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BICYCLE INFRASTRUCTURE: AN ELEMENT OF SUSTAINABLE MOBILITY IN THE WEST POMERANIAN VOIVODESHIP

Summary. This article presents the results of transportation research conducted in the urban area of Koszalin, the region, and the West Pomeranian Voivodeship. The study's purpose is to identify bicycle infrastructure's role in promoting sustainable mobility in the West Pomeranian region. The paper provides an overview of the bicycle infrastructure in the West Pomeranian Voivodeship. The analysis is supplemented by a survey conducted among residents of the West Pomeranian region who use the aforementioned infrastructure. A diagnostic survey using a questionnaire was employed.

1. INTRODUCTION

The bicycle is a faster means of transportation than walking while producing no noise and emitting no pollutants, including harmful gases and dust. Furthermore, it does not contribute to traffic congestion. The design and development of bicycle infrastructure should prioritize the creation of safe, convenient, and aesthetically appealing routes for cyclists. These routes should form a cohesive network within a city or region and should be built in connection with neighboring countries. Additionally, infrastructure hubs should be established for the convenience of users. The concentration of businesses, commerce, services, and people in relatively small urban areas gives rise to mobility challenges, prompting the exploration of alternatives such as cycling. The facilitation of efficient movement requires the development of the necessary infrastructure. Bicycle paths should be clearly designated, and ample parking spaces should be provided in accordance with the regulations [1]. Measures can be taken to enhance coordination and the effectiveness of cycling initiatives and to better engage the input of residents.

The challenges arising from transportation activities in cities and metropolitan areas have prompted a shift in the approach to mobility within these regions. This shift is often referred to as the "new mobility culture." This term should be understood as an elevated level of well-being resulting from improved transportation processes within urban and metropolitan systems. This improvement benefits residents, commuters, visitors, and the owners of the goods being transported. It is achieved through the greater involvement of stakeholders and a balance of economic, social, and environmental objectives [2]. This shift in focus also translates to a change in the approach to urban and regional transportation issues. These initiatives, driven by shifts in goals, tools, and problem areas, collectively form a long-term strategy for the operation and growth of urban and regional transportation. Mobility management emerges as a tool to align transport mobility with sustainable development. Its primary aim is to induce a change in the transportation behavior of communities. This approach is rooted in the use of "soft measures," such as information and communication, service organization, and partnership coordination. These soft measures often necessitate "hard measures," such as infrastructure development [3].

Various sustainable mobility goals can be considered [4-5]:

- striving for rational rather than minimal travel time;

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- treating travel as an independent activity, not just as a means of satisfying a transportation need secondary to primary activities, such as work or study;
- reducing the need to travel (e.g., by shortening travel distances, providing work using remote computer connections);
- increasing the proportion of trips made on foot, by bicycle, and by public transportation relative to trips by personal car;
- reducing the level of air and noise pollution caused by transportation while improving the energy efficiency of transportation;
- increasing capacity utilization through better vehicle utilization;
- increasing the capacity of infrastructure by introducing the principle of payment for its use;
- increasing the quality of urban space, such as by introducing Tempo 30 zones (regarding to 30 km/h speed limits).

Regardless of the concept of sustainable urban development and its defining characteristics, local authorities are actively pursuing initiatives to “green” urban life [6]. The spatial aspect of sustainable development is often closely tied to urbanization and urban planning [7]. Mobility plays a central role in ensuring freedom of movement and a high quality of life. It is intricately linked to sustainability, which guides urban development and transportation strategies. Mobility facilitates access to goods and services, making it a vital component of participation in social and economic life. In fact, it can be seen as a fundamental human right and a marker of personal freedom. Limiting mobility, including situations in which individuals are excluded, curtails these essential rights. The realization of the right to mobility should not infringe upon the rights of others, which is especially important in urban areas where space is limited and alternative transportation methods may be necessary [8].

