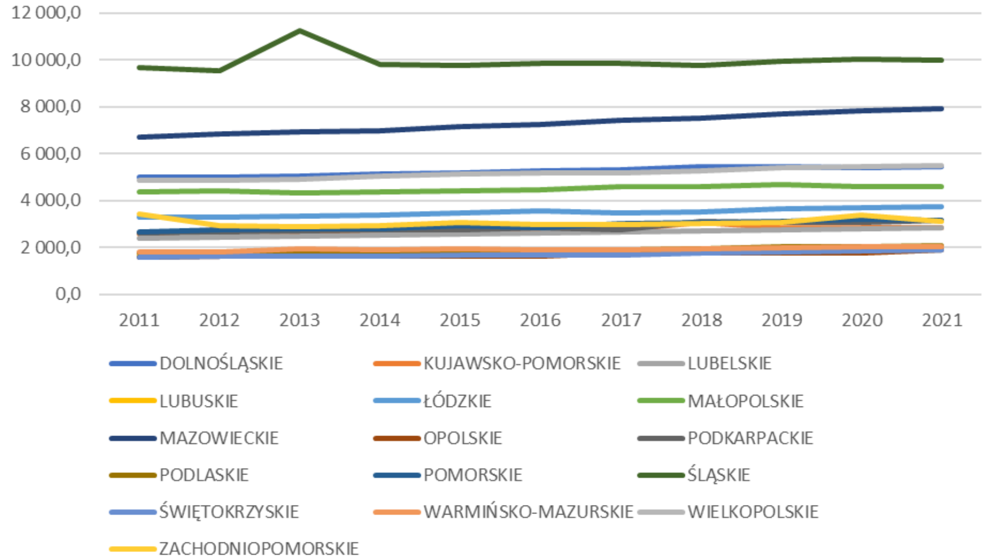
Roads in the administration of county offices will be treated as primary and supplementary routes. All these roads in the analysis are treated as urban roads. Firstly, however, the context for analyzing this data should be presented.

Since the study focuses on the urban environment, the context for analyzing the length of bicycle roads will be the length of hardened urban roads. The data also come from official CSO statistics. Figure 1 presents data concerning the length of hardened roads classified as urban in each of the 16 provinces in 2011-2021.

Their cumulative length in 2011 throughout Poland was 55,985.9 km, and in 2021 it was 62,321.3 km. Over the 11-year period of analysis, the length of hardened roads in cities throughout Poland increased by 11.3%. A record increase in this regard was recorded in the Świętokrzyskie (20.6%), as well as in the Podkarpackie (20.3%) and Opolskie (19.7%). Only in the Zachodniopomorskie was a decrease recorded at -8.4%.

In the analyzed period not all provinces carried out investments that contributed to the increase in the length of such roads. Some of them did not carry out renovations allowing for the maintenance of the existing length of roads, which in the Zachodniopomorskie could not be made up for. Thus, in the Śląskie, for 6 years between 2012-2021, the length of hardened roads in cities was decreasing year on year.

Figure 1. *Total length of hard urban roads in Poland from 2011-2021.*



Source: *Own elaboration based on https://bdl.stat.gov.pl/*

A similar situation occurred in the Zachodniopomorskie (5 years), Opolskie (4 years), and Kujawsko-Pomorskie (5 years). In the remaining provinces, a decrease in the length of hardened roads in cities did not occur more than 3 times over 11 years. Whereas in the Lubelskie, Mazowieckie, and Świętokrzyskie, in no year covered by the analysis, did the length of hardened roads in cities decrease. This shows how large the differentiation between provinces is in terms of road investments carried out in cities.

The last element that is worth presenting to build the appropriate background for analyzing data concerning bicycle roads is indicating what percentage of all hardened roads in Poland are represented by the above-described hardened roads in cities (Table 2).

Firstly, it should be noticed that in the period covered by the analysis, despite the increase in the total length of the described type of roads by 11.3% (2011/2021), their share in the total sum of all hardened roads in Poland dropped from the level of 20% (in 2011) to 19.8% (in 2021). This means that more roads are being created outside cities, and certainly, the dynamics of their increase are larger.

Secondly, this comparison shows how very diversified the situation in the provinces is. The largest share of urban hardened roads in 2021 is in the Śląskie – 45.6%, and comparing this to the relationship from 2011 (share 43.7%), it dropped only by 0.1%. In second place is the Dolnośląskie with a share of 25.4% and a drop by 1.1% (comparison to the share from 2011).

Table 2. *Share of the length of hard urban roads in the total length of hard roads from 2011-2021 (%).*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	20,0	20,0	20,4	20,0	20,0	19,9	19,8	19,9	20,0	19,8	19,8
DOLNO-ŚLĄSKIE	26,5	26,5	26,9	26,8	26,7	27,0	27,0	26,9	26,5	25,4	25,4
KUJAWSKO-POMORSKIE	15,9	16,8	16,1	16,2	15,5	15,4	15,1	16,4	14,9	14,9	14,7
LUBELSKIE	11,3	11,9	11,8	11,7	11,9	11,9	11,9	11,5	12,0	11,7	11,8
LUBUSKIE	19,6	19,8	20,2	21,0	21,0	21,0	21,3	21,3	21,2	19,8	21,5
ŁÓDZKIE	16,7	17,2	17,3	17,0	17,2	17,4	16,8	17,0	17,5	17,4	17,4
MAŁO-POLSKIE	18,2	18,2	17,9	17,9	17,9	18,0	17,8	17,8	17,8	17,6	17,5
MAZO-WIECKIE	19,4	19,5	19,7	19,5	19,6	19,6	19,5	19,5	19,7	19,6	19,5
OPOLSKIE	18,7	19,0	19,0	19,3	19,5	19,3	20,9	21,0	20,8	20,6	21,7
PODKARPAC-KIE	17,2	17,0	17,1	17,1	16,9	17,0	16,5	18,4	17,7	17,3	17,7
PODLASKIE	14,3	14,4	14,6	14,5	14,3	14,1	14,4	14,5	14,8	14,5	14,5
POMORSKIE	21,6	22,0	21,7	21,6	22,0	21,2	21,8	21,5	21,6	21,2	20,7
ŚLĄSKIE	43,7	44,7	48,6	45,0	45,2	45,4	45,2	44,9	45,2	44,7	45,6
ŚWIĘTO-KRZYSKIE	11,9	11,9	12,0	11,9	11,7	11,6	11,7	12,0	12,3	12,6	13,0
WARMIŃSKO-MAZURSKIE	14,0	14,2	14,9	14,6	14,6	14,3	14,2	14,0	14,2	14,3	14,3
WIELKO-POLSKIE	18,0	17,8	17,7	18,1	18,0	18,0	17,6	17,7	17,9	17,7	17,7
ZACHODNIO-POMORSKIE	25,2	21,5	21,2	21,3	22,0	21,4	21,2	21,7	22,0	23,5	22,0

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

In third place was the Zachodniopomorskie with a share of 22% and a decline of 3.2% compared to the share in 2011. The worst result was obtained by the Lubelskie with a share of 11.8%, which still increased compared to the share in 2011 – 11.3%. Analysis of Table 2 also shows that the voivodeships in the top 3 and the three at the bottom of the list remain unchanged.

Essentially, this is not surprising, as it is a consequence of the degree of urbanization and population density in the given voivodeships. It is therefore a derivative of their characteristics and level of development. A justified question arises as to whether an analogous hierarchy, or rather its repetition, will be observed in the context of bicycle paths.

From the perspective of the total length of bicycle paths in Poland, there was a significant increase between 2011-2021. In 2011, there were 5,782.80 km of bicycle paths throughout Poland. Whereas, 10 years later, the length increased to 18,509.9 km – this is 320.1% more than in 2011. Nominal value indicates more than a twofold increase in the total length of bicycle paths in the country. This very satisfying dynamics at the national level signifies the development of bicycle infrastructure.

At the voivodeship level, the situation is diverse, yet very satisfying. The largest nominal increase in the length of bicycle paths in a voivodeship can be observed in voivodeships which had the longest bicycle infrastructure in 2021:

• Mazowieckie – infrastructure length in 2021 – 2,709.8 km, nominal increase compared to 2011 – 1,954 km; increase in bicycle path length over the last 10 years – 2.58 times;
• Wielkopolskie – infrastructure length in 2021 – 2,338.7 km, nominal increase compared to 2011 – 1,644.4 km; increase in bicycle path length over the last 10 years – 2.36 times;
• Pomorskie – infrastructure length in 2021 – 1,549.9 km, nominal increase compared to 2011 – 1,055.2 km; increase in bicycle path length over the last 10 years – 2.13 times.

The remaining voivodeships also recorded an increase in the length of bicycle infrastructure, and at least a doubling of its length is observed in 11 out of all 16 voivodeships. The largest nominal increase in terms of the difference between the value in 2021 and the value in 2011 occurred in the Lubelskie – 3.35. The nominal increase amounted to 847 km, and the final total length of bicycle paths amounted to 1,099.3 km (details in Table 3).

Table 3. *Total bicycle roads in Poland from 2011-2021.*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	20,0	20,0	20,4	20,0	20,0	19,9	19,8	19,9	20,0	19,8	19,8
DOLNO-ŚLĄSKIE	509,1	588,7	607,2	779,6	805,9	694	751,7	894,8	1 012,40	1 119,20	1 082,50
KUJAWSKO-POMORSKIE	453,6	499,2	573,8	771,3	904,2	933,1	956,3	1 052,10	1 123,90	1 218,90	1 381,90
LUBELSKIE	252,3	285,2	350,7	425,4	563,3	636,1	682,8	762	912,5	1 031,00	1 099,30
LUBUSKIE	260,9	369,3	406,6	463,7	523,9	521,2	576,7	599,1	643,3	713,6	744,2
ŁÓDZKIE	287,4	375	471,9	543,8	591,8	639,5	728,5	769,2	868,5	945,9	1 044,60
MAŁO-POLSKIE	193,3	249,2	279,8	319,8	370,6	409,3	496	541,8	636,7	772,1	837,2
MAZO-WIECKIE	755,8	875,4	912,6	1 108,30	1 279,10	1 408,40	1 561,10	1 995,60	2 342,10	2 565,80	2 709,80

OPOLSKIE	251,5	296	251,4	282,2	306,3	310,2	330,5	418,2	511	556,8	582,3
PODKAR-PACKIE	186,5	319,2	281,1	369,3	577,2	533,1	591,1	615,9	644,6	675,5	719,3
PODLASKIE	179,9	225,2	224,8	326,9	453,8	465,1	517,4	576,8	629,7	731,9	786,9
POMORSKIE	494,7	602,7	790,5	987,3	1 050,50	1 103,70	1 161,90	1 243,20	1 347,60	1 479,30	1 549,90
ŚLĄSKIE	560	624,7	598	648,7	725,3	783,7	824,1	933,7	1 047,60	1 194,90	1 368,90
ŚWIĘTO-KRZYSKIE	97,5	105,6	137,6	161,8	216,2	230,2	239,7	276,1	324	392,8	418,8
WARMIŃSKO-MAZURSKIE	212,3	251	272,6	379	481,8	508	500,9	553,9	634,2	677,4	743,6
WIELKO-POLSKIE	694,3	819,5	1 031,80	1 160,20	1 268,90	1 350,00	1 464,20	1 824,40	1 963,80	2 163,20	2 338,70
ZACHODNIO-POMORSKIE	393,7	469,4	535,6	620,2	678,4	732,8	755,3	847,9	896,8	1 016,30	1 102,00

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

Analyzing the year-to-year dynamics from Table 4, it's noticeable that in several voivodeships, the total length of bicycle paths decreased at certain periods, mainly in 2013 and 2016.

