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Effectiveness of Urban Mobility Decarbonization Instruments

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Abstract: Decarbonization of urban mobility requires complex, interconnected actions. The instruments for decarbonizing urban mobility include urban collective transport, bicycles and means of personal transport, cybermobility and electromobility. The article presents the results of research on the transport behavior of the creative class, the effects of the COVID-19 pandemic on the functioning of urban mobility, and the results of research on the efficiency of electromobility in the field of the implementation of battery-powered buses. The research was aimed at a critical assessment of the current mobility model and creation of the basis for change in this area. In particular, these studies focused on changes in transport needs and greater use of cyberspace for various activities, which should reduce the volume of physical flows of people in urban transport networks. The aim of the article is to present the conclusions of these studies in terms of their use to change mobility models in cities. The practical significance of the presented research consists in indicating the factors of building individualized urban mobility strategies, with particular emphasis on the issues of sustainable development and decarbonization. The authors' contribution to the development of science is demonstration of the possibilities of changing the mobility model in the city and reducing greenhouse gas emissions. In particular, this applies to urban metropolises that are moving away from heavy mining and processing industries, i.e., the number of jobs in business and educational services is increasing, and the industry of new technologies is developing. The conclusions formulated in the paper indicate, in particular, the significant decarbonization potential of cybermobility and the use of zero-emission means of transport, such as bicycles and scooters, which can be released by changing the approach to the organization of work and learning, in particular their virtualization and deconcentration of travel sources.

Keywords: decarbonization of mobility; electromobility; COVID-19 pandemic; battery-powered buses; cyberspace for activities

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1. Introduction

Mobility in cities is one of the main sources of greenhouse gas emissions, which is why the decarbonization of mobility is important in protecting the climate. The instruments for decarbonizing urban mobility include urban collective transport, zero-emission bicycle and personal transport, electromobility and cybermobility. These instruments were indicated on the basis of a review of the literature and practice of implementation works carried out by the authors in Poland. The context of the selection of instruments for further analysis is presented in publications [1–4]. Research on the specificity, effectiveness and competitiveness of these instruments is conducted in many research centers around the world. The article presents the work carried out in this area by researchers from the University of Economics in Katowice and the Silesian University of Technology in Gliwice (in Poland).

The research of the University of Economics in Katowice covered the modeling of mobility in agglomeration areas and concerned two problems: the communication behavior

of the creative class in the three largest Polish agglomerations and the change in mobility caused by the COVID-19 pandemic.

At the Silesian University of Technology, the effectiveness of electromobility in the field of battery-powered buses was tested. The research concerned the analysis and assessment of the possibility of implementing such buses by organizers and operators of public collective transport and the development of tools supporting the creation of strategies for such activities.

The aim of this article is to present the conclusions of these studies in terms of their use to change urban mobility models. For this purpose, research questions were formulated, described in more detail in Section 2.2, which concern the examination of the possibility of changing mobility models and the use of the experience of the COVID-19 pandemic in this regard and the assessment of the susceptibility of communication lines to be operated by electric buses. The creative class sets future trends in the field of communication behavior, remote work and learning experiences during the pandemic, showing the possibilities of limiting physical mobility in cities, while electromobility research identifies the critical issues of using alternative drives in mobility, including the risks resulting from an uncritical approach to this instrument.

In the first part of the paper (Section 2), the purpose of the research problem is justified in terms of the literature review, methodology of the presented empirical research on mobility, as well as a brief description of research projects on electromobility. In the second part (Section 3) of this paper, the results of the research on mobility of the creative class and the results of research on mobility under conditions of movement restrictions are presented in detail. As a supplement to these results, the key results of scientific and research projects on electromobility in the aspect of the implementation of battery-powered buses are presented. The third part of the paper (Sections 4 and 5) consists of synthetic conclusions from the presented research results and a discussion constituting a critical assessment of the current mobility model and creating the basis for changes in this area, which was the purpose of this article. The paper ends with conclusions (Section 6).

The authors' contribution to the development of science is the demonstration of the possibilities of changing the model of urban mobility and reducing greenhouse gas emissions. In particular, it concerns the Upper Silesian and Zagłębie Metropolis, which is moving away from heavy mining and processing industry, i.e., the number of jobs in business and educational services is increasing, and the industry of new technologies is developing. Thus, the creative class is becoming more numerous and has an increasingly strong impact on various aspects of life, including mobility. The importance of the creative class for shaping mobility models is growing especially in the studied agglomerations, which, in the conditions of economic and energy transformation, not only grow, but, above all, change their character. The practical significance of the presented research consists in indicating the factors of building individualized urban mobility strategies, especially taking into account the issues of sustainability and decarbonization.

2. Research Characteristics

In this section, the purpose of the research problem is justified in terms of the literature review, methodology of the presented empirical research on mobility, as well as a brief description of research projects on electromobility.

2.1. Literature Review

The empirical research was preceded by a literature review, in particular in the scope of —the role of mobility in urban development,—factors shaping communication behavior,— the role of the creative class as an indicator of the development of mobility in metropolises,— characteristics of mobility balancing instruments.

The literature review was carried out as part of the research conducted in 2018–2021. A full list of sources examined and used is presented in three monographs prepared at the

University of Economics in Katowice [1]—the publication a review and it is here that a broad, critical review of the literature can be found [3,4].

The literature defining the role of urban mobility consists primarily of reports from international organizations such as UN-Habitat [5], EU [6] and EMTA [7]. Based on the data and analyzes of these organizations, it was possible to present the model of urban mobility that existed before the pandemic. The processes characterizing this model have been widely described in the literature, e.g., by A.R. Cuthbert [8], J. Szołtysek [9], A. Brdulak and H. Brdulak [10].

The dominant view in the literature is that public transport plays a leading role in the sustainable development of cities. Publications on mobility focus primarily on urban collective transport [11], sharing means of personal transport and managing urban space in terms of limiting the access of cars to cities; the key instrument here is the parking policy. A lot of publications concern the factors that influence the development of mobility and communication behavior. In Poland, research on transport behavior supported by marketing research has been conducted on a large scale for many years by scientists from the University of Gdańsk in Poland, who combine theory with practice at the Public Transport Authority in Gdynia City. Among the authors of publications in this field, O. Wyszomirski [12] and his associates should be mentioned above all [13].

In the search for the future model of mobility, the opinion of the creative class was used in the research presented in this article. The creator of this concept is Richard Florida who, already in 2002, in his works [14,15], drew attention to the influence that this group of scientists, engineers, artists, designers and architects, programmers, representatives of opinion-makers and creative professionals working in various fields can exert on different areas of life, including the development of mobility service models.

The literature on mobility balancing instruments that simultaneously cause decarbonization is equally extensive. In general, publications concern sustainable development and those concerning public transport, bicycles and personal transport, and in recent years also electromobility, come to the fore. Sustainable mobility instruments are the basis for building Sustainable Urban Mobility Plans (SUMPs), and this practical challenge implies publications that are both theoretical and practical—they appeared already in the 20th century and concerned shaping transport policy in accordance with the principle of sustainable development. The work of S. Marshall and D. Banister, devoted to the reduction in external costs [16], should be especially mentioned here.

