

Article

Classification of Smart and Sustainable Urban Mobility

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Abstract: The main purpose of this article is to identify and classify smart and sustainable urban mobility solutions in the context of three narratives for sustainable mobility: electromobility, collective transport 2.0 and low-mobility societies. The research process of this study included the following methods: review of the literature, namely, strategic European documents, sustainable urban mobility plans in chosen cities and scientific publications addressing smart and sustainable mobility, case studies of selected cities in Europe and technology mapping to visualize the study results. The main result of this study is the review of various smart and sustainable urban solutions (SSUM) and their classification within the three narratives of electromobility, collective transport 2.0 and low-mobility societies. This article expands the concept of the three narratives for sustainable mobility with the aspect of smart mobility enriched with the variety of example solutions, case studies and good practices within mobility strategies in European cities. The study results can be useful for different stakeholders engaged in developing and introducing the sustainable mobility strategies in cities. Based on the catalogue of SSUM solutions, presented case studies and good practices, they may gain the necessary knowledge, consider the possible initiatives towards green transformation in cities and finally adjust them to the citizens' need.

Keywords: smart mobility; sustainable mobility; sustainable transport; intelligent transport system; Green Deal; smart city



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1. Introduction

Currently, cities are striving for intelligent and sustainable development to ensure the best existence for residents. Cities focus on environmental, social, technological or economic aspects. The concept of smart and sustainable mobility (SSUM) is one of the dimensions of the European Green Deal Strategy of the European Union to manage urban mobility and transport problems. It sets an ambitious goal toward achieving climate neutrality, aiming to reduce emissions in the transportation sector by 90% by 2050 [1]. In accordance with the European Green Deal, the European Commission developed the document Strategy for Sustainable and Smart Mobility Strategy—putting European transport on track for the future. The most important goal of the Sustainable and Smart Mobility Strategy is to make European transport sustainable, smart and resilient [2]. However, mobility and transport in smart cities require an increasing amount of energy. With the frequent energy crises arising worldwide and the need for a more sustainable and environment-friendly economy, optimizing energy consumption especially in cities becomes a must. Due to this fact, most cities have adopted modern solutions to save and optimize energy consumption, thanks to the introduction of intelligent transportation systems [3], but also the replacement of traditional fossil fuel vehicles by electric ones [4] and pacing the shift towards green energy by testing eco-taxis, solar-powered electric cars to carry passengers or squad solar city cars [5]. In many cities around the world, successful practices of implementing smart and sustainable solutions can be noted. The range of solutions encompasses technical and technological alternatives, organizational approaches and purely economic measures, but also requires the implementation of strategies and measures to obtain a sustainable and

effective transport service [6]. It is necessary to use various solutions to transform into green energy and reduce air pollution, traffic congestion and noise in cities.

Considering the growing importance of sustainable and smart urban mobility approach, the authors used the following methods: a literature review of scientific articles and strategic documents, a case study method to present good practices and a technology mapping method to organize solutions. The purpose of this article is to identify and classify smart and sustainable urban mobility solutions in the context of three grand narratives elaborated by Holden et al. [7]: electromobility (EM), collective transport 2.0 (CT) and low-mobility societies (LM). While the study by Holden et al. provides a conceptual review that presents nine narratives addressing elements of sustainable mobility and three grand narratives, this study develops the concept of three narratives with the “smart” aspect of mobility. It includes an in-depth presentation of a wide range of the existing SSUM solutions, but also new innovative ones, which are still being tested. This article constitutes an introduction to the future research considering the factors affecting social acceptance of the chosen SSUM solutions in Polish cities.

This paper is divided into four sections. The first part presents the impact of sustainable and smart mobility on urban development. Examples of solutions and good practices in selected cities are shown. The second chapter describes the methodology used to group and classify the solutions. The third chapter presents the research results and discussion including the description of three strategies (EM, CT and LM), and finally, the last chapter is dedicated to conclusions.

2. Literature Review

Cities are characterized by the complexity of many elements and their connections, which enable their development as well as functioning of residents [8]. The concept of city development in the literature is defined as the total of society actions, which can be taken consciously and subconsciously to improve living conditions [9].

The development of civilization, the associated expansion of cities and the demands of modern society are forcing the development of cities [10], which requires introducing a number of continuous and long-term processes [11]. Urban development is driven by rapid urbanization and a growing demand among residents for innovative solutions [12], which consists of improvements in urban infrastructure or public services [13]. Słaboń [14] defines urban development in two categories: material (buildings, streets, utility facilities or technical infrastructure) and immaterial, referring to relations between different groups in society. The concept of development can be applied in cities on several levels: social, economic, technical-technological, political, cultural or ecological-spatial [15].