It can be speculated that this was related to infrastructure reconstruction, and such projects usually last a few to several months, depending on the scale. An interesting observation can also be made based on the average dynamics of changes for the voivodeships.

It is clear that there are two periods; the first from 2012 to 2015, when the average dynamics of increases in the total length of bicycle paths were double-digit, fluctuating between 22%-10%; the second from 2016 to 2021, when the average dynamics of increases in the total length of bicycle paths were significantly lower, not exceeding 14% in the peak year.

In other words, in general terms, the period 2012-2015 saw the largest average increase in the length of bicycle paths across all voivodeships. In the years 2016-2017 and 2021, there is a clear decline in this dynamic to levels below 10%. Meanwhile, in the period 2018-2020, the average increase in the length of bicycle paths across all voivodeships was above 10% and had a relatively stable level.

Table 4. *Dynamics of the length of bicycle routes in Poland from 2012-2021 (%).*

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	*20,3*	*11,1*	*21,0*	*15,5*	*4,3*	*7,8*	*14,6*	*11,8*	*11,0*	*7,3*
DOLNO-ŚLĄSKIE	*15,6*	*3,1*	*28,4*	*3,4*	*-13,9*	*8,3*	*19,0*	*13,1*	*10,5*	*-3,3*
KUJAWSKO-POMORSKIE	*10,1*	*14,9*	*34,4*	*17,2*	*3,2*	*2,5*	*10,0*	*6,8*	*8,5*	*13,4*
LUBELSKIE	*13,0*	*23,0*	*21,3*	*32,4*	*12,9*	*7,3*	*11,6*	*19,8*	*13,0*	*6,6*
LUBUSKIE	*41,5*	*10,1*	*14,0*	*13,0*	*-0,5*	*10,6*	*3,9*	*7,4*	*10,9*	*4,3*
ŁÓDZKIE	*30,5*	*25,8*	*15,2*	*8,8*	*8,1*	*13,9*	*5,6*	*12,9*	*8,9*	*10,4*
MAŁO-POLSKIE	*28,9*	*12,3*	*14,3*	*15,9*	*10,4*	*21,2*	*9,2*	*17,5*	*21,3*	*8,4*
MAZO-WIECKIE	*15,8*	*4,2*	*21,4*	*15,4*	*10,1*	*10,8*	*27,8*	*17,4*	*9,6*	*5,6*
OPOLSKIE	*17,7*	*-15,1*	*12,3*	*8,5*	*1,3*	*6,5*	*26,5*	*22,2*	*9,0*	*4,6*
PODKARPAC-KIE	*71,2*	*-11,9*	*31,4*	*56,3*	*-7,6*	*10,9*	*4,2*	*4,7*	*4,8*	*6,5*
PODLASKIE	*25,2*	*-0,2*	*45,4*	*38,8*	*2,5*	*11,2*	*11,5*	*9,2*	*16,2*	*7,5*
POMORSKIE	*21,8*	*31,2*	*24,9*	*6,4*	*5,1*	*5,3*	*7,0*	*8,4*	*9,8*	*4,8*
ŚLĄSKIE	*11,6*	*-4,3*	*8,5*	*11,8*	*8,1*	*5,2*	*13,3*	*12,2*	*14,1*	*14,6*
ŚWIĘTO-KRZYSKIE	*8,3*	*30,3*	*17,6*	*33,6*	*6,5*	*4,1*	*15,2*	*17,3*	*21,2*	*6,6*
WARMIŃSKO-MAZURSKIE	*18,2*	*8,6*	*39,0*	*27,1*	*5,4*	*-1,4*	*10,6*	*14,5*	*6,8*	*9,8*
WIELKO-POLSKIE	*18,0*	*25,9*	*12,4*	*9,4*	*6,4*	*8,5*	*24,6*	*7,6*	*10,2*	*8,1*
ZACHODNIO-POMORSKIE	*19,2*	*14,1*	*15,8*	*9,4*	*8,0*	*3,1*	*12,3*	*5,8*	*13,3*	*8,4*
AVERAGE	*22,8*	*10,8*	*22,2*	*19,0*	*4,1*	*8,0*	*13,3*	*12,3*	*11,7*	*7,3*

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

The next issue is the analysis of the structure for each of the years covered by the study (Table 5). This analysis will indicate which voivodeship had what contribution to the total sum of bicycle paths in Poland. The analysis of the table confirms the observation from the earlier analysis – voivodeships, which recorded at least a one-year decline in the total length of bicycle paths, ultimately lost their share in the structure, which is also reflected by the trend line in the last part of the table.

An example can be the Śląskie, which in 2011 had a share of 8.8%, and in 2021 only 5.85%. In 2016 and 2021, it experienced negative year-to-year dynamics. Meanwhile, the Lubelskie, which in 2011 had a share in the structure of 4.43%, increased its share to 5.94% in 2021. This voivodeship in 2016 and 2019 recorded one of the three highest levels of dynamics year-to-year.

The analysis shows that any delays or “loss” of bicycle path lengths in one of the years covered by the analysis, are not “made up for”, which results in a decrease in share in the overall structure of the sum of bicycle paths in Poland. Poland is dynamically developing its bicycle road infrastructure, so any delays at the voivodeship level push them down in terms of their contribution to the structure of the national road infrastructure for cyclists.

Table 5. *Structure of the national total of bicycle roads from 2011-2021.*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Trend
DOLNOŚLĄSKIE	8,80%	8,46%	7,86%	8,34%	7,46%	6,16%	6,19%	6,44%	6,52%	6,49%	5,85%	
KUJAWSKO-POMORSKIE	7,84%	7,18%	7,43%	8,25%	8,37%	8,29%	7,88%	7,57%	7,23%	7,06%	7,47%	
LUBELSKIE	4,36%	4,10%	4,54%	4,55%	5,22%	5,65%	5,63%	5,48%	5,87%	5,98%	5,94%	
LUBUSKIE	4,51%	5,31%	5,26%	4,96%	4,85%	4,63%	4,75%	4,31%	4,14%	4,14%	4,02%	
ŁÓDZKIE	4,97%	5,39%	6,11%	5,82%	5,48%	5,68%	6,00%	5,53%	5,59%	5,48%	5,64%	
MAŁOPOLSKIE	3,34%	3,58%	3,62%	3,42%	3,43%	3,64%	4,09%	3,90%	4,10%	4,47%	4,52%	
MAZOWIECKIE	13,07%	12,59%	11,81%	11,86%	11,85%	12,51%	12,86%	14,35%	15,07%	14,87%	14,64%	
OPOLSKIE	4,35%	4,26%	3,25%	3,02%	2,84%	2,76%	2,72%	3,01%	3,29%	3,23%	3,15%	
PODKARPACKIE	3,23%	4,59%	3,64%	3,95%	5,35%	4,74%	4,87%	4,43%	4,15%	3,91%	3,89%	
PODLASKIE	3,11%	3,24%	2,91%	3,50%	4,20%	4,13%	4,26%	4,15%	4,05%	4,24%	4,25%	
POMORSKIE	8,55%	8,67%	10,23%	10,56%	9,73%	9,80%	9,57%	8,94%	8,67%	8,57%	8,37%	
ŚLĄSKIE	9,68%	8,98%	7,74%	6,94%	6,72%	6,96%	6,79%	6,71%	6,74%	6,93%	7,40%	
ŚWIĘTOKRZYSKIE	1,69%	1,52%	1,78%	1,73%	2,00%	2,04%	1,97%	1,99%	2,09%	2,28%	2,26%	
WARMIŃSKO-MAZURSKIE	3,67%	3,61%	3,53%	4,05%	4,46%	4,51%	4,13%	3,98%	4,08%	3,93%	4,02%	
WIELKOPOLSKIE	12,01%	11,78%	13,35%	12,41%	11,75%	11,99%	12,06%	13,12%	12,64%	12,54%	12,63%	
ZACHODNIOPOMORSKIE	6,81%	6,75%	6,93%	6,63%	6,28%	6,51%	6,22%	6,10%	5,77%	5,89%	5,95%	

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

Another method to evaluate bicycle infrastructure in individual voivodeships and their changes over the years 2011-2021 is the analysis of the saturation index expressed by the ratio of the length of bicycle paths to the area of the voivodeship (Table 6). In 2011, in Poland, the index of road length per 100 km^2 was 1.85, and the average for all voivodeships was 1.91.

Across the voivodeships, this index for seven voivodeships was above the average. The three voivodeships with the highest index were: Śląskie (4.54), Pomorskie (2.7), and Opolskie (2.67). In 2012, the average for voivodeships increased to 2.3, and eight of them achieved an index above this level. In 2013, the average increased to 2.51, and this time nine voivodeships had an index value above the average. In 2014 and 2015, seven voivodeships had an index level above the average. This rose to levels of 3.02 and 3.48, respectively. In 2016, only six voivodeships had an index above the average, which was 3.62.

In the period 2017-2020, again seven voivodeships had an index above the average, which consistently increased every year – specifically: 2017 – 3.9; 2018 – 4.41; 2019 – 4.94; 2020 – 5.5. In 2021 alone, the average increased to 5.92, continuing the upward trend. This time only six voivodeships had a value above the average. The leaders were: Śląskie (again) – 11.1; Pomorskie (again) – 8.46; Wielkopolskie – 7.84. At the national level, the index was 5.92. This analysis shows that there is a consistent increase in the length of bicycle infrastructure in all voivodeships.

However, there is a large disparity between the voivodeship with the highest index – 11.1 (Śląskie) and the voivodeship with the lowest index – 3.08 (Warmińsko-Mazurskie). It can be observed that there is a very uneven development of road infrastructure for bicycles in the voivodeships, despite maintaining a relatively analogous trend in the context of the analyzed index, across all voivodeships. This can be interpreted as an insufficient level of investment, which results from the diversification in the incomes of individual voivodeships.