In Poland, publications mainly concern urban collective transport, including its organization. Among the relevant authors, one should mention especially O. Wyszomirski, W. Starowicz, and M. Wolański [17]. A special role is played by cyclical conferences devoted to public collective transport organized by the scientific community of the Cracow University of Technology. Articles from these conferences are published in the journal *Transport Miejski i Regionalny* [18].

Recently, papers have also been published presenting newly developed methodologies regarding the concept of designing public transport systems using systems engineering methods [19–22]. For the metropolitan area of Upper Silesian and Zagłębie Metropolis (GZM), which is the area of research presented in this paper, a methodology for designing metropolitan rail transport introduced by Karoń G., Janecki R., Mikulski J. [22,23] can be indicated. This is important because in this methodology, the main issue is the aspirations of stakeholders who are residents of Metropolis GZM regarding their mobility and accessibility to metropolitan rail transport in connection with other means of transport. It is also worth recalling that rail transport is one of the basic transport systems that has long favored decarbonization due to the use of electric traction. Therefore, it is also a means of transport that should be included in electromobility.

There are also more and more research papers and publications on electromobility, including critical papers drawing attention to the ambiguity of own and external cost accounting. The most recent publications include articles by economist M. Wolański [17] and representatives of technical sciences M. Bartłomiejczyk and M. Połom [18]. An inter-

esting issue in the context of the research presented in this article is the issue of lowering prices, and especially the introduction of zero tariffs in public transport—Free Fare Public Transport (FFPT). This issue was discussed in the literature, e.g., by H.J. Baum [24], N. Fearnley [25] or A. De Witte et al. [26]. R. Tomanek wrote about it in Poland [27].

Research works concern both the assessment of the possibility of implementing Battery Electric Buses (BEV) [28], as well as systemic analyzes of the use of Electric (EV) [29–33] and Hybrid Electric Vehicles (HEV) [34].

The results indicate that the implementation of electric buses requires taking into account many decision-making problems, among which are issues related to economic conditions to introduce the battery drive to buses in the urban public transport and especially models of total cost of ownership (TCO) for the conversion of the conventional bus to electric one [35–38]. Moreover, research indicates the development of tools to support electric bus deployment in transport networks taking into account development tendencies and economic models of electric buses implementation [39].

On the other hand, the issues related to Electric (EV) and Hybrid Electric Vehicles (HEV) include advanced problems in the design, implementation, and operation of EVs. Among others, issues persist concerning the energy efficiency of the operation of such vehicles, both in terms of optimizing routes in the smart cities [30] and taking into account the installation of batteries in vehicles, topologies for fuel cells and energy-management systems with intelligent batteries, the operation of a microgrid network with EVs, and the use of EVs in power systems with renewable energy resources [31,32]. Electric (EV) and Hybrid Electric Vehicles (HEV) are the alternatives for conventional vehicles with combustion engines for decarbonization of mobility [34]. It is worth emphasizing that, according to the author's own experience [35], HEV vehicles have an additional property that is rarely mentioned and which is not present in EVs. This property applies to some models of HEV vehicles with a very well-designed power control unit, which allows driving such a vehicle even during the failure of the electric subsystem in the hybrid system. Driving then takes place using only the internal combustion engine, but in a special emergency mode, i.e., with significantly reduced power and speed. This is a very useful advantage of HEVs, which increases their reliability in accordance with the "operating in failure" design principle, which is complementary to the "fail-safe" design principle in systems engineering.

2.2. Characteristics of Empirical Research on Mobility in Agglomeration Areas

In research on urban mobility conducted at the University of Economics in Katowice, two research questions were formulated:

- How will urban mobility models change in the future? This question was verified based on the study of the behavior of the creative class.
- How can shock situations such as the COVID-19 pandemic affect mobility behavior and future mobility patterns?

In the case of the study of the creative class, a questionnaire was used, which allowed to examine opinions in three metropolitan areas in Poland: Warsaw, Gdańsk and Katowice. Spatial characteristics of the studied metropolitan areas are included in the publications [2,3]. The PAPI method (Paper And Pen Personal Interview) was used and 150 survey interviews were conducted in each of them in 2019. The creative class was selected for the research, because based on the literature review it was assumed that it is the attitudes and behavior of the creative class that determine the development of post-industrial societies [15]. The research results were analyzed and presented in a publication published by the authors of the project [3]. In addition to the characteristics of the mobility behavior of the creative class, the research showed that respondents are not very optimistic about mobility balancing tools related to the sharing economy, such as systems of public scooters or bicycles. Interestingly, the purchase of an electric car is also perceived as a distant and expensive prospect. Although the creative class sees the disadvantages of individual motoring, the priority of the respondents is to meet the mobility needs related mainly to

commuting. During the COVID-19 pandemic, there have been significant changes in the mobility experience. In particular, the transition to remote work and learning resulted in a decrease in transport intensity, which was visible in the form of much lower car traffic, as well as reduced travel by public transport. In addition, public transport recorded a significant decrease in transport as a result of supply constraints: the number of seats in vehicles was limited and this also resulted in a decrease in transport, so not only demand decreased, but also supply.

The study of mobility during the pandemic was carried out in Katowice, a city with a population of approximately 290,000 and the center of an agglomeration with over two million inhabitants. Katowice belongs to the metropolitan association (together with other 40 local government units) which is called the Upper Silesian and Zagłębie Metropolis (GZM). As part of the research work, an analysis of traffic intensity was carried out based on data from the city's road monitoring system, an analysis of data on the flow of people between city districts (mobile network data), and qualitative research carried out using a questionnaire in a mobile channel on a group of one thousand respondents. The results of the research are presented in the publication of the author's team [4]. The road monitoring system in Katowice city consists of 10 measurement points equipped with cameras that allow the identification of vehicles in two directions of traffic. The data obtained from this system made it possible to assess the decrease in vehicle traffic during the lockdowns, which in particular made it possible to assess the impact of remote work and remote learning on mobility. The information obtained from the data warehouse made it possible to assess the decrease in the movements of mobile phone users and indicated their directions between 22 districts of Katowice for the first half of 2019 and the first half of 2020. In the period of 23–30 June 2021, qualitative research was also conducted using interviews on mobile devices. A total of 1000 people out of approx. 290,000 inhabitants of Katowice participated in the research, characterizing their communication behavior in the questionnaire before and during the pandemic. Invitations to participate in the survey were only granted to those persons who were present in the area of Katowice between 22:00 and 6:00.

2.3. Electromobility Research

Scientific and research projects conducted in the years 2014–2020 in Upper Silesian and Zagłębie Metropolis (GZM) on the issues of implementing electric buses with a battery drive was focused on answering the questions related to the susceptibility of existing bus lines to handling electric buses [28].

One of the main factors in this case is the terrain, with lines running on hillsides which significantly increase the electric energy consumption from the battery by the drive system while driving on a hill and thus significantly shorten the range (course) of the bus between successive cycles of battery charging [39]. The traffic conditions in the city network also affect the interval between charging the batteries of electric buses. This affects the specific profile of electricity consumption when driving at low speed and with frequent stops of the bus in the queue of vehicles waiting to enter the intersection without traffic lights and with traffic lights without priority and with priority for buses [36].