Sustainable development aims to address the mobility challenges faced by many urbanized areas in Europe. Local development encompasses a series of continuous, long-term processes aimed at leveraging local resources to achieve quantitative growth and qualitative improvement based on community needs [9]. The direction of this development is determined by the community’s needs, local resources, local government, and various organizations and institutions within the municipality [10]. Cities, as hubs of increased mobility demand, are increasingly taking measures to reduce emissions of gases and other pollutants associated with transportation services [11].

Polish local governments have adopted solutions applied in Western European cities (i.e., the appointment of specialists responsible for bicycle traffic, commonly known as bicycle officers) within their administrative structures. Practice shows that in Poland, it is not local governments but social bicycle organizations that lead the way in promoting cycling in the city and spreading the idea of sustainable transportation [12]. In addition, and this is often forgotten, low-emission bicycle traffic and pedestrian crossings are also substitutes for public transportation but, unlike cars, for short distances [13].

2. BICYCLE TRAFFIC AS AN ELEMENT OF A SUSTAINABLE TRANSPORT SYSTEM

An urban transportation system in which residents have only the passenger car as their mode of choice (because it is the only one that gets them from point A to point B at a relatively low cost and in a relatively short time) is less “sustainable” than a system in which residents have an affordable and fast alternative form of a streetcar, bicycle, or subway [14]. Some means of transportation, primarily electric boards and scooters, are currently developing dynamically in Europe and, thus, in Poland. The latter is considered an important instrument of sustainable development in collaborative consumption (sharing economy) [15-16] and has already appeared on the streets of virtually all European and Polish cities. In addition to its primary function of moving people from point A to point B, bicycle transportation has many additional functions, which include tourist, recreation and sports, and health functions. Bicycle infrastructure, therefore, needs to be continuously upgraded and expanded with new facilities to meet all kinds of user needs [17]. The design and creation of bicycle infrastructure should lead to providing cyclists with the safest, most comfortable, and most attractive routes possible, forming a coherent bicycle system that should meet the following conditions [18]:

- cross-section and gauge,
- riding in pairs side by side,
- the resistance experienced by the cyclist while riding,
- the limits of physical and mental stress to which a cyclist is exposed,
- bicycle traffic as an integral part of road traffic, the transportation system, and accompanying policy.

In addition, inadequate preparation for cycling due to a lack of the authority of safety equipment can result in loss of health. Riding a bicycle on the street rather than on designated paths not only causes difficulties on the road but also involves risks for the riders. Fortunately, few such accidents occur, and 2019 statistics showed that the number of accidents per 1,000 residents in major cities ranged from 0.4 to 0.81 cyclists in 2020. Poles were involved in 3,768 traffic accidents. This is 658 fewer accidents than in 2019, but still a very sad statistic. In 2020, 249 cyclists were killed in accidents, and 3,403 people were injured, including 3,393 cyclists and 10 passengers.[19] Other road users, particularly those operating passenger cars, have also significantly contributed to most accidents involving injured cyclists, underscoring the need for enhanced bicycle infrastructure. The effectiveness of this infrastructure depends on properly designing it so that it effectively separates bicycles from regular urban traffic to enable faster and safer movement. The most advantageous approach is sustainable transportation, which prioritizes public health and aligns with transportation needs in line with the principles of utilizing renewable resources below their regenerative capacity and non-renewable resources below their depletion threshold [20].

Many studies emphasize that the basis of building the bicycle infrastructure is the limiting conditions resulting from the specific nature of the means of transport, which is the bicycle. When designing bicycle infrastructure, three principles should be observed [21-23]:

1. the principle of maximum efficiency at the lowest possible cost to achieve the best possible results with a given technical solution.
2. the principle of the “weakest link”: bicycle infrastructure should take into account the needs of the weakest users (children, the elderly, and cyclists on non-standard bicycles),
3. meeting the five requirements of Centre for Research and Contract Standardization in Civil and Traffic Engineering (CROW). The Manual for Bicycle Traffic is a publication on bicycle transportation planning and engineering in the Netherlands. It is published by CROW, a non-profit agency advising the Directorate-General for Public Works and Water Management, formerly the Ministry of Transport and Water Management (Netherlands). It is the most influential bicycle traffic planning manual both worldwide and in the Netherlands. It was last updated in 2016. It is considered best practice [23-24]:

- consistency – creates a whole that connects all cyclists’ sources and goals;
- directness – offers an optimal route due to the length of the route and its travel time;
- safety – guarantees traffic safety for cyclists and other road users;
- attractiveness – designed and adapted to the surroundings in such a way that cycling is relatively more attractive compared to other modes of transportation;
- convenience – allows for quick and convenient travel by bicycle.

However, the roads or bicycle paths themselves are only an element of the broader linear bicycle infrastructure, which also consists of appropriate road signage, signaling, bicycle racks, etc., which determine the functionality of bicycle path solutions.

Point-to-point infrastructure is just as important as linear infrastructure and makes bicycle use much more enjoyable. Point-to-point bicycle infrastructure can include [25-27] bike rooms, bike parking spaces, and bike lifts. Additional elements complement the overall infrastructure and make it easier to use, such as bike racks or automatic detection of cyclists in the form of microwave radar or induction loops [28].

Moreover, numerous authors emphasize the pivotal role of cycling in urban sustainability and its significance in the context of smart cities [29-31]. Studies on smart urban mobility incorporate cycling as a key component of mobility as a service [32-34]. They consider bikeways a critical sub-indicator within their technical infrastructure criteria [35-37]. A city lacking a robust bikeway system cannot be classified as a smart city, as it would struggle to implement innovative concepts like bike sharing. Bike-

sharing systems, by which bicycles can be briefly rented and tracked through smartphone apps, offer considerable benefits for cities [38-39].

Bicycle routes should be seamlessly integrated with public transport, with a preference for rail transport, which provides optimal opportunities for bicycle transportation. Long-distance routes should strategically connect what are known as “nodal points,” which are locations that serve as integral components of rail, bus, or ferry networks and are within reasonable cycling distance (ideally up to a maximum of 150 km, but shorter segments are preferable). To ensure the smooth and safe operation of bicycle paths, responsible authorities must maintain them effectively. The surfaces must remain consistently flat and unobstructed and must feature clear signage for cyclists and other road users.

3. CHARACTERISTICS OF THE BICYCLE TRANSPORTATION SYSTEM IN THE WEST POMERANIAN VOIVODESHIP

The province has a population of 1,682,003, a population density of 75 persons per km², and an urbanization rate of 68.9%. West Pomeranian Voivodeship consists of three cities with county rights (Szczecin, Koszalin, and Swinoujście) and 18 counties. In the province, 51.4% of the population is female and 48.6% is male. Between 2002 and 2021, the population decreased by 0.9%. Moreover, 59.5% of the voivodeship’s residents are of working age, 17.2% of pre-working age, and 23.2% of post-working age. The average age of residents is 42.7 years, which is comparable to the average age of Polish residents. The capital of the West Pomeranian region is Szczecin, located at the mouth of the Oder River into the Szczecin Lagoon. The city covers an area of 300.8 km², of which 41.6% is green space and 23.9% is land under water [40]. In terms of the size of the year-round accommodation base (51,600 places), the West Pomeranian region ranks third in Poland. The average length of stay (5.3 days) is the longest in Poland, indicating the leisurely nature of tourist arrivals. The tourism intensity index, 131.5 per 100 residents of the province, ranks the West Pomeranian province first in the country and is more than twice as high as the national average (65.1). This allows us to conclude that the West Pomeranian Voivodeship is among the top tourist regions in Poland, and active recreation, such as cycling, can play an important role. The creation of a comprehensive network of provincial bicycle routes could significantly improve traffic conditions and increase the attractiveness of the region as a place of residence and recreation. The Concept for the Construction of a Network of Bicycle Routes of Western Pomerania, developed in 2015 by the Regional Spatial Management Office of the Western Pomeranian Voivodeship in cooperation with the substantive departments of the Marshal’s Office, is a planning area for the development of bicycle transportation. Its preparation took a year and cost PLN 550,000. The next stage is the construction of 1,100 km of routes, for which about PLN 222 million has been allocated between 2016 and 2023 [41].