Table 6. *Values of the indicator of bicycle roads length per 100 km² area from 2011-2021.*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2021/2011	Trend
POLSKA	1,85	2,22	2,47	2,99	3,45	3,60	3,88	4,45	4,97	5,52	5,92	320%	
DOLNOŚLĄSKIE	2,55	2,95	3,04	3,91	4,04	3,48	3,77	4,49	5,08	5,61	5,43	213%	
KUJAWSKO-POMORSKIE	2,52	2,78	3,19	4,29	5,03	5,19	5,32	5,85	6,25	6,78	7,69	305%	
LUBELSKIE	1	1,14	1,4	1,69	2,24	2,53	2,72	3,03	3,63	4,10	4,38	438%	
LUBUSKIE	1,87	2,64	2,91	3,32	3,75	3,73	4,12	4,28	4,6	5,1	5,32	284%	
ŁÓDZKIE	1,58	2,06	2,59	2,98	3,25	3,51	4	4,22	4,77	5,19	5,73	363%	
MAŁOPOLSKIE	1,27	1,64	1,84	2,11	2,44	2,7	3,27	3,57	4,19	5,09	5,51	434%	
MAZOWIECKIE	2,13	2,46	2,57	3,12	3,60	3,96	4,39	5,61	6,59	7,22	7,62	358%	
OPOLSKIE	2,67	3,14	2,67	3	3,25	3,3	3,51	4,44	5,43	5,92	6,19	232%	
PODKARPACKIE	1,05	1,79	1,58	2,07	3,23	2,99	3,31	3,45	3,61	3,79	4,03	384%	
PODLASKIE	0,89	1,12	1,11	1,62	2,25	2,3	2,56	2,86	3,12	3,63	3,9	438%	
POMORSKIE	2,7	3,29	4,32	5,39	5,74	6,03	6,35	6,79	7,35	8,07	8,46	313%	
ŚLĄSKIE	4,54	5,07	4,85	5,26	5,88	6,35	6,68	7,57	8,49	9,69	11,10	244%	
ŚWIĘTOKRZYSKIE	0,83	0,9	1,18	1,38	1,85	1,97	2,05	2,36	2,77	3,35	3,58	431%	
WARMIŃSKO-MAZURSKIE	0,88	1,04	1,13	1,57	1,99	2,1	2,07	2,29	2,62	2,8	3,08	350%	
WIELKOPOLSKIE	2,33	2,75	3,46	3,89	4,25	4,53	4,91	6,12	6,58	7,25	7,84	336%	
ZACHODNIOPOMORSKIE	1,72	2,05	2,34	2,71	2,96	3,2	3,3	3,7	3,92	4,44	4,81	280%	

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

The second part of the above assessment is the analysis of the relationship of the length of bicycle routes in the voivodeship per 10,000 inhabitants. Infrastructure exists primarily to meet the communication and/or bicycle tourism needs of residents (and occasionally visitors), so this index should be interpreted as a sort of complement to the previous index of voivodeship area covered by bicycle roads. The data is presented in Table 7.

Table 7. *Values of the indicator of bicycle roads length per 10 thousand residents from 2011-2021.*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	*1,50*	*1,81*	*2,01*	*2,43*	*2,81*	*2,93*	*3,16*	*3,62*	*4,05*	*4,53*	*4,88*
DOLNO-ŚLĄSKIE	*1,75*	*2,02*	*2,09*	*2,68*	*2,77*	*2,39*	*2,59*	*3,08*	*3,49*	*3,85*	*3,74*
KUJAWSKO-POMORSKIE	*2,16*	*2,38*	*2,74*	*3,69*	*4,33*	*4,48*	*4,59*	*5,06*	*5,42*	*6,00*	*6,85*
LUBELSKIE	*1,16*	*1,32*	*1,63*	*1,98*	*2,63*	*2,98*	*3,21*	*3,6*	*4,33*	*5,01*	*5,39*
LUBUSKIE	*2,55*	*3,61*	*3,98*	*4,54*	*5,15*	*5,12*	*5,67*	*5,91*	*6,36*	*7,18*	*7,55*
ŁÓDZKIE	*1,13*	*1,49*	*1,88*	*2,17*	*2,37*	*2,57*	*2,94*	*3,12*	*3,54*	*3,92*	*4,36*
MAŁO-POLSKIE	*0,58*	*0,74*	*0,83*	*0,95*	*1,1*	*1,21*	*1,46*	*1,59*	*1,87*	*2,25*	*2,44*
MAZO-WIECKIE	*1,43*	*1,65*	*1,72*	*2,08*	*2,39*	*2,62*	*2,90*	*3,69*	*4,32*	*4,65*	*4,92*
OPOLSKIE	*2,48*	*2,93*	*2,5*	*2,82*	*3,08*	*3,12*	*3,34*	*4,24*	*5,2*	*5,83*	*6,14*
PODKARPAC-KIE	*0,88*	*1,5*	*1,32*	*1,73*	*2,71*	*2,51*	*2,78*	*2,89*	*3,03*	*3,22*	*3,45*
PODLASKIE	*1,5*	*1,88*	*1,88*	*2,74*	*3,82*	*3,92*	*4,37*	*4,88*	*5,34*	*6,33*	*6,85*
POMORSKIE	*2,17*	*2,63*	*3,44*	*4,29*	*4,55*	*4,77*	*5,00*	*5,33*	*5,75*	*6,27*	*6,57*
ŚLĄSKIE	*1,21*	*1,35*	*1,3*	*1,41*	*1,59*	*1,72*	*1,81*	*2,06*	*2,32*	*2,71*	*3,13*
ŚWIĘTO-KRZYSKIE	*0,76*	*0,83*	*1,08*	*1,28*	*1,72*	*1,84*	*1,92*	*2,22*	*2,63*	*3,27*	*3,53*
WARMIŃSKO-MAZURSKIE	*1,46*	*1,73*	*1,88*	*2,62*	*3,35*	*3,54*	*3,49*	*3,88*	*4,46*	*4,89*	*5,41*
WIELKO-POLSKIE	*2,01*	*2,37*	*2,98*	*3,34*	*3,65*	*3,88*	*4,20*	*5,22*	*5,61*	*6,17*	*6,68*

ZACHODNIO -POMORSKIE	*2,29*	*2,73*	*3,12*	*3,62*	*3,97*	*4,29*	*4,43*	*4,98*	*5,29*	*6,12*	*6,68*
AVERAGE	*1,60*	*1,95*	*2,15*	*2,62*	*3,07*	*3,19*	*3,42*	*3,86*	*4,31*	*4,85*	*5,23*

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

The relationship of road length to population in the voivodeships (per 10,000 population) also reflects the upward trend in the length of road infrastructure for cyclists. This is consistent with expectations based on the previous analysis – the number of bicycle roads is increasing faster than the number of residents in the voivodeships.

Additionally, the negative demographic trend favors the overall acceleration of this index's increase (the base – the denominator decreases). Of course, there is migration between voivodeships, which locally may offset the negative demographic trend, but it is not the subject of the analysis, so the above statement should be treated as a general observation.

In 2011, the average for voivodeships was 1.6, and the index value for Poland was 1.5. The three voivodeships with the highest index were: Lubuskie (2.56), Opolskie (2.48), and Zachodniopomorskie (2.29). During the period covered by the analysis, the indices of all voivodeships are increasing.

In 2021, the index value for Poland was 4.88, and the average for voivodeships was 5.23. The three voivodeships with the highest index were: Lubuskie (7.55), Kujawsko-Pomorskie (6.58), and Podlaskie (6.85). The greatest improvement in this index occurred in Lubelskie, Świętokrzyskie, and Podlaskie.

All voivodeships in the period 2011-2021 improved their indicators of the relationship of bicycle road lengths per 10 thousand inhabitants. Similar to the relationship of bicycle road lengths to the voivodeship area, the biggest improvement did not always coincide with the highest value of the indicator in 2021. This shows that there was a significant difference in the base level (i.e., values from 2011) - the length of bicycle roads in 2011.

All voivodeships invested in bicycle infrastructure, but the level of these investments translated into a diversified pace of growth in absolute measures (expressed in km of length), as well as relative (expressed in relation to the area and population) describing the bicycle infrastructure in individual voivodeships.

This means that: firstly - the costs of investments made in individual voivodeships, despite comparable dynamics of the increase in bicycle infrastructure length measures, are decidedly different; secondly - based on the above analyses, one can only infer the direction and dynamics of the development of road infrastructure for bicycles, showing their scale in relation to the values from previous years. Therefore, one cannot infer about the financial dimensions of these changes (values of investment outlays). The available data does not allow for justified formulation of such conclusions.

Focusing solely on urban bicycle roads, hence being under the management of county offices and marshal offices, it is essential to emphasize that the time horizon of the analysis narrows. Data at such a level of detail in public statistics have been available since 2013. Consequently, the analysis will be conducted in the horizon of 2013-2021.

Table 8. *Share of urban bicycle roads in the total length of bicycle roads from 2013-2021 (%).*

	2013	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	*27,6*	*30,5*	*32,9*	*31,6*	*32,9*	*33,4*	*34,4*	*34,1*	*34,3*
DOLNO-ŚLĄSKIE	*19,4*	*35,6*	*35,5*	*23,2*	*23,5*	*22,4*	*21,4*	*19,7*	*20,3*
KUJAWSKO-POMORSKIE	*35,2*	*36,7*	*34,9*	*34,0*	*36,6*	*34,5*	*37,7*	*37,2*	*37,7*
LUBELSKIE	*39,8*	*39,3*	*42,5*	*46,6*	*44,4*	*45,7*	*47,1*	*47,1*	*46,2*
LUBUSKIE	*36,8*	*38,6*	*34,5*	*35,5*	*38,5*	*38,1*	*39,5*	*38,7*	*36,8*
ŁÓDZKIE	*39,5*	*32,8*	*35,7*	*34,7*	*37,0*	*34,3*	*37,4*	*38,5*	*37,9*
MAŁO-POLSKIE	*8,8*	*11,1*	*11,1*	*12,6*	*15,7*	*12,0*	*11,7*	*12,1*	*14,7*
MAZO-WIECKIE	*21,2*	*26,6*	*27,7*	*28,1*	*29,6*	*34,8*	*37,0*	*35,7*	*35,8*
OPOLSKIE	*42,8*	*38,9*	*38,8*	*39,6*	*45,0*	*43,6*	*47,5*	*45,5*	*45,0*
PODKARPAC-KIE	*18,3*	*23,3*	*43,9*	*32,3*	*30,4*	*32,6*	*33,1*	*33,5*	*34,2*
PODLASKIE	*13,0*	*29,3*	*41,5*	*42,0*	*43,2*	*46,5*	*40,5*	*44,4*	*45,0*
POMORSKIE	*24,5*	*23,2*	*23,8*	*23,4*	*24,9*	*22,6*	*23,3*	*26,2*	*25,7*
ŚLĄSKIE	*15,9*	*15,6*	*15,9*	*15,7*	*16,2*	*17,6*	*17,4*	*15,8*	*17,8*
ŚWIĘTO-KRZYSKIE	*51,5*	*50,4*	*55,6*	*53,8*	*54,9*	*59,1*	*61,5*	*58,2*	*56,1*
WARMIŃSKO-MAZURSKIE	*28,1*	*42,5*	*46,5*	*46,9*	*43,8*	*42,6*	*43,2*	*43,9*	*45,4*
WIELKO-POLSKIE	*31,2*	*31,8*	*34,3*	*34,8*	*37,6*	*38,9*	*40,1*	*39,8*	*40,3*
ZACHODNIO-POMORSKIE	*32,3*	*32,3*	*31,5*	*31,2*	*33,2*	*32,7*	*32,0*	*30,1*	*29,6*
AVERAGE	*28,6*	*31,8*	*34,6*	*33,4*	*34,7*	*34,9*	*35,7*	*35,4*	*35,5*

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

According to the Central Statistical Office data, the number of urban bicycle roads in Poland in 2013 amounted to a total of 2,133.7 km. Whereas in 2021, it already amounted to 6,357.20 km, which meant an increase of 4,223.5 km, thus an increase in the length of bicycle roads by 197.94% over the 9 years covered by the analysis. Of course, this varied across voivodeships, which will be described below.