The analysis of the bus operation process in terms of the implementation of electric buses involves additional main problems with the type of technical equipment necessary for their operation and the problems of spatial distribution of various types of power supply devices for charging electric buses, on the route (e.g., at stops or between stops) or at end points (end stops or loops) [38].

3. Application to Case Studies on Urban Mobility

In this section, the results of the research on mobility of the creative class and the results of research on mobility under conditions of movement restrictions are presented in detail. As a supplement to these results, the key results of scientific and research projects on electromobility in the aspect of the implementation of battery-powered buses are showcased.

3.1. Mobility of the Creative Class

Research on the creative class shows that public transport is less competitive than cars, which, given the primacy of accessibility, means that despite its higher efficiency, public transport is less often chosen to meet mobility needs than cars. In the surveyed urban agglomerations in 2019, only in Warsaw the creative class chose public transport more often than the car, and in the Metropolis GZM, as much as 57% of trips were made by car. For the entire population, according to other data, this indicator was lower, and in the 2017 study amounted to 51% [4]. The reasons for this situation should be sought in the criteria for choosing the means of transport. In Metropolis GZM, the criterion of time is mentioned as the key factor in choosing a means of transport, as both in Warsaw and in the Tri-City, respondents from the creative class clearly put the issue of costs first, then, usually, convenience, and then time (Figure 1).

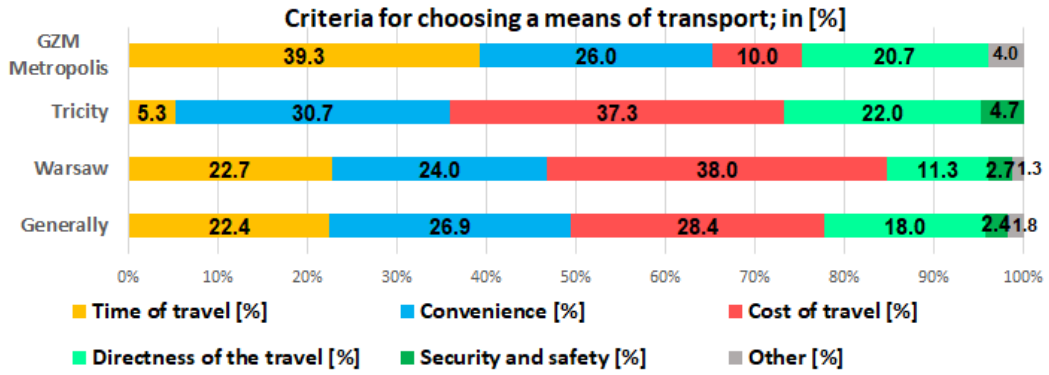


Figure 1. Criteria for choosing a means of transport. Source: based on [3].

In the current model of mobility in the area of the Metropolis, the key factor influencing the choice of means of transport is time, which means that optimization activities aimed at changing the service structure should focus on investments and organizational activities allowing to shorten the travel time by means of transport alternative to the car. Such a hierarchy of criteria is caused, among others, by the spatial structure of a given area, which affects the distance and thus the travel time.

In the case of the examined urban agglomeration areas, it is clearly visible that both the average travel distance and the average daily distance are the highest in the area of the Metropolis GZM (Table 1). Spatial issues are an important issue affecting the efficiency of urban collective transport—longer journeys require more complex transport systems, are more challenging for integration and timetable construction. The travel time distance may be shortened at the supply level (by redeveloping the network layout, introducing priorities for collective transport, construction of separate tracks, and changing timetables), but also at the demand level, in particular by changing the location of traffic sources and thus shortening the travel distance.

Table 1. Creative class travel distance in urban agglomerations.

The Scope of Data	Daily Distance [km]	Average Trip Distance [km]	Average Daily Distance [km]
Generally	12,109	11.60	26.91
Warsaw	3345	9.53	22.30
Tri-City	3711	11.38	24.74
GZM Metropolis	5033	13.77	33.69

Source: based on [3].

In the study of the creative class, respondents were also asked about the factors that would encourage the respondents to replace the car with public transport. In the first question, restrictive urban policy instruments were compared with the offer of free public

transport—the results were in line with expectations, respondents chose the "less painful solution" (Figure 2). Therefore, a similar question was asked, but in combination with instruments increasing the competitiveness of urban collective transport (Figure 3). In this case, price reduction and several positive instruments were proposed. It is clear that with this question, the respondents paid attention to the importance of frequency, comfort/convenience and the possibility of combining car trips with public transport.

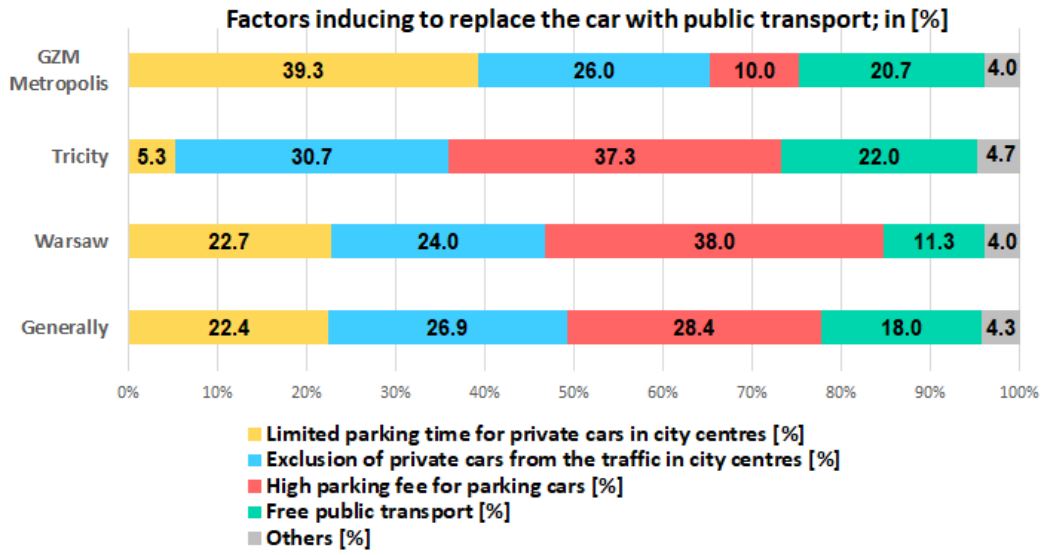


Figure 2. Factors inducing to replace the car with public transport. Source: based on [3].