Western Pomerania is crossed by two international routes belonging to the EuroVelo network and nine regional and provincial routes (Table 1).

With the development of bicycle infrastructure, bicycle rental systems are being created. In Europe, the scale of bicycle rental is at the level of 70% (of all bicycle rental systems). The trend of using rented bicycles as a means of transport began in the late 1990s in Copenhagen. The data in Table 2 present the development of this phenomenon in Poland in Western Pomerania.

The West Pomeranian region has a bicycle-sharing system in five localities, where the main operator is the Nextbike company (located in four cities), while the oldest urban bicycle system is located in Szczecinek.

4. RESEARCH METHODOLOGY

An important topic undertaken by researchers in the context of sustainable development is the impact of changes in the functional structure of cities on the quality of life of their residents [46-47]. Studies on cycling in urban space rarely refer to the territory of Poland in articles on bicycle communication in urban space [48-50]. Such studies have dealt with the infrastructure of bicycle communication in the

city of Szczecin [51-52] and not the region. In earlier studies, bicycle communication was undertaken in short sections. The purpose of the present study is to identify bicycle infrastructure in the formation of sustainable mobility in the West Pomeranian region.

Table 1

Bike-sharing systems in Western Pomerania [42-45]

Route name	Distance [km]	Beginning - end of the route
Euro Velo (EV10)	514	Szczecin - Gdansk - Klaipeda - Riga - Tallinn - St. Petersburg - Helsinki - Haparanda - Stockholm - Copenhagen
Euro Velo (EV13)	793	Kirkenes (Norway) - St. Petersburg - Gdansk - Szczecin - Lübeck - Vienna - Strumica - Rezovo (Bulgaria)
Western Lakes Route	423	Cedynia - Mysliborz, Barlinek, Choszczno, Insko - Szczecin - Drawsko Pomorskie, Zloceniec - Czaplinek - Szczecinka - Bialy Bor
Old Railway Route	231	Kołobrzeg - Mielno - Koszalin - Bialogard - Połczyn Zdrój - Zloceniec - Swierczyna - Walcz
Route Around the Szczecin Lagoon	170	surrounds the Szczecin Lagoon and runs mostly within the municipalities of the Szczecin Metropolitan Area
Route of the Tywa Valley	100	Gryfino - Trzcińsko - Zdrój - Dębno - Chwarszczany - Kostrzyn
Route of the Pomeranian Wall	230	Darlowo, Slawno, Szczecinek - Walcz - Drawsko Pomorskie
Route of the Rega Valley	180	Mrzezyno - Trzebiatow - Gryfice - Płoty - Resko - Lobeż
Route of the Winding Tracks	125	Kołobrzeg - Bialogard
Ploni Valley	65	Mysliborz Lakeland
Lower Oder Route	152	Szczecin through the Oder Valley to the southwestern border of the province
Route of Palaces and Castles	168	Wolin - Krag near Polanow

Table 2

Bike-sharing systems in Western Pomerania

City	Operator	Start-up year	Number of stations	Number of bicycles
Kołobrzeg	Nextbike	2017	13	135
Koszalin	Nextbike	2018	10	100
Szczecin	Nextbike	2014	87	520
Szczecinek	Comodrev	2009	22	150
Tychowo	Nextbike	2017	2	20

This is justified by the growing number of supporters of this type of communication. This paper presents the results of transportation research conducted in the urban space of Koszalin, the region and the West Pomeranian Voivodeship. It illustrates the current conditions of cycling in the area of the West Pomeranian Voivodeship and attempts to determine whether the bicycle can be an alternative means of transport to other modes of travel not only for short distances but also across the entire voivodeship.