Urban bicycle roads constituted, on average, about 28.6% of all bicycle roads in the voivodeships in 2013 (Table 8).

The share of this type of roads in the total sum of bicycle roads in voivodeships in 2021 increased to 35.5% (on average). It is visible that investments in the expansion of bicycle roads largely pertained to investments in cities.

In 2013, in the Świętokrzyskie, urban bicycle roads accounted for 51.5% of all bicycle roads in the voivodeship. Exactly the same situation occurred 8 years later (in 2021), when the share of these roads increased to 56.1%. It can therefore be assumed that investments in road infrastructure in this voivodeship were mainly focused on roads in cities from the outset.

However, it should be noted that in the case of the Świętokrzyskie, we are dealing with a low base effect. Urban bicycle roads in 2013 had a total length of 70.9 km (137.6 km of all bicycle roads in the voivodeship), which was the lowest value in the whole country.

The aforementioned investments focused on the expansion of bicycle roads in cities contributed to the construction of an additional 164.2 km of bicycle roads. This gives a growth close to the national average for the period 2021/2013 (3.33; average 3.66), however, it's still a relatively small increase in length. In this respect, the Podlaskie and Małopolskie also fare equally poorly.

The latter in 2013 had urban bicycle roads with a total length of 24.6 km, which can rather be considered as a preliminary stage of implementing organized and safe bicycle traffic into the cities of the voivodeship, not an urban bicycle infrastructure. Although in 2021 the total length of bicycle roads in the city amounted to 123.1 km, thus increased by 98.5 km, leading to one of the more impressive values of chain change indicator (comparing 2013/2021).

Still, the bicycle infrastructure in the cities of Małopolskie remains symbolic. A more or less similar situation occurs in the context of the aforementioned top 3 voivodeships at the beginning of the paragraph, with the highest share of the length of bicycle roads in cities in relation to the total length of roads for bicycles in the voivodeship. This confirms the thesis that investments in bicycle infrastructure in the voivodeships are mainly focused on urban infrastructure. This is particularly evident in the context of voivodeships with relatively small bicycle infrastructure.

Focusing on 2021, the Lubelskie and Warmińsko-Mazurskie also have the highest share of urban bicycle roads in relation to the total length of bicycle roads in the voivodeship.

In the case of the Lubelskie, the relationship of the length of bicycle roads in the city in 2021 to 2013 amounted to 3.64 (2013 – 139.6 km; 2021 – 508.3 km). Whereas in the case of the Warmińsko-Mazurskie, the relationship of the length of bicycle roads in the city in 2021 to 2013 amounted to 4.41 (2013 – 76.5 km; 2021 – 337.40 km).

Deepening the analysis of changes in the length of urban bicycle roads, it is necessary to analyze the values of chain dynamics indicators to measure the changes that occurred in individual years. The increases described above are the result of cumulative changes that occurred over the 9 years covered by the analysis.

Table 9. *Chain dynamics of the length of urban bicycle roads from 2014-2021.*

	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	*33,6*	*24,5*	*0,4*	*12,0*	*16,4*	*15,1*	*10,1*	*8,0*
DOLNO-ŚLĄSKIE	*135,2*	*3,1*	*-43,9*	*9,9*	*13,3*	*8,4*	*1,8*	*-0,5*
KUJAWSKO-POMORSKIE	*40,2*	*11,4*	*0,7*	*10,4*	*3,7*	*16,5*	*7,2*	*14,9*
LUBELSKIE	*19,6*	*43,4*	*23,9*	*2,3*	*14,8*	*23,3*	*13,1*	*4,7*
LUBUSKIE	*19,7*	*1,1*	*2,2*	*19,9*	*3,0*	*11,2*	*8,7*	*-0,9*
ŁÓDZKIE	*-4,1*	*18,5*	*4,8*	*21,6*	*-2,1*	*23,2*	*12,2*	*8,7*
MAŁO-POLSKIE	*44,7*	*15,2*	*25,9*	*50,8*	*-16,2*	*14,6*	*25,4*	*31,4*
MAZO-WIECKIE	*52,0*	*20,2*	*11,9*	*16,7*	*50,1*	*24,9*	*5,8*	*5,8*
OPOLSKIE	*2,1*	*8,1*	*3,5*	*21,1*	*22,6*	*33,0*	*4,5*	*3,3*
PODKARPAC-KIE	*67,4*	*193,9*	*-32,1*	*4,2*	*11,9*	*6,4*	*6,0*	*8,5*
PODLASKIE	*226,6*	*96,7*	*3,9*	*14,2*	*20,1*	*-4,8*	*27,2*	*9,0*
POMORSKIE	*18,3*	*9,1*	*3,5*	*12,0*	*-3,0*	*11,7*	*23,3*	*2,9*
ŚLĄSKIE	*6,5*	*13,3*	*7,1*	*8,2*	*23,5*	*10,8*	*3,8*	*28,7*
ŚWIĘTO-KRZYSKIE	*15,1*	*47,2*	*3,1*	*6,4*	*24,0*	*22,1*	*14,6*	*2,8*
WARMIŃSKO-MAZURSKIE	*110,5*	*39,2*	*6,2*	*-7,8*	*7,4*	*16,2*	*8,7*	*13,3*
WIELKO-POLSKIE	*14,6*	*17,9*	*7,9*	*17,3*	*28,7*	*11,1*	*9,2*	*9,5*
ZACHODNIO-POMORSKIE	*15,8*	*6,6*	*7,0*	*9,6*	*10,5*	*3,6*	*6,5*	*6,7*
AVERAGE	49,0 *(14,8)**	34,1 *(18,2)*	*2,2*	*13,5*	*13,3*	*14,5*	*11,1*	*9,3*

Note: ** Average excluding outliers (excessively high values - above 40-50%).*
Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

Over the span of the analyzed 9 years, some voivodeships experienced a sharp increase in the length of urban bicycle roads, while others saw a decline in year-on-year terms. However, what's more significant is that the compilation from Table 9 allows for inferring two crucial aspects of urban bicycle infrastructure development:

• Consistency of scale increment – the question arises whether urban bicycle infrastructure is growing with a steady dynamics, hence, whether a consistent policy of development (measured by the length increment of roads) of urban bicycle infrastructure is being pursued. From the perspective of average change dynamics, it can be observed that investments in road infrastructure for bicycles in cities are carried out in cycles. The years 2014-2015 saw double-digit dynamics. Then, a slowdown occurred in 2016. The year 2017 marks the beginning of another three years of investments with double-digit chain dynamics. From 2020 onwards, a slowdown ensues, leading to a single-digit average indicator of bicycle roads increment dynamics in 2021. Thus, the average dynamics of bicycle roads increment in the voivodeships in Poland has a cyclical nature, which, in the context of planning and implementing public investments, can be seen as a situation where a consistent scale increment occurs. Additionally, in no year is the average dynamics of bicycle roads increment in the voivodeships in Poland negative.

• Maintenance of existing infrastructure – hence, whether the dynamics of change in the length of urban bicycle roads is not negative, which indicates the elimination of roads due to their poor technical condition or the implementation of other investments. In this dimension, many voivodeships experienced negative chain dynamics of change in the length of urban bicycle roads. This occurred in eight voivodeships over the span of the analyzed 9 years. In nearly half of the voivodeships, there was a periodic reduction in the length of bicycle roads. The instability of bicycle infrastructure does not favor the construction of an alternative communication system or the building of residents' habits.

Table 10. *Ratio of the length of bicycle roads to hard roads in the city from 2013-2021 (%).*

	2013	2014	2015	2016	2017	2018	2019	2020	2021
POLSKA	*3,7*	*5,0*	*6,1*	*6,1*	*6,7*	*7,7*	*8,7*	*9,5*	*10,2*
DOLNO-ŚLĄSKIE	*2,3*	*5,4*	*5,5*	*3,0*	*3,3*	*3,7*	*4,0*	*4,1*	*4,0*
KUJAWSKO-POMORSKIE	*7,5*	*10,3*	*11,8*	*11,6*	*12,7*	*11,9*	*14,8*	*16,0*	*18,2*
LUBELSKIE	*5,6*	*6,6*	*9,3*	*11,4*	*11,4*	*12,9*	*15,6*	*17,3*	*17,7*
LUBUSKIE	*8,7*	*9,9*	*10,0*	*10,1*	*11,8*	*12,0*	*13,3*	*14,4*	*14,1*
ŁÓDZKIE	*5,6*	*5,3*	*6,1*	*6,2*	*7,8*	*7,5*	*8,8*	*9,8*	*10,6*
MAŁO-POLSKIE	*0,6*	*0,8*	*0,9*	*1,2*	*1,7*	*1,4*	*1,6*	*2,0*	*2,7*
MAZO-WIECKIE	*2,8*	*4,2*	*4,9*	*5,4*	*6,2*	*9,2*	*11,2*	*11,7*	*12,3*
OPOLSKIE	*6,6*	*6,8*	*7,3*	*7,6*	*8,4*	*10,2*	*13,8*	*14,4*	*13,8*
PODKARPAC-KIE	*1,9*	*3,1*	*9,1*	*6,1*	*6,5*	*6,4*	*7,0*	*7,4*	*7,8*
PODLASKIE	*1,6*	*5,2*	*10,2*	*10,6*	*11,6*	*13,8*	*12,5*	*15,8*	*16,8*
POMORSKIE	*6,9*	*8,2*	*8,5*	*9,1*	*9,6*	*9,2*	*10,0*	*12,1*	*12,6*
ŚLĄSKIE	*0,8*	*1,0*	*1,2*	*1,2*	*1,4*	*1,7*	*1,8*	*1,9*	*2,4*
ŚWIĘTO-KRZYSKIE	*4,4*	*5,0*	*7,2*	*7,5*	*7,8*	*9,3*	*11,0*	*12,3*	*12,2*
WARMIŃSKO-MAZURSKIE	*3,9*	*8,4*	*11,5*	*12,4*	*11,4*	*12,2*	*13,8*	*14,5*	*16,5*
WIELKO-POLSKIE	*6,5*	*7,3*	*8,5*	*9,0*	*10,6*	*13,5*	*14,6*	*15,8*	*17,1*
ZACHODNIO-POMORSKIE	*6,0*	*6,8*	*6,9*	*7,7*	*8,4*	*9,1*	*9,4*	*9,0*	*10,4*
AVERAGE	*4,5*	*5,9*	*7,4*	*7,5*	*8,2*	*9,0*	*10,2*	*11,2*	*11,8*

Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

Another dimension of the analysis is the reference of the length of urban bicycle roads to the length of paved urban roads designated for road traffic (automotive +

bicycle). This will help determine whether the bicycle infrastructure in cities is becoming a real alternative to automotive traffic (Table 10).

Utilizing the average values for voivodeships, a positive trend is observed, consisting of the increase in the ratio of the length of bicycle roads in cities to the length of paved roads. Over the analyzed period, their share increased from 4.5% to 11.8%. In the context of voivodeships, in 2021 the highest ratio of bicycle roads to paved roads was recorded in the Kujawsko-Pomorskie (18.2%), Lubelskie (17.7%), and Wielkopolskie (17.1%).