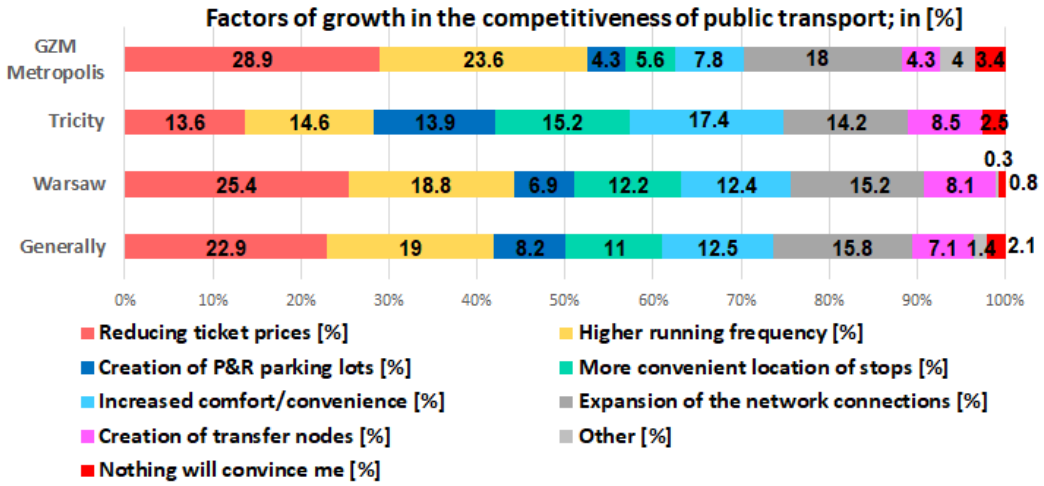


Figure 3. Factors of growth in the competitiveness of public transport. Source: based on [3].

The presented results show that public transport can gain greater competitiveness, but this requires market adaptation. Its greater use in mobility services can improve not only the efficiency of the transport system itself, but more broadly the entire urban mobility model.

Bicycles and other means of personal transport, especially scooters, play an increasingly important role in handling mobility in cities. Various European studies show that the bicycle may take up over 20% of the journey, but the share is dominated by a few percent and it is no different in Poland, where the bicycle in urban spaces is treated mainly as a means of recreational travel, and not as a tool for commuting to work or a place of study. According to the European Cyclists' Federation (EFC), this share rarely exceeds 10%, mainly in the Scandinavian countries (approx. 16%) and the Netherlands (as much as 27%); in other countries, it is at the level of 1–5%. It is difficult to detect a regularity in this case; for example, the impact of unfavorable climate seems to be completely irrelevant, since

in Spain this share is slightly more than 1%, and in Copenhagen it exceeds 49% [40]. In the study of the creative class, the respondents were asked about the factors that would encourage the respondents to use bicycles more widely (Figure 4). The data contained in the table show that the respondents expect convenient access, and the key issue is the possibility of safely leaving the bike after its use. In Poland, quite often, only racks are installed in front of various workplaces and institutions, which, unfortunately, do not allow one to safely lock a bicycle or leave it under a roof. Investments in the field of bicycle infrastructure are undoubtedly on the side of the municipal authorities, but parking spaces should also be of interest to facilities and institutions to which access is provided.

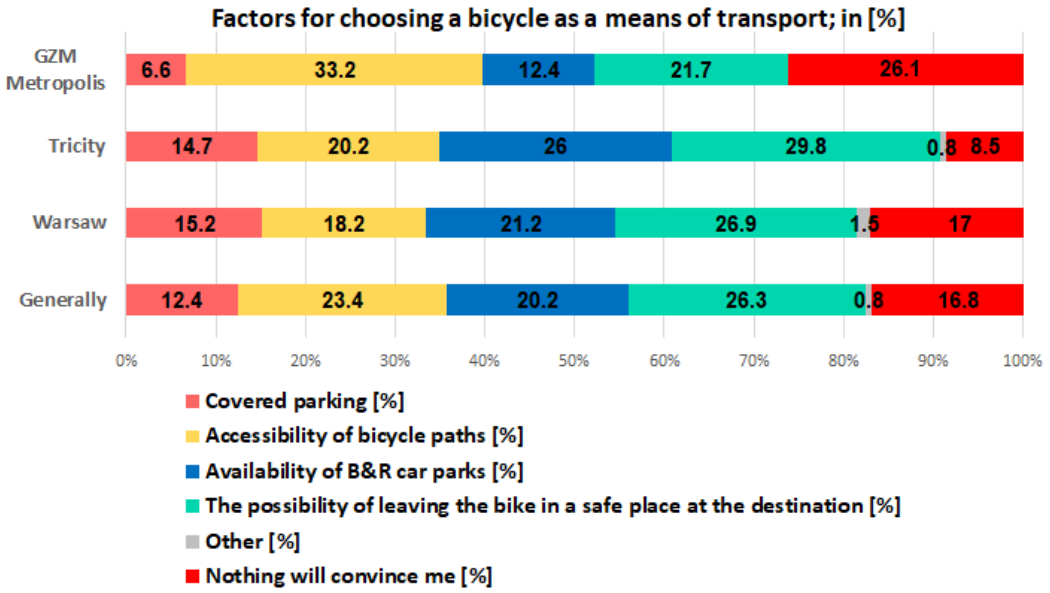


Figure 4. Factors for choosing a bicycle as a means of transport. Source: based on [3].

In the period covered by the study, city bike systems operated in all agglomerations that were surveyed. However, the system went bankrupt and liquidated in the Tri-City area quite quickly. City bikes operate in the Warsaw and Katowice agglomerations, but they are seasonal and have a limited range. Due to seasonality, the share of bicycles in mobility services is clearly overestimated in the research—in the creative class research from 2019, it was from 4 to 8% in the analyzed agglomerations, and in Katowice in the research during the 2020 COVID-19 pandemic, as much as 13% was reported ([3], p. 105), ([4], p. 103).

It should be emphasized that, unlike scooter systems, city bikes operate on the basis of the business-to-business (B2B) model, where the main contractor of the bike operator is the city authorities, and revenues from end users constitute a small percentage of total revenues. Perhaps the business formula is one of the reasons for the limited range and problems with the functioning of city bikes, which is important because there is a lot of tourist traffic in agglomeration areas such as Warsaw and the Tri-City, and visitors usually do not have their own bikes. According to the research of the Central Statistical Office in Poland published in 2015, much more households in Katowice have bicycles (62%) than in Warsaw and Gdańsk from the Tri-City (approx. 52 and 43%) [41].

Scooters and other means of personal transport, although used in Polish cities, are not yet clearly identified in the research. However, it can be suspected that they play and will play an increasingly important role in the service of the first and last mile, serving the transport of passengers to the urban collective transport system. The dynamic development of these systems and observations of interest from users and operators operating in the business-to-consumer (B2C) model seem to prove great potential of this means of transport.

The increase in the importance of bicycles in the service of mobility will depend on many factors, primarily on their inclusion in the service of the so-called first and last miles of the trip. Their use is primarily aimed at making public transport more attractive,

because the increase in accessibility resulting from the inclusion of bicycles and scooters at the beginning and end of the journey next to pedestrian access and direct access to the destination is a condition for effective competition between public transport and individual motoring [42]. Another factor increasing the share of bicycles in mobility services is the decentralization of traffic sources caused by new forms of work, including remote and hybrid work (e.g., the agora model, where the office is a place of discussion) or stationary work in a dispersed office network (the so-called satellite model, which allows you to move your job close to your place of residence) [43]. In remote work and in the satellite model of stationary (on-site) and hybrid work, there is a strong reduction in the need to travel to work (in the case of remote work, work commute does not occur, and in the case of the satellite model, it is definitely shorter and less frequent if the work adopts the hybrid model). Therefore, in the satellite model, the bicycle can be an alternative means of transport. Undoubtedly, the use of a bicycle in mobility service provides many benefits, and the bicycle itself should be treated as an equal subsystem of mobility service. Thus, the role of this means of transport in mobility strategies should be taken into account [44].