The favourable terrain and relatively favourable development of space mean that the actions taken in the field of bicycle infrastructure development result in an increase in the number of routes and an increase in the possibilities of their use as part of rented city bikes. It should be noted that there are still

areas where the key barriers to development and cycling are inadequacies of transport infrastructure to the needs [53]. A study of the transport accessibility of cycling Polish with neighbouring EU countries showed an improvement by strengthening the links between the main cities of the macro-region and Berlin, Dresden, Copenhagen and Prague (as part of the EuroVelo routes 10 and 13). Increasing transport accessibility is treated as a priority by local government units, as it is a kind of economic offer of the macro-region aimed at increasing the number of tourists and the sale of accompanying services. Therefore, new concepts of cycling routes, with the right involvement of all stakeholders, can be more than just a regional tourism product.

For the purposes of the study, a survey was carried out using a questionnaire among the inhabitants of the West Pomeranian Voivodeship who are users of the bicycle infrastructure in question. The survey included 396 people who live in West Pomerania and regularly ride bicycles. The survey showed that 54% of the respondents were women and 46% were men. Respondents were assigned to six age categories, with the largest group being those aged 36-45 (39.4%). The next largest group was those aged 46-55 (25.3%). In second place were those aged 26-35 (10.6%). Only 10% of respondents were aged 56-65 (10.1%). The least numerous groups of people in the survey were those aged 18-25 (6.6%) and those over 65 (8.1%). Based on the survey, it is possible to determine the respondents' place of residence:

- 200,000 to 500,000 residents (24.7%);
- rural residents make up 22.% of the respondents;
- respondents living in cities with up to 20,000 residents make up 17.7% of the respondents;
- residents of cities with 20,000 to 50,000 residents make up 10.6% of the respondents;
- residents of cities with more than 500,000 residents make up 10.1% of the respondents;
- only 8.1% responded that they live in cities with 50,000 to 100,000 residents;
- 6.8% of respondents were residents of cities with 100,000 to 200,000 residents.

From the structure of the presented responses, it is clear that cycling is most popular among middle-aged people. This group is very likely to include people who have already formed habits, as well as those who have some experience from the past connected with cycling, which is extremely important in this study and can give an idea of the veracity of the answers given.

5. RESULTS

The bicycle is a frequently chosen means of transportation. Fig. 1 shows the means of transportation chosen by respondents. Nearly 60% of respondents declared that they get around either by car or bicycle on a daily basis. Another large group is those who move on foot on a daily basis (27.8%). Public transportation is a similarly popular mode of transportation, chosen by 16.7% of people. Respondents also pointed to such modes of transportation as motorcycles, electric scooters, private transportation methods, city bicycles, and trains. By inference, respondents do not use only one mode of transportation. Their choices probably depend on a number of factors, such as seasonality occurring in Poland, weather conditions, distance to be traveled, and proximity to bicycle paths.

Respondents are familiar with the concept of the West Pomeranian Bicycle Route Network. Respondents were provided with a list of all routes and had the opportunity to add their own suggested answers regarding their familiarity with bicycle routes in the West Pomeranian region. The vast majority of respondents recognized four main priority routes: the Velo Baltica Route (77.3% of respondents), the Western Lakes Route (51.5%), the route around the Szczecin Lagoon (61.1%), and the Old Railway Route (48.5%). Respondents were slightly less likely to associate other trails included in the concept of the West Pomeranian Bicycle Route Network (Fig. 2). Additional trails that respondents presented included the Oder-Nysa Route, the Oak Route, the Green Necklace of the North, and the Salt Route. Overall, the West Pomeranian community is up to date on matters concerning the design of new bicycle routes and their concepts.

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Oder-Nysa Route, the Oak Route, the Green Necklace of the North (EV10) and the Salt Route. Overall, it is apparent that the West Pomeranian community is up to date on matters concerning the design of new bicycle routes and their concepts.