At this level of analysis, the differences in the scale of road infrastructure of cities in the western and southwestern voivodeships are very clearly visible. For example, the Śląskie is characterized throughout the analysis period by a ratio of the length of bicycle infrastructure in cities to the length of paved roads in cities between 0.8% and 2.4% in 2021. In 2021, the length of this infrastructure totaled 243 km (paved roads in the city - 10,013.7 km, thus the most among the analyzed voivodeships).

This was almost as much as in the Podkarpackie (245.7 km) in 2021, which had a ratio of the length of bicycle roads to the length of paved roads in the city of 7.8%. This leads to the conclusion that regional development, and thus the communication infrastructure and urban centers, is significant for the interpretation of results in the scope of the development of bicycle infrastructure in cities.

Voivodeships with a lower level of urbanization and smaller urban centers achieve higher levels of bicycle to road infrastructure ratios in cities faster. Moreover, they achieve them with lower levels of investment (fewer kilometers to build = lower costs).

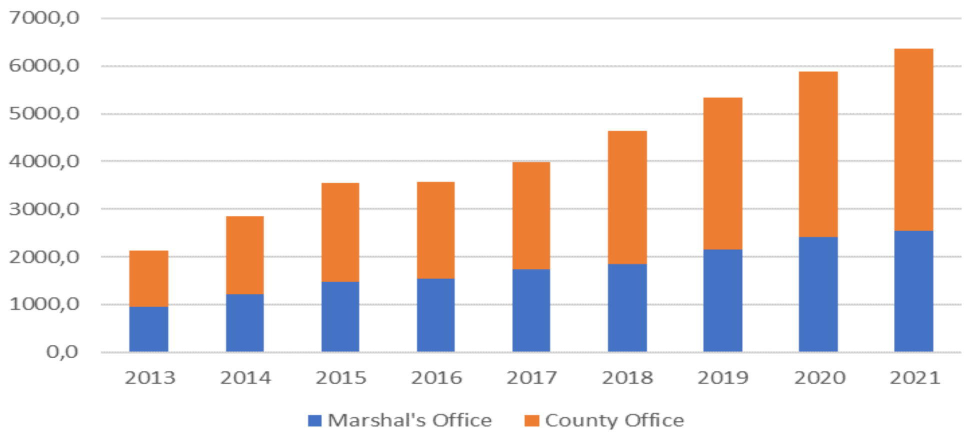
The cost of developing bicycle infrastructure in cities will therefore be very diversified in each of the voivodeships, and achieving a balanced level will require a different scale of investment tailored to the characteristics of each of the voivodeships and its urban centers.

This also means a completely different time horizon for the implementation of individual investments. Actions at the local level are necessary, rather than within national programs. A national program may set objectives and directions if it does not have separate financing.

The structure of bicycle roads in the city at the national level (summary perspective) shows that roads under the administration of the county office prevail. Moreover, there's a faster growth of these roads compared to those under the administration of the marshal's offices (Figure 2).

It is clear that the district governorships have the most significant impact on building and shaping the size of bicycle infrastructure in cities.

Figure 2. *Structure of urban bicycle roads by administrator from 2013-2021.*



Source: *Own elaboration based on https://bdl.stat.gov.pl/.*

The length of bicycle roads in cities under the administration of the marshal's office grew very unevenly. The dynamics of change (year-over-year) in the length of such roads in a summary perspective (for Poland) in the years 2014-2015 were respectively: 29.2% and 20.8%. Then in 2016, it dropped to 4.4% only to rise to 12.5% in 2017 and fall again to 6.6% in 2018.

The period 2019-2020 is a return to double-digit values, respectively: 16.7% and 11.9%. In 2021, it drops to 6%. It is visible that the intensification of investments conducted by the marshal's office occurs roughly in 2-year cycles. This is probably the time needed for investment preparation. Moreover, there are periods when negative dynamics were recorded for individual voivodeships, indicating a reduction in the length of bicycle roads in cities.

In the context of urban bicycle roads under the administration of county offices, there are also years when individual voivodeships exhibit negative dynamics - the length of this type of bicycle roads decreases. In the comprehensive perspective for Poland, the dynamics of change in the length of urban bicycle roads under the administration of the county office is basically greater almost every year covered by the analysis. In the period 2014-2015, it was respectively 37.1% and 27.2%. In 2016, it was negative at -2.4%. In 2017, it was 11.6% and began a three-year period with double-digit dynamics, respectively: 24% - 2018, and 14% - 2019. In 2020, the dynamics dropped to 8.9%, and in 2021 it was 9.4%.

Analyzing the average chain dynamics of the change in the length of urban bicycle roads for each voivodeship over the analyzed 9 years, it can be indicated which voivodeships took the top three places. In the context of the length of urban bicycle roads under the administration of county offices, the first place was taken by

Podkarpackie, with an average dynamics of 85.1%. Such a high level of dynamics is due to the changes that occurred in 2015 compared to 2014 when the chain index of dynamics of change was 677.5%.

Then, the largest investment for this voivodeship (in the analyzed period) in road infrastructure for bicycles in cities was realized (the total length of bicycle roads increased from 23.6 km to 183.5 km). The second place was taken by the Dolnośląskie with an average dynamics of 42.5%.

In the Dolnośląskie, the largest investment in the examined period was made in 2014. At that time, the total length of bicycle roads in cities increased from 47.3km to 212.4 km. The third place was taken by the Podlaskie with an average dynamics of 33.2%. Similar to the Podkarpackie, this is the effect of a large investment in 2015 - the total length of bicycle roads in cities increased from 20.6 km to 35.8 km.

In the context of the length of urban bicycle roads under the management of the marshal's office, the Podlaskie took the first place with an average dynamics of 93.1%. This is thanks to a large investment made in 2014, as a result of which the length of such roads increased from 8.7 km to 59.9 km. The second place goes to the Małopolskie with an average dynamics for the entire analysis period equal to 75%.

This is credited to two major investments made in 2017 and 2021. In the first case, the length of roads increased from 8.4 km to 37.3 km; in the second case, it increased from 27.2 km to 41.1 km. It's worth noting that in this case, it's the only voivodeship that did not have even 1 km of bicycle road in this particular case until 2015. The third place is occupied by the Warmińsko-Mazurskie with an average dynamics at the level of 65.7%.

This is also a consequence of a large investment made in 2014, which increased the length of roads from 17.5 km to 97.6 km. Two of the three cases described above are voivodeships where a single large investment was made, usually at the beginning of the creation of bicycle infrastructure in cities. It can be suspected that the data for the voivodeships largely reflect the situation in the largest cities of the voivodeship, especially in the early years of the analysis. County offices seem to develop bicycle infrastructure much more consistently than marshal's offices.

3.2 Perspective of Selected Largest Cities in Poland in 2023

The final element of the analysis is a reference to the numerical data above for selected examples of bicycle paths in the largest cities of Poland. To this end, the database of the European Cyclists' Federation (ECF) (https://european-cyclists-federation.github.io/) was consulted, which was last updated in July 2023 (thus containing the most up-to-date data). As of now, the available data allows for an analysis of city examples as shown in Table 11.

Therefore, these data are the most recent, hence there are differences in some figures in relation to the Central Statistical Office data for the last period covered by the analysis (i.e., 2021).

Table 11. *Bicycle roads in the largest cities of Poland according to ECF (km).*

	City area	Main	Local	Total	Shared with pedestrians	Bicycles only	Bicycle lanes	Restricted access
Kraków	327,57	624,78	1 268,12	266,33	198,66	46,71	12,28	8,68
Poznań	261,95	507,04	1 047,53	282,85	142,54	119,37	12,13	8,81
Szczecin	300,30	365,54	705,43	163,90	27,46	121,83	10,92	3,70
Warszawa	517,69	1 476,33	2 366,37	746,17	191,13	509,01	28,11	17,93
Wrocław	292,07	578,34	843,08	366,17	216,32	122,24	15,22	12,39
Łódź	293,46	695,33	1 042,28	240,50	56,02	144,24	21,86	18,38

Source: *Own elaboration based on https://european-cyclists-federation.github.io/.*

Among the analyzed largest cities of Poland, Warsaw's superiority over other cities in terms of overall road infrastructure is clearly visible. This also translates into the matter of bicycle infrastructure, or at least its length. However, to assess in which city the cycling infrastructure is best developed, one should analyze the indicator describing the relationship of bicycle paths to general roads in each of the cities (Table 12).

Table 12. *Bicycle routes to general roads ratio according to ECF.*

	Relation to main roads					Relation to area				
	Total	Shared with pedestrians	Bicycles only	Bicycle lanes	Restricted access	Total	Shared with pedestrians	Bicycles only	Bicycle lanes	Restricted access
Kraków	42,6%	31,8%	7,5%	2,0%	1,4%	0,81	0,61	0,14	0,04	0,03
Poznań	55,8%	28,1%	23,5%	2,4%	1,7%	1,08	0,54	0,46	0,05	0,03
Szczecin	44,8%	7,5%	33,3%	3,0%	1,0%	0,55	0,09	0,41	0,04	0,01
Warszawa	50,5%	12,9%	34,5%	1,9%	1,2%	1,44	0,37	0,98	0,05	0,03
Wrocław	63,3%	37,4%	21,1%	2,6%	2,1%	1,25	0,74	0,42	0,05	0,04
Łódź	34,6%	8,1%	20,7%	3,1%	2,6%	0,82	0,19	0,49	0,07	0,06

Source: *Own elaboration based on https://european-cyclists-federation.github.io/.*

The data show that the ratio of bicycle path length to the length of roads in a city varies greatly across the analyzed cities. Warsaw, which was expected to have an advantage over other cities, ranks third in terms of the ratio of bicycle path length to the length of city roads, with an index of 50.5%.

Wrocław comes in first with an index of 63.3%. Poznań takes the second spot with an index of 55.8%.

Another observation that can be made is the statement that the analyzed cities can be divided into two groups. The first predominantly has bicycle paths designated solely for bicycles. This group includes: Szczecin, Warsaw, and Łódź. In the second group, shared paths with pedestrians prevail. This group consists of: Kraków, Poznań, and Wrocław.

A third conclusion that can be drawn is that only Poznań, Warsaw, and Wrocław have reached a "saturation" of bicycle paths in the city above 1. This means that there is more than 1 km of bicycle path per 1 km^2 of the city's area.

The final conclusion drawn from the analysis of ECF data pertains to the concentration of investments in urban bicycle infrastructure in provincial cities. In the Dolnośląskie, 21% of the length of bicycle paths in cities is attributed to Wrocław. In the Mazowieckie, 27% of the length of bicycle paths are located in Warsaw. In the Małopolskie, bicycle paths in Krakow account for 17% of the total length of urban bicycle paths in the province.

In the Wielkopolskie, Poznań has 13% of all urban bicycle paths throughout the province. Meanwhile, in the Łódzkie, 22% of all urban bicycle paths are found solely in Łódź. In Zachodniopomorskie, Szczecin and its urban bicycle paths amount to 9% of all urban bicycle paths in the province. As can be seen, not in every province does the provincial city possess more than 15% of the length of urban bicycle paths. From this perspective, there's significant variation, leading again to a division into two groups, this time at the provincial level.