Research on the transport behavior of the creative class shows that although the car is the basic means of transport, actions aimed at balancing mobility and decarbonization are accepted and understood. Instruments that are restrictive in relation to car users are met with opposition, while measures that increase the efficiency and competitiveness of urban collective transport may count on support. Employers' actions to change mobility models are supported, including bonuses for the use of bicycles and public transport. Restrictive measures may also be met with support provided that alternatives are introduced to their implementation; for example, limiting car entry to the city center provided that alternative access by public transport or bicycles is possible (Figure 5).

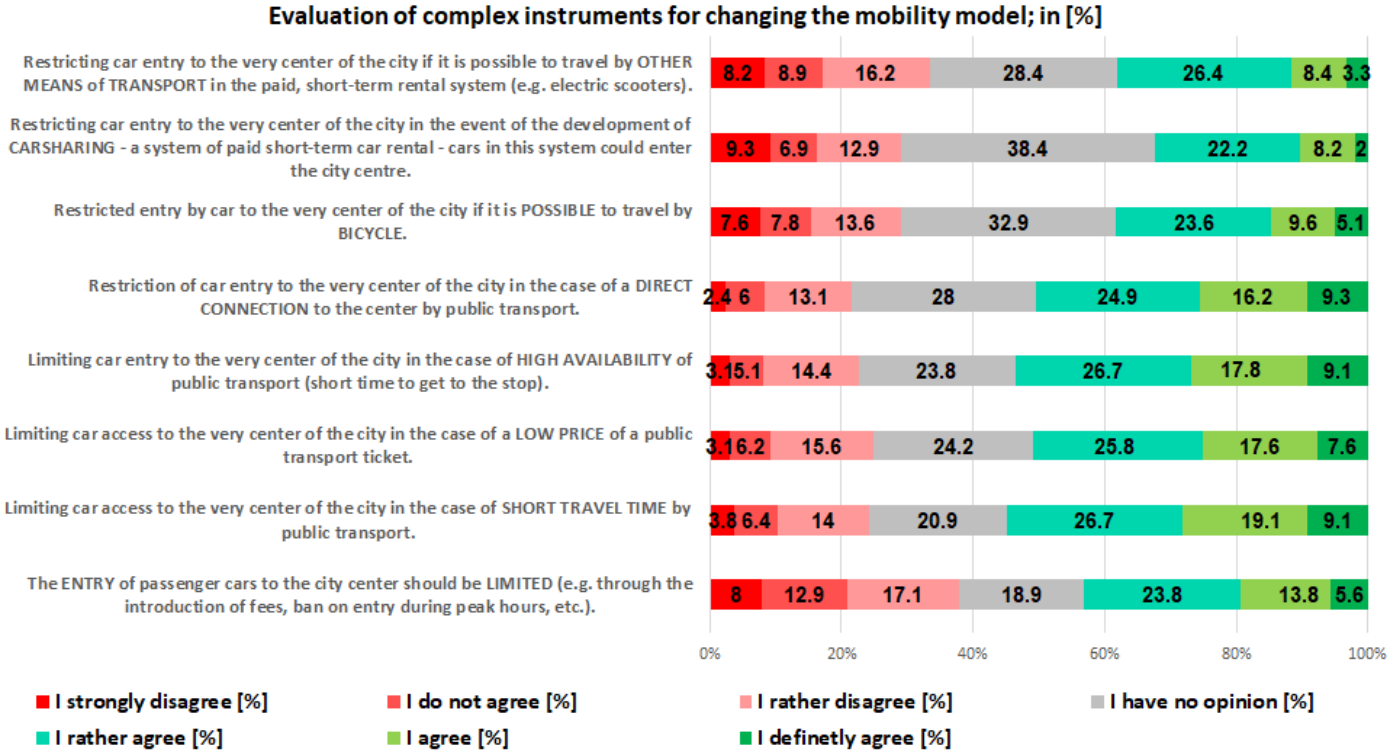


Figure 5. Evaluation of complex instruments for changing the mobility model. Source: based on [3].

Such a combined presentation of instruments in relation to restrictive and motivating tools supporting public transport is a kind of hint to a way to build a mobility strategy in cities.

3.2. Mobility under Conditions of Movement Restrictions

During the COVID-19 pandemic, the world has seen the possibilities of limiting physical mobility and transferring it to cyberspace. It was an exceptional time, but the conclusions from the use of work tools and remote learning have a long-term potential. Therefore, these issues were also the aim of mobility studies carried out at the University of Economics in Katowice. The research focused on assessing the impact of work and study in cyberspace on the use of means of transport for travel in the Katowice area.

The most visible effect of changes in the functioning of cities during the pandemic was a significant decrease in the number of vehicles on the streets; in the case of Katowice, the amount observed was at more than 25% of vehicles in daily traffic (Figure 6). On average, in the reference period, almost 440,000 cars per day moved through Katowice. During the greatest restrictions on movement, traffic decreased by up to 100,000 vehicles per day.

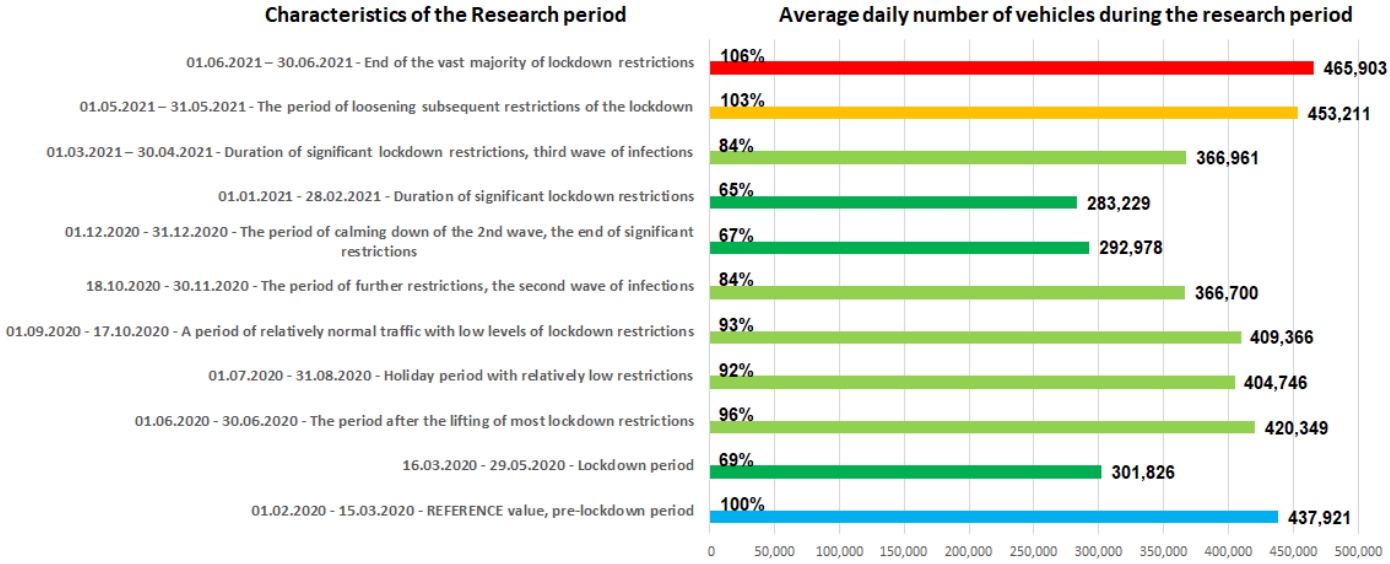


Figure 6. Average daily number of vehicles during the research period. Source: based on [4].