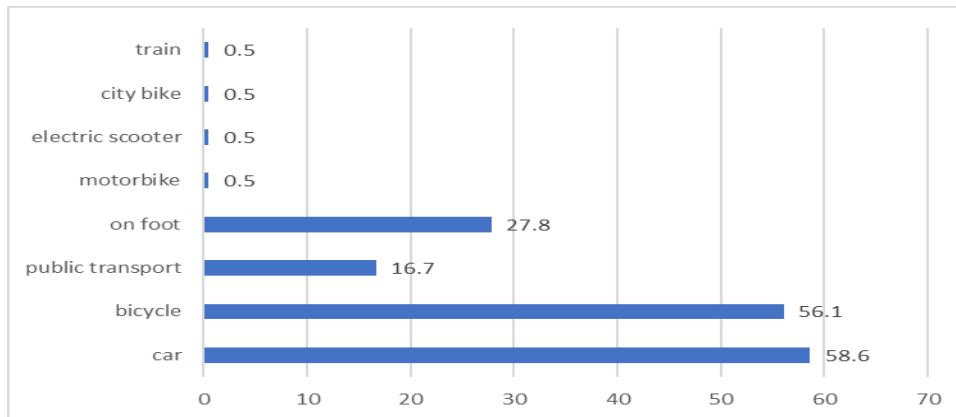


Fig. 1. Means of transport chosen by respondents

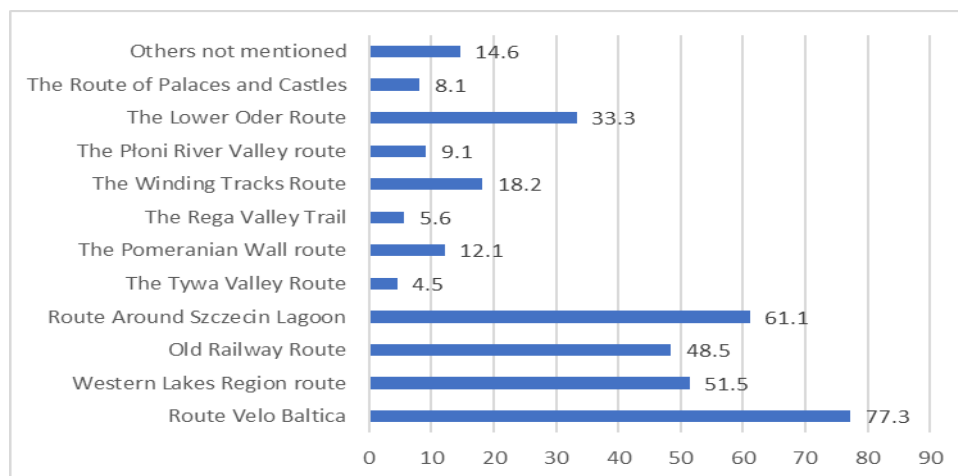


Fig. 2. Knowledge of bicycle routes in the West Pomeranian Voivodeship

The majority of respondents would definitely recommend touring the West Pomeranian Bicycle Route Network as a form of recreation (63.1%), while 27.3% would also recommend such a form of recreation. Only 7.6% of people had no opinion on the subject (Fig. 3).

The rise in positive feedback suggests that these paths are in excellent condition, making users feel safe while using them. This positive response also bodes well for the promotion of this recreational option. Negative feedback may come from individuals who had different expectations for these trails. The survey included an assessment of bicycle infrastructure in the West Pomeranian region (Fig. 4).

The most frequently chosen answer was that the condition of the bike paths is rather good, and this answer was chosen by exactly 50.5% of people. For another 17.2% of people, the condition of the paths is definitely good. As many as 20.7% of people had no opinion on the condition of bicycle paths, and 3% of people indicated that it is definitely bad.

The divergent opinions of the survey respondents on the state of bicycle paths show that the main factor differentiating these responses is that they come from different areas of West Pomerania, and their opinions concern one or two to three bicycle paths.