In the first group, where provincial cities do not concentrate more than 20% of the length of urban bicycle infrastructure, the provinces are: Zachodniopomorskie, Wielkopolskie, and Mazowieckie. These provinces, despite having a significant bicycle infrastructure in cities (respectively: Zachodniopomorskie – 1,779.37 km; Wielkopolskie – 2,257.45 km; Mazowieckie – 2,755.82 km), are not characterized by the concentration of this infrastructure in the largest urban centers of the region.

Investments are, therefore, distributed more broadly, offering a greater chance in the future to quickly build a coherent and effective communication infrastructure for bicycles at the provincial level.

In the second group are provinces concentrating more than 20% of urban bicycle infrastructure in provincial cities. These are the provinces: Łódzkie – 22%; Mazowieckie – 27%; Dolnośląskie – 21%. In these provinces, investments in urban road infrastructure were focused on the largest urban centers.

Establishing a foundation for the development of effective bicycle infrastructure at the provincial level will require numerous investments in smaller cities, consuming more time and resources than in provinces from the previous group.

3.3 Evaluating the Potential of Bicycle Transport as a Solution for Meeting Urban Transportation Needs while Addressing the Challenges of Transport Decarbonization

Attempting to assess the potential of bicycle transport as a substitute for personal car transportation in the city is a relatively challenging task, as many factors play a significant role. It seems appropriate to outline the primary groups of factors that have the potential to serve as determinants of such a transformation. For this purpose, the PESTEL analysis algorithm (Perera, 2017), a modification of the PEST analysis (Igliński, Iglińska, Cichosz, Kujawski, Buczkowski, 2016) was utilized.

Table 13. *Main groups of potential factors for transformation towards bicycle traffic dominance in the city.*

Group of factors	*Examples of factors*	*Description*
Political Environment	Taxes, energy transformation, accident reduction, etc.	Top-down policy directions – framework programs, supporting pollution reduction in the city or creation of car-free zones.
Economic Environment	Loan interest rates, GDP, inflation, fuel prices.	Shaping conditions and economic instruments supporting the increase of bicycle usage in the city.
Social Environment	Consumer trends, education standard, safety knowledge (awareness and habits), living standard.	Transformations in the awareness and attitudes of city residents and bicycle users; building awareness regarding the benefits and safety of cycling in the city.
Technological Environment	Innovations in e-bike sector, bike rentals, new bicycle designs – e.g. cargo.	Progress (and accessibility) in the field of enhancing the usability of bicycles in daily life, utilizing, for instance, electric drives; new bicycle designs for cargo transport
Legal Environment	Bicycle registration, facilitations in city movement (bicycle traffic zones), protection of bicycle accident victims.	Legal actions and initiatives for the protection of bicycle ownership and rights of bicycle accident victims; new entitlements for cyclists in designated areas within urban space.
Environmental Environment	Transformations in the public space of cities (infrastructure), expansion of inter-city public transport, eco trend.	Changes in the physical environment of cities favoring bicycle use; facilitating the use of inter-city and intra-city public transport with a bicycle; increased ecological awareness among residents and city authorities.

Source: *Own elaboration.*

Using the PESTEL analysis tool in this case is fully justified, as this analysis allows for a broader perspective on the issue, thereby providing an excellent reference for conducting a SWOT analysis. Table 13 helps to realize that a shift towards the dominance of bicycle traffic in cities requires a combination of many factors and actions across multiple areas. Firstly, there needs to be an appropriate mindset in the governing environment. Political will is necessary to initiate change and support emerging initiatives.

At the national and EU levels, this means creating the right legal frameworks for actions aimed at genuinely integrating bicycles into urban spaces. This implies both overarching transportation and urban planning policies. An example of such a policy is FIT for 55, which is the EU's main initiative for pollution reduction, and thus, transport decarbonization.

This overarching threshold creates a favorable environment for initiatives to replace car traffic in cities with alternative forms of transport – bicycles being one of them. At the national level, this could be initiatives related to urban planning or increasing the flexibility of local authorities in shaping certain aspects associated with, for example, city traffic rules or the realization of specific investments.

In the economic environment, one of the most natural determinants is the availability of financing initiatives related to promoting bicycle transport, especially in cities. The author refers to the availability of special programs for favorable financing of infrastructure development, infrastructure modernization, private community initiatives, and initiatives like bicycle rental services, etc.

The GDP level and the inflation rate will also be significant, reflecting the general wealth level and living standard of city residents. These factors should be considered in the context of fuel prices and the costs of purchasing and using vehicles. At this point, there is also a reference to the political environment - taxes.

In the social environment, the most significant factor seems to be the attitude and awareness of city residents. Both the attitude towards bicycles and bicycle movement as an alternative to cars in the city, and awareness regarding the safety of using bicycles in the city, are the result of education. Education is also necessary in promoting the environmental and health benefits of choosing bicycles over cars. Trends promoting an ecological lifestyle, environmental awareness, or eco-friendly cities can play a significant role in this area.

The technological environment primarily refers to the availability of solutions that enhance the use of bicycles in the city. The author is referring to new bicycle designs (e.g., e-bikes) that allow not only those with adequate physical fitness to use bicycles. Solutions that increase the safety of cyclists or enable cargo transportation are also important. Many of these technologies are available today; the challenge remains the relatively low interest in these solutions. Technology also encompasses technological improvements in infrastructure – for example, automatic lights, barriers at crossings, and so on.

The legal environment is a deepening of the political setting. In this environment, national legislation and local regulatory initiatives play the most significant role. Legal regulations operate within the framework set by policy and translate goals and general concepts to an operational level. This also applies to issues related to, for example, increasing the freedom of local authorities in shaping certain rules concerning the creation of zones closed to vehicle traffic or other types of regulations that influence the accessibility for vehicles other than bicycles.

The environmental enviroment refer to the broadly understood physical and natural environment of cities. Within this scope, the most significant factors will be infrastructural investments dedicated to bicycles. Another example will be the creation of aforementioned zones with restricted car traffic but open for bicycles. Additionally, an essential component will be investments in the expansion of point (ancillary) infrastructure for urban and suburban transport. In other words, all initiatives facilitating the use of bicycles in the city and its outskirts.

In the context of assessing the potential of bicycle transport as a substitute for personal car transport in the city, the above-mentioned elements of the PESTEL analysis need to be supplemented. The primary issue remains the possibility and method of remodeling the urban environment for bicycle transport. This matter has been quite well presented by CPB ITF in a report developed in 2022 (ITF CPB Report, 2022).

At the outset of the study, it was noted that city roads are a "scarce resource" currently allocated to transport solutions that are inefficient in terms of space required (mainly car transport). Thus, a framework solution was presented for modeling new ways of ensuring transport utility and travel patterns in the city with limited space (Crozet, 2020). This issue becomes particularly significant in the context of cities with old or dense buildings where investment cannot involve demolitions or a complete change in the way a given plot is used. The proposed methodology focuses on the city's inhabitants and their needs and how urban space serves those needs.

This approach contrasts with today's perspective, which considers how a given space (traffic in the city) is used by vehicles. This leads to the favoring of car transport. Therefore, the authors of the discussed study emphasize the differences between: the use of road space and the allocation of road space (Levinson, Zhu, 2012). In the former, they associate the concept with the demand for space to travel through the city. In other words, it is about the actual "consumption" of space by people and vehicles when they move. In the latter, it's about the availability of space (roads and related infrastructure) for communication (traveling around the city).

This distinction helps understand the static nature of current solutions. Traffic intensity at various times of the day is not taken into account, and the available space is allocated to the most space-consuming modes of transport (cars). In this way, it is not used efficiently from the residents' perspective (Mattioli, Roberts, Steinberger, Brown, 2020).

The described framework solution is associated with a methodology that allows for determining the space demand depending on the type of transport in both static and dynamic perspectives. This methodology, in turn, facilitates further analysis in the context of benefits and changes that can be achieved in the urban space by modifying the form of transport available in a given area. It is thus crucial to present the assumptions underlying this methodology (Table 14). These assumptions enable the determination of differences in space "consumption" during movement in the urban environment for various modes of transport.

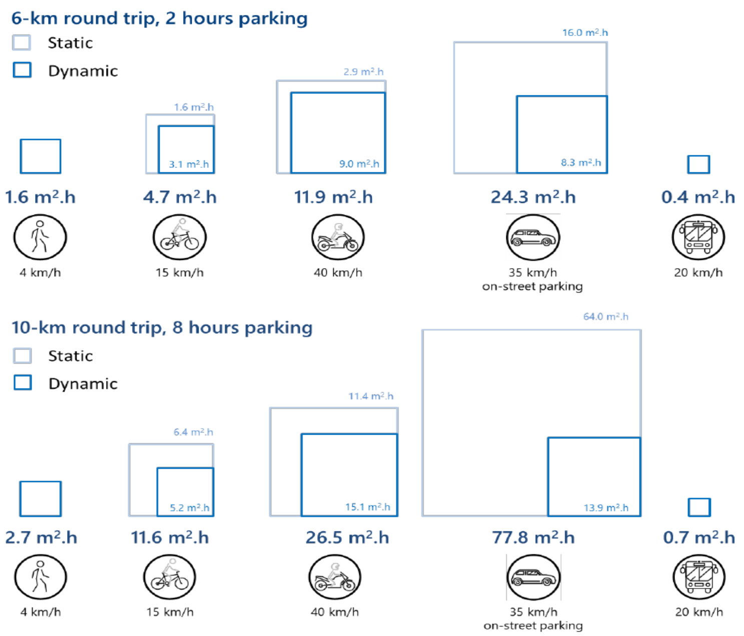
Table 14. *Basic assumptions regarding static and dynamic consumption of various types of transport.*

Static space consumption per person according to mode and configuration						
Type and configuration (situation)	Parking space per vehicle (m^2)	Auxiliary and maneuvering space (m^2)	Space consumption per vehicle (m^2)	Average load factor per vehicle (person/vehicle)	Static space consumption per person (m^2)	
Car (on street, parallel)	10		10	1.3	9.2	
Car (on street, angled)	12		12	1.3	9.2	
Car (parking lot)	10	15	25	1.3	19.2	
Car (multi-level parking)	15	10	25	1.3	19.2	
Motorized two-wheeler (on street)	1.5		1.5	1.05	1.4	
Motorized two-wheeler (car parking lot))	1.5	1.0	2.5	1.05	2.4	
Bicycle (rack)	0.8		0.8	1	0.8	
Bicycle (double-decker rack)	0.4	0.2	0.6	1	0.6	
Bus (12-meters)	42	28	70	17	4.1	
Bus (12-meters, rush hours)	42	28	70	50	1.4	
Pedestrian					(0.25)	
Maximum throughput of vehicles and persons according to mode for various roadways						
Type of transport	Vehicles per hour and direction	Distance between vehicles in public transport (in minutes)	Average load factor (persons/vevicle)	Hourly person throughput per direction	Roadway width	Hourly throughput per meter of roadway width
Walking				9 000	3	3 000
Bicycling	9 000		1	5 000	3	1 667
Bus (12-meter in street traffic)	20	3.0	70	1 400	3	467
Bus (18-meter, bus lane)	25	2.4	100	2 500	3.5	714
Tram	30	2.0	300	9 000	3	3 000
Metro	40	1.5	800	32 000	3.5	9 143
Urban rail	20	3.0	1 000	20 000	4	5 000
High-speed urban rail	30	2.0	2 000	60 000	4	15 000
Car (highway/expressway)	2 400		1.25	3 000	3.5	857
Car (urban road)	900		1.25	1 125	3	375

Source: *Own elaboration based on ITF CPB Report, Streets That Fit Re-allocating Space for Better Cities. Paris 2022.*

Based on the above assumptions, sample calculations were made for space consumed by one individual when moving around the city using various means of transport for two exemplary transport operations (Figure 3).