The change in the volume of transport satisfying the mandatory needs of mobility (i.e., commuting to work and places of study) is evidenced by changes in the number of trips that ended in individual districts of the city of Katowice during the morning rush hours—the decreases exceeded 25%, and the largest ones even exceeded 30% in districts that received traffic from outside the city of Katowice (Table 2). The data show the effect of the change in the work and study model on mobility.

In the study of mobility before and during the pandemic in the city of Katowice, attention was also paid to the modal split of transport systems (Figure 7). The results show that during the pandemic, public transport trips decreased significantly, while car trips increased.

It should be added that the reduction in public transport trips was caused not only by a general decrease in mobility (Figure 8), but also by numerous pandemic restrictions on access to urban collective transport, resulting from the limit of seats occupied in vehicles.

In the following months of the pandemic, the size of the decreases was smaller. Starting from May 2021, the volume of traffic returned and even exceeded reference volumes. This was due to the return of the economy to pre-pandemic activity as well as increased mobility and a large degree of disregard for lockdown restrictions. It can be assumed that the additional increase was caused by the permanent resignation of travelers from public transport, because during the pandemic, public transport was subject to exceptional restrictions that limited the number of passengers through the limit of occupied seats, keeping distance and wearing masks in vehicles. In addition, the promotion of threats

related to the use of urban public transport had an impact on permanent or semi- permanent changes in the handling of mobility by urban public transport.

Table 2. Changes in the number of trips ending in the districts of the city of Katowice during the morning rush hour (6:00–9:30).

Katowice City District	Śródmieście	Os. Paderewskiego—Muchowiec	Koszutka	Bogucice	Załęże
1st half of 2019	9787	6624	5071	5627	5379
1st half of 2020	6625	4614	3728	4716	4432
Changes	−32.3%	−30.3%	−26.5%	−16.2%	−17.6%
Katowice city district	Os. Witosa	Osiedle Tysiąclecia	Dąb	Wełnowiec-Józefowiec	Załęska Hałda—Brynów
1st half of 2019	5784	7486	4398	7190	6279
1st half of 2020	4114	6290	3264	4485	4365
Changes	−28.9%	−16.0%	−25.8%	−37.6%	−30.5%
Katowice city district	Brynów—Osiedle Zgrzebnioka	Ligota—Panewniki	Zawodzie	Dąbrówka Mała	Szopienice—Burowiec
1st half of 2019	4752	9196	5059	4688	5949
1st half of 2020	3256	7130	4156	2724	4415
Changes	−31.5%	−22.5%	−17.8%	−41.9%	−25.8%
Katowice city district	Janów—Nikiszowiec	Giszowiec	Murcki	Piotrowice—Ochojec	Zarzecze
1st half of 2019	5037	6357	3898	7414	4013
1st half of 2020	3431	4788	2858	6175	2583
Changes	−31.9%	−24.7%	−26.7%	−16.7%	−35.6%
Katowice city district	Kostuchna	Podlesie	Totally (Sum)		
1st half of 2019	5747	4403	130138		
1st half of 2020	3958	3125	95232		
Changes	−31.1%	−29.0%	−26.8%		

Source: based on [4].

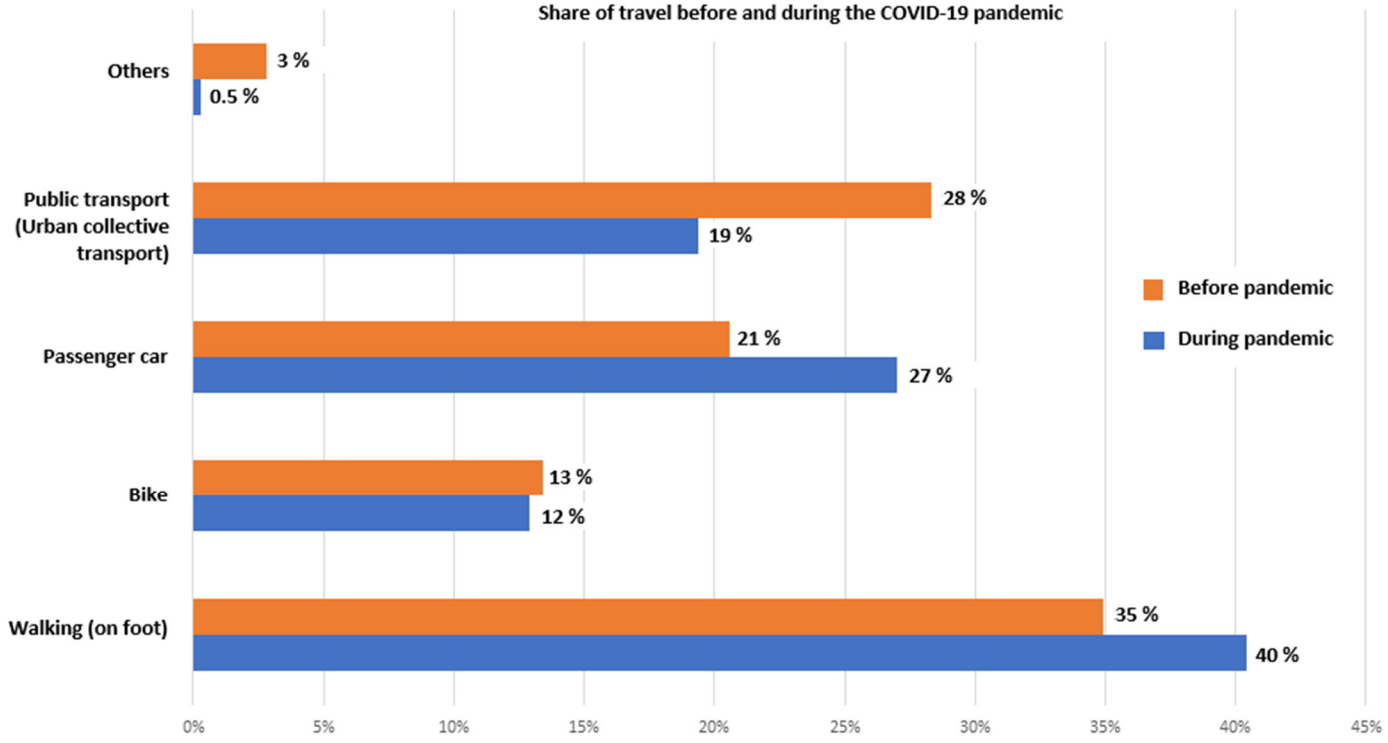


Figure 7. Share of travel before and during the COVID-19 pandemic. Source: based on [4].