In the past, cities were constantly changing in many aspects caused by the rapid development of countries in Western Europe, the destruction of the environment or urbanization [16]. The concept of smart and sustainable urban mobility emerged at the beginning of 20th century. Over the decades, there have been many documents that have addressed smart and sustainable mobility such as the following: The Environmental Impact of Transport. Joint Strategy for Sustainable Mobility [17]; White Paper European Transport Policy for 2010: Time to Decide [18]; Green Book. Towards a new culture of urban mobility [19]; Action plan for urban mobility [20]; EUROPE 2020. A Strategy for smart, sustainable and inclusive growth [21]; White Paper. Plan for a Single European Transport Area—Towards a competitive and resource-efficient transport system [22]. The most important document was elaborated in 2019, by the European Parliament and the Council of the European Union, called the European Green Deal consisting a package of policy initiatives [1]. The document indicates how the European Union member states should develop and suggests directions for the development [23]. One of the strategies included in the European Green Deal aims to move towards smart and sustainable mobility.

According to the European Commission, smart mobility focuses on intelligent traffic management systems originated from digital transformation and automation [2], while sustainable mobility means a stronger public transport, better active mobility options and efficient, zero-emission urban logistics and last-mile delivery [24]. Implementation of the smart and sustainable concept in cities is necessary to deal with the contemporary challenges in cities such as the following:

- rapid growth of urban population [25–27];
- increased pollution emissions [24,28–30];
- provision of adequate technical infrastructure [31,32];
- ensuring a high quality of life [10,33];
- urban logistics [34,35];
- poor citizen involvement in the management of public affairs [8,36].

Currently, approximately 56% of the world population lives in cities. By 2050, the urban population is expected to rise more than double that of now [37]. The European Union undertakes many activities to deal with these challenges and reduce the scale of the negative phenomenon caused by the fast development of urban transport. In 2020, the European Commission published the second important document, Strategy for Sustainable and Smart Mobility—European Transport on the Road to the Future, which contains leading initiatives, actions and mechanisms to achieve a green and digital transformation in the European Union transport system and become more resilient to future crises [2].

The application of the concept of smart and sustainable mobility in cities can affect their development and can bring many benefits such as the following:

- environmental benefits—reduction of air pollution [38], lower carbon footprint [39], reducing air and noise pollution in the city environment [40], energy optimization and savings [3–5];
- health and security benefits—reducing the health burden related to air pollution [41], improving safety by reducing street crime [42];
- transportation benefits—reducing traffic congestion and noise [41], solving last-mile problems in cities [43];
- social benefits—improving safety, comfort and speed of movement, increasing the attractiveness of the urban spaces [44,45].

Facing the identified challenges, there is an increasing need for the use of innovative and ecological solutions. Practical solutions for sustainable and smart urban mobility are implemented in many cities around the world (Table 1). In order to identify good practices used in different cities, a case study method was used, which refers to the analysis of phenomena and their description [46].

Table 1. Examples of good practices in sustainable and smart mobility in selected cities in Europe.

City/Country	Good Practices in the Framework of Smart and Sustainable Mobility	References
Barcelona, Spain	Use of electric vehicles for cleaning and waste management	[47]
	Night delivery systems with consideration of noise reduction	[48]
	Introduction of low-emission zone	[49]
	Integrated public transportation with other modes of transport	[50]
	“Barcelona Smart City” application	[50]
	“El Bicing” system	[50,51]
	Creation of “Superblocks” urban green space to reduce noise and pollution levels	[52]
	Hybrid-powered vehicles are being put into service on public transportation	[50]
	Extensive bicycle paths	[50]

Table 1. Cont.

City/Country	Good Practices in the Framework of Smart and Sustainable Mobility	References
Copenhagen, Denmark	Expansion of the city's network of electric vehicle charging stations	[53]
	Introduction of zero-emission buses by 2025	[54,55]
	Properly prepared bicycle infrastructure	[56]
	Ban on registration of diesel-powered cabs after 2025	[57]
	Properly planned public transport network (including S-tog commuter rail)	[50]
	"Bicycle Track Priority Plan" bicycle system	[50]
	"Bicycle snake"—cykelslangen	[58]
	Restriction of entry of vehicles with conventional engines	[50]
London, the United Kingdom	Paid parking zones	[51]
	"T-Charge" emissions surcharge	[59]
	Developed infrastructure for charging electric vehicles	[60]
	Use of double-decker hydrogen-powered buses and electric buses in public transportation	[61]
	Development of autonomous vehicles (approval of regulations)	[62]
	A low-emission zone throughout the city	[63]
Oslo, Norway	Creation of new jobs due to the development of autonomous vehicles	[64]
	Replacement of the public transport fleet with electric ones	[65–67]
	Free use of toll roads, ferries and city parking lots for electric vehicles	[65]
	VAT exemption on leasing cars powered by alternative energy sources	[68]
	Investment in charging stations for electric vehicles	[69,70]
	Sharing of electric vehicles and e-scooters and bicycles	[71]
	Zero-emission zone	[70]
Vienna, Austria	No-entry zone for diesel and tankless vehicles	[72]
	Introduction of modern electric fleet	[50]
	Integrated public transportation network system	[50]
	Mobile application for real-time monitoring of public transportation vehicles	[50,73,74]
	"Citybike Wien" system	[75]
	Introduction of a zone with a 30 km/h speed limit for cars	[50]
Warsaw, Poland	Reconstruction of intersections and sidewalks to reduce parking near intersections	[50]
	Progressive increase in the share of greenery in road corridors	[76]
	Well-developed integrated public transport system organized as part of the WTP in Warsaw (subway, streetcars, low- and zero-emission buses, rail)	[77]
	Introducing appropriate organizational, infrastructural and informational solutions for persons with disabilities and persons with reduced or limited mobility	[77]
	Improving the continuity of bicycle routes	[78]
	Tariff and ticket integration	[77]
	Increase the share of bus fleets of zero- and low-emission buses and the infrastructure for their maintenance and charging	[77]
	Construction of more P + R (Park and Ride) and B + R (Bike and Ride) parking areas	[50,77]
	Introduction of differentiated parking fees in subzones, including exemptions for selected groups of people and vehicles	[77]
	Introducing a Clean Transportation Zone from July 2024, which will protect people from chronic diseases and deaths caused by polluted air	[79]