Figure 3. *Space consumed by one person for 2 different transport operations, broken down by mode of transport.*



Source: *Own elaboration based on ITF CPB Report, Streets That Fit Re-allocating Space for Better Cities. Paris 2022.*

The above comparison vividly illustrates the differences in space "consumption" per person in both static and dynamic terms. It provides a pictorial view of the efficiency of transport modes in terms of the "consumed" urban space. As expected, the car is the least efficient in this regard. Interestingly, the difference in space "consumption" for a transport operation that's only 4km longer (and with a 6-hour longer stop), i.e., a typical commute within the same city, nearly triples the space "consumption" for cars.

Another essential element of the described framework solution is the adoption of two main assumptions:

• The permissible speed of traffic is related to the nature and purpose of the infrastructure and is not associated with the type of vehicle -> infrastructure accessibility for each type of vehicle is, therefore, based on the design and characteristics of the infrastructure.

• The weight and dimensions of vehicles determine which areas of the city's transportation infrastructure a given vehicle is allowed to access.

Both assumptions arise from ITF provisions regarding the traffic safety system and are an effective strategy for improving road safety. Deriving from these assumptions, the framework introduces a division into six vehicle groups pedestrians, bicycles and bicycle-like vehicles, small heavier vehicles (e.g., cargo bikes, mini transporters, motorized wheelchairs, rickshaws, etc.), cars, and trucks and delivery vehicles, trams, and trolleybuses. This division allows determining access to each element of the road transport infrastructure in the city for the respective transport groups. In this way, a framework solution is created that allows for modeling urban transport mobility.

In the report described an example application of the framework for the city of Dublin was presented in order to determine and assess the changes that can be achieved when selected approaches to modeling mobility and the allocation of transport space in the city are applied. The simulations were based on a sorting algorithm with a goal function (optimization).

After determining all constraining conditions, the goal function was set to minimize space consumption during the simulated variants of transport operations on given routes. The results were compared for four scenarios: 1) base; 2) full implementation being a combination of the next two variants, 3) dynamic networks - transport availability and mobility alternatives without changes compared to the base; 4) new mobility paradigm - introduces new types of transport considering the dynamic change of demand for a given type of transport and considering the possibilities of any change of transport type at any time, whenever it is possible and available. Variant 2 is, therefore, the closest to the real implementation in the near future of a solution in which bicycles dominate as a form of urban transport.

In terms of the efficiency of the urban communication network, in variant 2, efficiency increased by about 12% (in variant 3 – an increase of 9%; variant 4 – an increase of 3%). In terms of urban space consumption, the largest reduction was noted in variant 2 (for cars alone, it was about 19%). The space savings mainly concerned the center, opening up new possibilities for developing this space according to the needs of the city's residents.

The simulations also covered the ecological dimension of the impact of changes in the implementation of transport operations (mainly changes in the type of transport and sharing transport types), which is a particularly important issue from the point of view of decarbonization goals. As the authors of the study indicate, variant 2, despite the increase in kilometers/passenger in transport operations, allowed for a 5% reduction in CO_2 emissions compared to the base variant. Moreover, if motor vehicles in this simulation were partially replaced with electric ones and were used in a sharing model, the reduction could even reach 23%.

The described framework and the results of the simulation carried out on its basis show that it is possible to reduce CO2 emissions by flexibly organizing urban transport involving bicycles. This would be a multimodal transport, where the passenger can change the way they move around the city according to their needs and the availability of means of transport.

Thus, bicycles have significant potential in the context of reducing emissions/decarbonization of urban transport. The second conclusion drawn from the cited report is that bicycles can be an effective substitute for car transport within the city. The third conclusion pertains to the methodology underlying the described framework - the methodology itself does not seem overly complicated; difficulties arise at the stage of cataloging the resources of the urban transport/communication network and optimizing its use.

In practice, implementing any solution based on the cited methodology will require additional investment in infrastructure - e.g., automatic traffic intensity measuring devices with vehicle type identification, devices for dynamically managing infrastructure and transport, etc. Many investments are also associated with building points of contact between different types of transport (e.g., multi-story bicycle parking lots at train stations combined with bicycle rental) so that multimodality can be achieved at a satisfactory level.

ITF simulations have shown that in the context of urban transport, it is already possible to achieve a reduction in CO2 and other pollutants, thus achieving the goals related to the decarbonization of road transport. Popularizing modal transport in cities is an action that can be undertaken in the next decade (Kabaskin, 2023).

Bicycles play a crucial role in this context. By nature, they are environmentally friendly and emission-free (noise, pollutants). Thus, they seem to be an ideal response to the challenges associated with urban transport in the face of decarbonization challenges. However, the problem is issues related to the transformative reorganization of transport networks in cities. Major Polish cities have some advantages over smaller cities in this regard. In large urban centers, there is already some cycling infrastructure. It can provide an excellent backbone for further expansion and the city's future transport network.

However, there remains a range of problems related to the safety of cyclists in an urban environment. Paradoxically, solving these problems largely seems to be related to solving the problem of decarbonizing urban transport. Eliminating the use of cars for transport operations in the city and replacing them with public transport based on low-emission or zero-emission forms of transport – trams, railways, subways. This will reduce car traffic in the city, thus eliminating the risk for cyclists arising at the interface of these two types of transport in urban space.

Eliminating cars used for personal transport from cities is a step towards eliminating pollution and emissions from this transport in the city. Replacing them with bicycles is a real alternative. Of course, it should be emphasized that an efficient and effective communication network in the city cannot rely solely on bicycles. It is also necessary to use other vehicles, including cars. To achieve decarbonization goals, this means that these vehicles should be environmentally friendly and used as effectively as possible – which from today's perspective means, for example, sharing services or taxi services (Qiu, Huang, and Hawkins, 2022).

3.4 SWOT Analysis

Based on the aforementioned conclusions and prior observations derived from the application of the PESTEL analysis methodology, it is possible to conduct a SWOT analysis as a summary of considerations.

Table 15. *SWOT analysis along with evaluation matrix.*

Strengths					Weaknesses			
		Weight	Rating	Weighted rating		Weight	Rating	Weighted rating
1	Simple mechanical construction	0,1	5	0,5	Lack of active and passive protection guaranteed by the bicycle for the cyclist	0,2	3	0,6
2	Low operating cost (independence from fuel prices)	0,15	5	0,75	Shared infrastructure sections with buses or cars are associated with an increased risk for cyclists	0,2	4	0,8
3	With the appropriate infrastructure, more efficient than alternative modes of urban transport	0,2	4	0,8	Lower comfort of use compared to motor vehicles (comfort, effort)	0,15	3	0,45
4	Relatively low cost of purchasing/renting a bicycle	0,2	4	0,8	Dependence on weather conditions	0,15	2	0,3
5	Zero-emission and environmentally friendly mode of transportation (reduces pollution and noise)	0,1	4	0,4	Requires additional personal safety equipment	0,05	2	0,1
6	Beneficial for health as a means of transportation	0,15	4	0,6	Relatively low level of awareness regarding cycling safety (personal safety, habits)	0,1	3	0,3
7	Multifunctionality – personal transportation, sport, recreation	0,05	5	0,25	Limited transport capabilities of bicycles	0,1	3	0,3
8	Relatively high initial popularity among the population	0,05	5	0,25	Vulnerable to theft	0,05	2	0,1
	Rating	**1**		**4,35**	**Rating**	**1**		**2,95**

	Opportunities				Threats			
1	Existing partial infrastructure in large cities (the backbone of future infrastructure)	0,2	4	0,8	High popularity of cars as a personal mode of transportation in the city (habit)	0,15	4	0,6
2	Established standards for infrastructure investments of this type (technical and basic safety)	0,2	3	0,6	Increased risk of severe injury or death in bicycle accidents involving cars	0,2	4	0,8
3	Favorable legislative directions at the EU level	0,1	4	0,4	Insufficient safety level of bicycle infrastructure for potential users	0,15	3	0,45
4	Local government initiatives for cycling (selected cities - increasing awareness and investments, participatory budgets)	0,1	4	0,4	Popularity among the younger generation of e-scooters	0,1	3	0,3
5	Promotion of ecological and health awareness (eco and fitness trends)	0,05	3	0,15	Relatively low level of development of bicycle infrastructure within the multimodal transport network of cities	0,2	4	0,8
6	Improved activity and advocacy of cyclist communities in cities and beyond (higher activity and articulation of needs)	0,05	3	0,15	Relatively simple bicycle infrastructure (equipment, safety elements)	0,1	3	0,3
7	Growing popularity of sharing services (rental of electric scooters, bicycles)	0,15	4	0,6	Unwillingness of other road users towards cyclists	0,1	4	0,4
8	The prospect of creating green zones in cities and ecological revitalization of urban spaces	0,15	3	0,45				
	Rating	**1**		**3,55**	**Rating**	**1**		**3,65**

Source: *Own elaboration based on Seme S., Hadžiselimović M., Sprcic G., Brinovar I., Hanzic K., SWOT Analysis of Pedelecs and E-Cars in Selected Countries of the Danube Region. In 7th Symposium on Applied Electromagnetics SAEM18, Wyd. Založnik University of Maribor Press, 2019.*

The SWOT analysis reveals that strengths outweigh the weaknesses. The weighted evaluation of strengths was 4.35 compared to a 2.95 for weaknesses. Among the most significant strengths are: "With the right infrastructure, more efficient than alternative modes of urban transport" and "Relatively low cost of purchasing/renting a bicycle". The major weaknesses include: "Segments of shared infrastructure with buses or cars are characterized by an increased risk for cyclists" and "Lack of active and passive protection guaranteed by a bicycle for the rider", thus addressing the safety issues of cyclists.

Meanwhile, opportunities and threats are almost balanced (opportunities – 3.55; threats – 3.65), with a slight edge to threats. Key opportunities include: "In large cities, there is already partial infrastructure (the skeleton of future infrastructure)" and "Established standards for infrastructure investments of this kind (technical and basic safety)". The major threats include: "High popularity of cars as personal urban transport means (habit)" and "Increased risk of severe injury or death in a bicycle accident involving a car".

These environmental assessments suggest that cars are the "greatest enemy" of bicycles and cyclists. This argues for creating zones in cities free from car traffic and zones with limited motor vehicle movement.