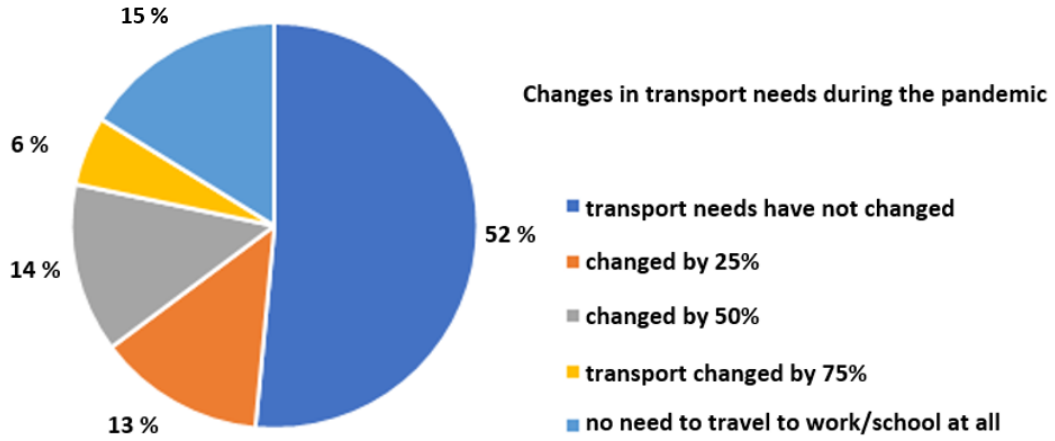


Figure 8. Changes in transport needs during the pandemic. Source: based on [4].

3.3. Mobility Using Electromobility

It is necessary to solve several fundamental problems for the proper operation of electric buses in public collective transport systems. Three of them of a technical and operational nature are as follows [35,37–39]:

- implementation of appropriate selection of routes for electric buses, so that the current timetable can be efficiently implemented, which should be a reference point for all solved problems; achieving satisfactory results from the point of view of the passenger, public transport organizer and operators requires resolutions on issues related to
  - the structure of the bus fleet in terms of the type of drive, including the share of buses with diesel drive, battery drive, or a fleet consisting only of electric buses,
  - maintaining the existing network of routes and bus lines and the timetable or making changes resulting from the structure of the bus fleet;
- determination of the optimal location of battery charging devices, assuming the implementation of the given operational plan, i.e., the network of routes and bus lines and the timetable, as well as taking into account the battery discharge process as a function of the following factors:
  - driving time,
  - ascents and descents of bus routes,
  - driving conditions, including, i.e., the number of stops and starts caused by congestion or traffic lights,
  - energy demand of on-board equipment, in particular heating and air conditioning systems;
- development of an optimal strategy for supplying buses with energy on the route, which requires resolving issues regarding battery charging or battery replacement.

As part of the projects described, e.g., in publications [28,35,37–39], innovative mathematical models, methods and simulation tools (computer application) were developed, which make it possible to search for solutions to the problems mentioned above for defined input data. The input data describe the functional conditions of the urban area, the city network, the aspirations of the city authorities and other stakeholders (e.g., organizers and carriers of public transport), and the strategy for the implementation of electric buses constituting the structure of the bus fleet. Implementation strategies take into account the share of electric buses in the entire bus fleet and the phased purchase of subsequent batches of buses; as transport needs change, the life cycle of electric buses, their batteries, and diesel buses are also considered, as well as the maintenance of an appropriate number of diesel buses in fleet, constituting a strategic reserve in the event of energy problems.

The results of research and analyzes using the developed economic model [38] and a tool supporting decision-making in the selection of bus routes suitable for service with such buses and the location of bus battery charging stations in the Upper Silesian and Zagłębie

Metropolis (GZM) area indicate very high costs of purchasing electric buses, which are acceptable only in the case of subsidies from outside the budget of the municipal authorities. Very high purchase costs have become a determinant of the development of algorithms and tools to support decision-making during the staged process of the conversion of the conventional bus fleet to electric one and the appropriate mapping of such a process in economic static and dynamic models for total cost of ownership calculation (TCO). Static TCO model means the purchase of one batch of electric buses but the dynamic TCO model, in turn, takes into account subsequent batches of electric buses to be purchased. The essence of support process is to define the organizational and economic aspects of each of the following decision-makers of the fleet conversion process stepwise approach. They are intended to serve the widest possible range of stakeholders in this process [35,37].

4. Key Research Findings

This section consists of key research findings from the presented research results.

- Public transport is treated as the second choice for meeting mobility needs after the passenger car. This primary importance of a passenger car is confirmed by the results of research in which respondents largely do not accept the restrictive instruments of transport policy, especially the parking policy.
- The main advantage of the passenger car in the examined agglomerations is the shorter travel time. Public transport still offers less accessibility and longer door-to-door travel times. This situation is aggravated by the extension of travel distances caused by deglomeration and the urban sprawl process, as well as low unemployment, which are associated with an increase in the scope of the labor market, thus extending the distance to the workplace.
- The basic factors for increasing the competitiveness and efficiency of collective transport as a decarbonization tool, apart from ticket price reductions, are higher frequency of departures, expansion of the network of connections and stops—that is, above all, availability in time and space.
- Restrictive measures of the transport policy limiting the use of a passenger car are accepted provided that restrictive measures are combined with incentive measures that shorten the travel time by public transport, increase the spatial accessibility of stops, increase the directness of connections, support the development of zero-emission delivery systems for collective transport, and, finally, reduce ticket prices for collective transport.
- Bicycles and means of personal transport are rated well by the respondents, but they are used mainly for recreational trips and to a lesser extent for everyday mobility. The condition for an increase in the share of bicycles in the mobility service in urban agglomeration areas is the improvement of infrastructure and facilitations in terms of parking bicycles and preparing commuters to work in this way. Much less is known about scooters, which seem to be used more for transport than recreationally.
- The great potential for decarbonization results from limiting physical mobility and replacing it with cybermobility. The period of the COVID-19 pandemic showed great opportunities in such activities. For example, in the city of Katowice, during the greatest lockdown restrictions, the volume of car traffic decreased by 1/3. The introduction of remote work and learning, as well as the hybrid model, reduces physical mobility, and thus reduces greenhouse gas emissions. It should be remembered that cybermobility also causes such emissions, but on a much smaller scale. The latest research of office workers conducted in 2022 by CISCO covering 27 countries and 28,000 employees [45] shows a sustained increase in expectations regarding the maintenance of remote work, and it seems that such expectations will increase. In addition, preliminary (pilot) studies [46] in Upper Silesian and Zagłębie Metropolis (GZM) indicate that synergistic factors in planning cybermobility are the results of research on objective and subjective personal factors of people related to a specific activity, especially in terms of the attitude of these people to the virtualization of a specific

activity, e.g., to introduce remote work and hybrid work along with flexible working hours and to assess the susceptibility of professional duties to remote work using modern ITC technologies (*Information and Communication Technologies*).