Fig. 5 shows that respondents feel safe on bicycle paths in the West Pomeranian region. The vast majority of respondents considered cycling routes to be safe, including 33.8% definitely safe and 38.4% somewhat safe. Almost 20% of people had no opinion on safety on bicycle paths in West Pomerania.

This proves that people using bicycle transport on the routes in question in the West Pomeranian Voivodeship feel safe. This sense of security is also the result of the use of horizontal and vertical

markings on the bicycle infrastructure. This is confirmed by the results of the survey, as 76% of respondents believe that vertical infrastructure is adequately applied (25% indicated that it is "clearly visible" and 51% that it is "quite visible"). The results in the assessment of horizontal infrastructure are slightly worse, where only 23% of respondents indicated "good visibility" and 44% considered it to be "quite visible". Ensuring the visibility of signs is essential for all road users to be aware of the infrastructure they are utilizing.

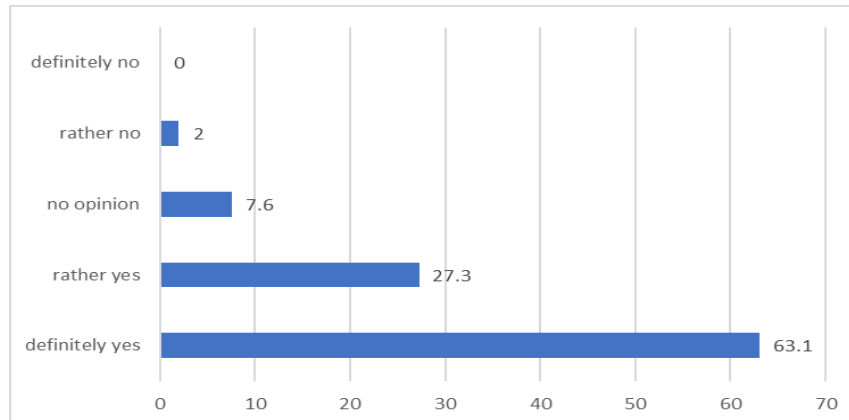


Fig. 3. Respondents' recommendations of West Pomeranian bicycle routes as a form of recreation