Bicycle transportation thus has significant potential for urban environments. This potential mainly arises from the inherent strengths of the bicycle as a means of transport. External conditions, however, are challenging. Ultimately, it will depend on these conditions whether bicycles will become widespread in the city as a personal transportation method or will remain one of the alternatives to public transport, as it is today.

4. Discussion

Bicycle paths in Poland can be classified as transportation infrastructure; however, this is a rather broad simplification. Just as in the case of linear road (automotive) infrastructure, one can point out areas in the country with low road density/areas with inferior road infrastructure. For cycling infrastructure, it is more apt to speak of "is-lands" rather than areas. The development level of cycling infrastructure in the country is relatively low compared to road infrastructure.

However, it's worth noting that between the years 2013-2021, there was clear growth in this area. The total length of bike paths in all 16 provinces increased. From a 2021 perspective, residents of the Kujawsko-Pomorskie, Lubelskie, and Wielkopolskie provinces could use bicycles on dedicated infrastructure to a greater extent than residents of other provinces.

In the aforementioned regions, there was a superior ratio of the length of bike paths to the length of paved roads – 18.2% for the Kujawsko-Pomorskie (the best result). It's also worth emphasizing that provinces with a lower level of urbanization and smaller urban centers achieve higher ratios of cycling infrastructure to road infrastructure in cities faster. Therefore, the degree of urbanization of the provinces is a significant factor in interpreting the above information. While the ratio of the length of bike paths to paved roads, standing at 18.2%, might seem high, it's still a low level.

The mentioned improvement in terms of the length of cycling infrastructure, such as bike paths, is favorable, yet it doesn't capture the essence of the problem. Further analysis reveals that the majority of these bike paths are developed in major urban centers. As such, the current state and development direction of cycling infrastructure largely focuses on creating supplementary infrastructure for big cities.

Bicycles have not yet become a genuine alternative for safe and efficient personal transportation between cities. Of course, this is a generalization, and in Poland, there are increasing longer and shorter stretches of bike paths connecting smaller and bigger towns in various provinces.

However, there cannot be talk of an alternative infrastructure for bicycles as well-developed and facilitating free movement as the road infrastructure in the country. The analysis of the growth in bike path lengths also shows that the expansion of this infrastructure largely remains under the jurisdiction of local authorities. This seems to be a good direction. Cycling infrastructure currently makes more sense within urban centers. Only then should investments be made to connect these structures with intercity routes (e.g., cycling highways).

It is essential to take actions at the local level, rather than under national programs. A national program can set objectives and directions if it does not have separate funding. Reflecting on this observation is the analysis conducted for the six largest cities in Poland. These cities cope well with the challenge of developing and maintaining bicycle-dedicated road infrastructure. In all cases, they are far from ideal, suggesting further efforts towards its development.

However, it is worth noting that some of these cities have already reached a bike path to main road ratio exceeding 50%. This means that in these cities, bicycles significantly become an alternative to cars as a personal means of transport. Furthermore, they can also serve as an alternative to public road transport. However, there's still a noticeable variation among these leading urban centers. Warsaw, from which a lead over other cities was expected, ranks third in terms of the bike path to road length ratio, with an index of 50.5%.

First place belongs to Wrocław, with an index of 63.3%. The second spot goes to Poznań, with an index of 55.8%. Moreover, the analyzed cities can be divided into two groups. In the first group, bike paths are solely for bicycles. This group includes Szczecin, Warsaw, and Łódź. In the second, paths are shared with pedestrians. This group consists of Kraków, Poznań, and Wrocław. What's important is that all these cities actively monitor bicycle traffic and the needs of residents in this regard. Thus, a necessary system to further support this type of vehicle as an effective and efficient means of moving around the city has been established.

Bicycle transport as a means of personal transportation within the city seems to be not only a possible and available option to replace motor vehicle transport (cars) but also favorable from the viewpoint of decarbonization challenges of road transport (Handy, van Wee, and Kroesen, 2014).

Analyses conducted showed that bicycle transport has potential in the area of personal transport within urban agglomerations. The strengths of this type of transportation in the city outweigh its weaknesses, yet the threats to bicycle transport as a substitute for other forms of urban transport are currently high.

This means that unlocking the potential of bicycle transport in cities requires active efforts to popular-ize this mode of transport and create legal solutions that streamline the implementation of solutions dedicated to this mode of transportation. It all boils down to support from legislators and local authorities, as well as providing funding and creating an environment conducive to such transformations.

Bicycle transport is one of the most accessible and simultaneously zero-emission modes of transport with such significant potential for use in an urban environment (Tomanek, 2022). Many large urban agglomerations worldwide lean towards bicycle transport as an integral part of public transport solutions in the city. However, the transformation of these transport systems is laborious and long-lasting. Moreover, both external factors (e.g., law, transportation culture, or attitude towards decarbonization goals) and internal ones (e.g., urban building structure) play a significant role in it.

At the administrative level, the challenge remains the proper preparation and implementation of such transformations. An issue in the context of urban transport system transformation programs appears to be the lack of a uniform and easy-to-apply methodology for replacing car transport with bicycle transport. In this context, the frame-work solution proposed by the ITF (International Transport Forum) seems particularly useful. The ITF methodology provides a basis for creating simulations considering both static and dynamic demand for space in the city for different modes of transport, including both the length of the distance traveled and idle time.

Thus, it perfectly reflects the real needs and functioning of urban transport using personal means of transport. Furthermore, this methodology also provides a basis for determining (estimating) the level of pollution reduction (e.g., CO2) associated with an alternative (in this case, bicycle) mode of transport. It is, therefore, a very useful solution from the perspective of aiming to reduce decarbonization goals. Simulations conducted by OTF based on this framework show that bicycle transport successfully replaces car transport in the city and additionally generates significant reductions in emissions associated with urban transport.

5. Conclusions

The conducted analyses showed that the current state of road infrastructure for bicycles in Poland is in the development phase. It is characterized by a concentration in large urban centers and selective and limited connections between these centers. The road infrastructure of bike highways or other types of bicycle paths located outside the cities is insufficiently developed. As a result, the current state of bicycle infrastructure does not allow for treating the bicycle as a fully substitutive (compared to cars) means of personal transport in the country.

The situation looks different at the level of provincial cities. Using the example of the largest cities in Poland, it can be stated that the existing bicycle road infrastructure in their area allows for efficient movement by bike within them. While bicycle paths in the largest Polish cities are successively being built and are forming an increasingly dense network of connections, there are still certain areas where one cannot reach by bike without using roads designated for motor vehicles. This is not a favorable situation in the context of the safety of cyclists.

In general terms, the cycling infrastructure in the country still leaves much to be desired, yet it is being continuously expanded. In this context, there is a significant disparity between different provinces. The ratio of the length of bicycle paths to roads intended for cars varies greatly. Provinces with a smaller scale of urbanization more quickly achieve higher ratios between the two types of roads.

This results from the fact that, for example, eastern provinces are characterized by smaller urban centers, which translates into a smaller road infrastructure (for motor vehicles). Consequently, implementing investments related to the construction of bike paths in and outside cities leads to faster development of a favorable ratio between the length of bike paths and roads for cars.

In this context, it's also important to mention the significant role played by local governments. Their initiatives and efforts mainly drive the construction and designation of new bike paths, both within cities and beyond. This leads to the conclusion that they play, and should continue to play, the most significant role in building such infrastructure. However, it's crucial to ensure they receive proper support and funding.

Cycling transport offers the possibility of creating a flexible, affordable, and efficient urban transport system based on the personal means of transport of residents (bicycles). Alternatively, it can be based on public means of personal transport in the form of city bikes (e.g., sharing), which still makes it cost-effective.

Bicycles require much less space to fulfill transport functions in the city than cars. Moreover, they are emission-free modes of transport. Thus, they support the achievement of decarbonization goals. Even their partial use within the urban transport network brings tangible benefits in the form of emission reductions. Therefore, it seems that bicycles as a form of urban transport remain a significant and vital alternative to combustion engine vehicles.

In conclusion, only the second hypothesis (H2) has been fully verified positively, while the other three have been only partially positive. In the case of the first hypothesis (H1), it is true that there are methods and methodologies (frameworks) that allow for determining the theoretical degree of replacing personal car transport with personal bicycle transport in urban conditions, taking into account spatial limitations (availability of space intended for communication routes and accompanying elements) in highly urbanized urban areas.

Unfortunately, there is no widely accepted consensus on this issue. In the context of the third hypothesis (H3), the investments related to cy-cling infrastructure, especially the development of road infrastructure for bicycles within urban centers in the country, are significant from the perspective of the years 2011-2021, so they cannot be considered unsatisfactory.

However, one can argue that they are insufficient. The relative increase is satisfactory, but the spatial and temporal distribution of the absolute increase in the length of bicycle paths in cities provides a basis for this. In the context of the fourth hypothesis (H4), bicycle transport within large urban centers, with the provision of proper and adequately developed infra-structure, can be an attractive alternative to personal road transport and public transport.

Thus, it has the potential to become an important part of the answer to the challenges associated with the decarbonization of road transport, in the context of urban logistics. In practice, activating its potential today depends on environmental conditions, and there is no indication that it will become a real alternative to personal road transport and public transport in the next 10 years. However, it can become an excellent complement to modern and multimodal transport networks in large cities, thereby eliminating the need to own a car.

Attempting to formulate the practical implications arising from the conducted analyses, one can conclude that:

• The development of road infrastructure for bicycles should be entirely based on the actions of local authorities at the city, county, and province level. It is necessary to create a conducive ecosystem (i.e., legal, administrative, and financial solutions) for actions taken by local government units to popularize and integrate bicycle transport into local public transport systems in and outside cities.

• The further development of bicycle infrastructure in the country should be included in a development plan that would provide general guidelines for creating a network of bicycle connections between the largest urban centers and set the rules for integrating bicycle transport into the public transport system.

• Investment and modernization processes of transportation infrastructure in cities should include a mandatory analysis of alternative forms of transport on planned sections of urban roads. In this regard, it seems reasonable to use the mentioned ITF framework solution, which allows for creating simulations considering both static and dynamic demand for space in the city for different types of transport, taking into ac-count both the length of the journey and the stop time. Thus, it perfectly considers the real needs and functioning of urban transport using personal means of transport. Moreover, this methodology also provides the basis for determining (estimating) the level of pollution reduction (e.g., CO2) in connection with an alternative (in this case, bicycle) means of transport.

• It is necessary to create modern intermodal urban communication systems. They should be characterized by flexibility and the ability to meet the needs of city residents as they arise (i.e., be synchronized with these needs). This means the need to create modern, flexible mixed transport systems, where the bicycle should play a significant role. This will allow both unlocking the potential that lies in bicycle transport within cities and reducing emissions from urban transport.

• In future plans for the use of urban space for communication needs, it should be possible to operate many zones - both those with restrictions for specific means of transport and those mixed, where exclusions are covered by a daily and weekly timeframe.

All activities promoting ecological and simultaneously efficient and convenient communication and transport solutions in cities should be carried out in multiple tracks and include - in addition to technical and organizational aspects - also spatial and economic issues (Banach, 2018; Mężyk and Zamkowska, 2019). However, this requires the cooperation of specialists from various fields, including urban planning, economics, urban spatial development, and engineering sciences (Bruntlett and Bruntlett, 2021).

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