- The calculation of the costs of electromobility in the case of city buses shows that this solution is effective only under certain conditions: changes in the energy mix, organization of transport ensuring the use of the potential of the electric bus on routes with an appropriate longitudinal profile, appropriate charging network. In addition, the type and size of the batteries used in connection with the organization of service by vehicles have an impact on the efficiency; in particular, it is about limiting or eliminating the replacement of batteries during the life cycle of a bus and a passenger car.
- One of the negative effects of the pandemic was the deterioration of the competitive position of urban collective transport. In the city of Katowice, which is the center of the urban agglomeration, the share of public transport in handling mobility during the pandemic decreased by as much as nine percentage points in favor of the passenger car, as well as pedestrian movements. According to data from public transport organizers, the share of this system in modal split is currently returning to pre-pandemic levels, which is the result of economic recovery, as well as probably also due to a large number of people arriving to Poland from Ukraine as a result of the war that is taking place there.

5. Discussion

This section consists of discussion constituting a critical assessment of the current mobility model and creating the basis for changes in this area.

The competitiveness and effectiveness of urban collective transport, especially when measured by the share of this system in handling mobility, depends on accessibility—both in space and time. Accessibility can be improved by extending the public transport offer, and this requires investment. Actions improving the competitiveness of public transport should be anticipatory, so they should be treated as a motivational, positive measure as opposed to restrictive actions limiting the availability of passenger cars. Maintaining the required level of mobility service and obtaining acceptance by city residents is possible provided that restrictive instruments are introduced in close connection with positive measures that motivate to use public transport. The procedure is of a practical nature and must be adapted to the spatial, economic and social characteristics of a given city.

Adjustment in prices and investments in the development of the accessibility of urban collective transport mean that this system requires financing from public funds. This raises numerous questions, including the following:—in what business model should this system operate?—from what sources should this system be financed?—which measures to improve competitiveness should be used and how to implement them? Public funding seems necessary, but the question remains: To what extent and according to what rules should the different levels of public authority be involved in this process? The next issue concerns the regulation of tariffs, because the introduction of zero tariffs has not been justified in scientific research from the economic point of view, but regulation of tariffs is a fact, and the question remains: To what extent should one agree to regulate prices and prevent their adaptation to market rules?

Bicycles and means of personal transport will become increasingly important in supporting urban mobility. Their use is also associated with public health benefits and the development of new markets, especially leisure markets. The low share of these means of transport in handling mobility means that urban mobility policies should pay attention to the use of instruments encouraging changes in transport behaviour. It is necessary to invest in the development of bicycle infrastructure, including public linear transport infrastructure and public and non-public point transport infrastructure, in particular bicycle parking lots. It should become a standard to organize space in such a way that bicycle users can easily reach their destination and park safely. In addition, in this case, the transport preferences

identified in the research of the creative class allow us to hypothesize that the bicycle can significantly increase its share in servicing mobility, but this requires not only significant investments, but above all a strategic approach consisting in integrating various activities tailored to the conditions of local strategies mobility. The area of discussion are the actions that should be used in this case in the field of motivation, organization of public bicycle systems and detailed investment solutions in the field of transport infrastructure.

Further analyzes of the efficiency of electromobility are needed, in particular in urban public transport, where the level of electromobility based on rail transport and trolleybus is still high, so the question arises whether investing in electric buses should not be limited to specific applications. Separate doubts concern facilities for electric car users, which may limit the mobility of other users and lead to inclusivity.

Cybermobility is becoming not only an economic, but also a cultural challenge: opponents of remote work and learning raise the issue of social relations, interpersonal contacts and the unspecified effectiveness of relationships. These voices are not supported by research or even in-depth case studies. It is assumed that remote contacts were the exception to the rule and cause psychological damage and lower efficiency. At the same time, statements and analyzes of this type omit the commonly visible facts of increasingly extensive Internet communication and the use of social media, especially in the case of the young generation. It also completely disregards the expected technological changes that will affect communication in the coming years. This is particularly worrying in relation to educational institutions such as universities: they educate in a forward-looking manner, but at the same time they do not go beyond the solutions of the past in their methods. Life and practice will certainly supplement these gaps, but the question remains debatable and problematic whether this should be accepted in a situation of a dynamically changing world and ever higher expectations for future generations. Of all the decarbonization instruments, cybermobility has the greatest impact, because by transferring activities to cyberspace, the carbon footprint is significantly reduced. This is a great experience and achievement of the difficult period of the pandemic. However, the following question arises: how much time will the modern world need to use this experience? Mobility is not only a response to the real needs of moving people related to work or study, but it is also a reflection of more complex psychological issues related to management models and expectations and desires of people taking up work and other activities. The complexity of this issue can be clearly seen in the academic environment itself, where mobility issues have been raised to the rank of a paradigm, and at the same time academic exchange often takes the form of business tourism, both for academics and students. It is no different in the case of business. The huge conference and hotel business that caters to this type of needs should also be considered. It is hard to expect these sectors to surrender their areas of influence without a fight. This means that the expected rationality of cybermobility encounters and will encounter numerous obstacles that will affect mobility in a conscious and unconscious way.

The decarbonization potential of cybermobility and the use of zero-emission means of transport such as bicycles and scooters can be unleashed by changing the approach to the organization of work and learning, in particular by deconcentrating travel sources, which will enable commuting or walking without the use of a personal car to workplaces and organization of work in hybrid models. As a result of such actions, the volume of travel by car and public transport could significantly decrease. However, this requires changes in the approach to spatial planning and taking up challenges not only by city authorities, but also by companies and universities.

6. Conclusions

The presented research results indicate that public transport can be a decarbonization tool in the new model of mobility, provided that its competitiveness and efficiency are increased in relation to the passenger car. Measures to improve the competitiveness and efficiency of public transport should be anticipatory, and thus should be treated as a

positive incentive as opposed to restrictive measures limiting the availability of passenger cars. However, the calculation of the costs of electromobility in the case of city buses shows that this solution is effective only under certain conditions: changes in the energy mix, transport organization ensuring the use of the potential of the electric bus on routes with an appropriate longitudinal profile, and an appropriate charging network. Bicycles, scooters and personal transport will play an increasingly important role in supporting urban mobility. The condition for increasing the share of these means of transport in the mobility service in the areas of urban agglomerations is the improvement of infrastructure and facilitations in terms of parking and preparation of people commuting to work in this way. However, among all decarbonization instruments, cybermobility has the greatest impact, because by moving activities to cyberspace, it significantly reduces the carbon footprint. Synergistic activities in planning cybermobility are analyzes of objective and subjective personal factors of people related to a specific activity, especially the attitude of these people to the virtualization of a specific activity, e.g., the introduction of remote work and hybrid work with flexible working time and the assessment of the susceptibility of work duties to remote work using modern ITC (Information and Communication Technologies) technologies.

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