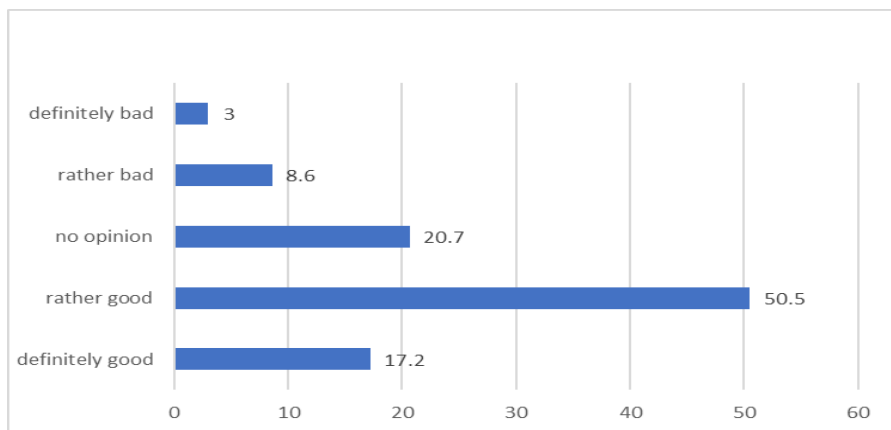


Fig. 4. Evaluation of bicycle routes in the West Pomeranian province

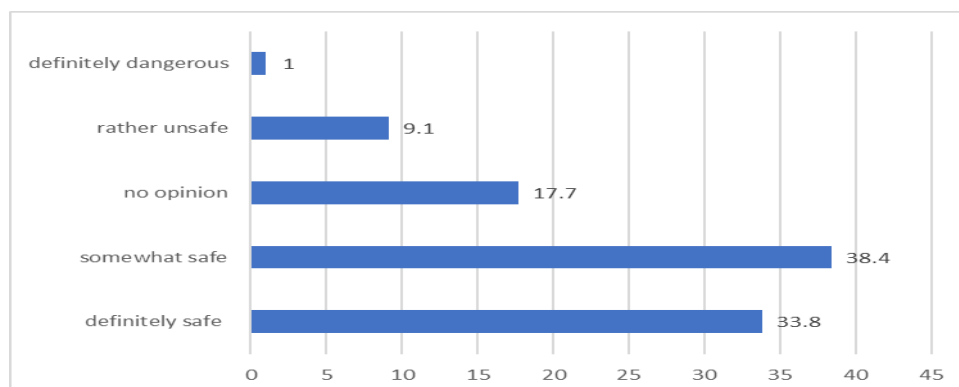


Fig. 5. Perception of safety of those using bicycle paths in Western Pomerania

6. CONCLUSIONS AND RECOMMENDATIONS

The future of bicycle routes in the West Pomeranian Voivodeship hinges on the proactive engagement of individuals who view cycling as both a recreational activity and a part of people's daily

routines. The pursuit of enhanced coordination and increased effectiveness in advancing bicycle traffic while giving due consideration to public opinion is exemplified by the utilization of surveys and their outcomes, which is a practice borrowed from Western European cities.

The feedback from respondents provides a clear call for the enhancement of cycling infrastructure through the establishment of designated paths and the creation of new connections. These improvements will not only elevate the status of the West Pomeranian Voivodeship but also contribute to its overall development. Adequate transportation connections, including roads, streets, pedestrian routes, bicycle paths, and public transport systems, are indispensable for the well-being of the area's residents and the vitality of urban life. Transport system concepts within the city must be coherent, comprehensive, and user-centric. Furthermore, cycling infrastructure should be integrated across the national, regional, and city levels.

The enhancement of transportation accessibility for external urban functional areas is a pressing issue. Promoting the sharing economy, the "smart city" concept, and low-emission transportation in the West Pomerania region should take precedence. The existing and planned bicycle infrastructure within the West Pomeranian Voivodeship has the potential to encourage a substantial portion of residents to opt for cycling as their daily mode of transport while maintaining the competitiveness of cycling compared to car transportation. The bicycle plays a vital role in sustainable transportation development and exemplifies the principles of the sharing economy. It remains a relatively new phenomenon, but in the case of the West Pomeranian Voivodeship, it stands as a fundamental means of transport and a cornerstone of tourism policy. In this region, it serves both as a means of recreation and a catalyst for active leisure. When assessing and analyzing bicycle infrastructure, Western Pomerania can be regarded as an area in Poland characterized by some of the most favorable parameters. This is attributable to its design principles, favorable economic and climatic conditions, and the positive attitudes of not only the local population but also youth and foreign tourists.

This study revealed that a significant number of respondents are familiar with the West Pomeranian Cycle Route Network and were inclined to endorse cycling along these routes as a recreational activity. The data indicate that over 50% of participants expressed that they use bicycles for transportation. However, their usage depends on external factors, including linear and point infrastructure.

In line with sustainable development policies, the bicycle should be recognized as a significant urban transportation mode and should be integrated into the strategy of the West Pomeranian Voivodeship. Electrification may act as a catalyst for cycling in cities. The electric bicycle market is in its early stages but is growing rapidly, and electric bicycles should be incorporated into city rental systems as well.

Transport policies, not only in cities but also in regions and voivodeships, should strive to ensure an appropriate quality of life, which is assessed both objectively and subjectively. Therefore, it is imperative to adopt the principles of sustainable transportation development policy that take into account residents' well-being.

Residents can shape the future of urban transportation, which should predominantly favor eco-friendly public transport, cycling, and walking. While conducting this study, the authors recognized the need to expand analytical research assessing the social, economic, and environmental benefits that will be experienced by both residents and tourists as a result of the sustainable development of bicycle infrastructure in the West Pomeranian Voivodeship. Simultaneously, the authors are contemplating conducting further comparative analyses of this issue with other voivodeships in Poland.

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