good practices that occur only in a specific city are marked in blue colour.

Many cities can serve as a model for others on how to implement smart and sustainable mobility. In different cities, it is possible to indicate good practices that occur only in a specific city (highlighted in blue color—Table 1). City authorities in Vienna take a modern approach to mobility, focusing on increasing the share of low-emission vehicles in personal transportation. The city uses an integrated public transport network system that links buses, subways and streetcars together, making it easier for travelers to get around and use public transportation [50]. Copenhagen public transportation network has been adequately laid out through suburban rail (S-tog), subways and buses (including water) [56]. The city government also takes actions to reduce private car traffic; for example, they introduced restrictions on the entry of vehicles with conventional engines and a network of paid

parking zones [51,80]. Residents are encouraged to use city bicycles. The city bicycle infrastructure is being improved in the form of paths in green areas, among other things, and parking lots are being adapted for single-wheelers [81]. Another example of a city offering sustainable and smart mobility solutions is Barcelona. The city authorities have to deal with a number of problems occurring in the city, including the growing need for transport service of people and goods [48] and environmental pollution [51]. A prosperous public transportation system has been integrated with other modes of transportation. Barcelona city authorities, similar to Vienna and Copenhagen, also promote bicycling as a means of transport around the city. The city has a system called “El Bicing” to rent city bicycles by the city residents [50].

Implementation of sustainable and intelligent mobility solutions improves urban conditions. In the city of Barcelona, after the introduction of the “Superblocks” solution, pollution and noise levels were reduced; for example, NO₂ levels dropped by 25%, while noise levels dropped by 9 decibels [82]. Similarly, air quality was improved in the City of London due to the introduction of the Ultra-Low-Emission Zone and its expansion. According to the London Atmospheric Emissions Inventory (LAEI), between 2016 and 2019, NO₂ emissions caused by road transport decreased by 31% across London and 43% in central London [83]. Meanwhile, in Warsaw, according to the CleanCities report, the city expects to notice a 17% decrease in nitrogen dioxide concentrations in the air by 2025 and a 34% decrease by 2027, after the implementation of the Clean Transportation Zone [84]. The introduction of this solution is also expected to reduce deaths caused by smog by 5 to 10% [79]. Another example is the city of Copenhagen which is introducing various solutions like the Bicycle Track Priority Plan “bicycle system, Bicycle Snake”—Cykelslangen or properly prepared bicycle infrastructure. The city encourages residents to choose bicycles instead of cars for their daily travel. The Cykelredegørelse report shows that the share of bicycle traffic in all trips in Copenhagen reached 28% in 2019, while the share of cars decreased from 32% to 30% [85]. In the city of Warsaw, solutions such as the construction of Park and Ride or improving the continuity of bicycle routes are also being implemented to encourage residents to use bicycles. According to data from the Central Statistical Office, the length of bicycle routes in the city of Warsaw in 2018 was 590 km, with an increase to 708 km in 2021 [86]. According to a report by the Warsaw Roads Authority, more than 37% more cyclists were registered in 2022 than in 2021 and more than 58% compared to 2020; while in 2023, cycling traffic in Warsaw increased by more than 11% compared to 2022 [87,88]. The sustainable and intelligent mobility solutions that are being introduced have the effect of reducing noise levels, encouraging people to use sustainable means of transport, which is related to a reduction in urban emissions and deaths among people exposed to smog.

Smart and sustainable urban mobility planning focuses on a wide range of stakeholders, both practitioners and academic researchers [89]. It is important to comprehensively plan and design urban policies with the participation of various stakeholders [89] from four sectors: public sector, business, scientific institutions and local communities [90]. However, today, there is no single approach or method to ensure sustainable and smart urban mobility [91]. Each city is characterized by different goals, needs of residents or availability of financial resources, but city authorities should introduce appropriate solutions and incentives to ensure sustainable urban development.

A catalogue of SSUM solutions includes technical-technological solutions (electromobility), organizational solutions (creation of low-emission zones) or purely economic ones (financial mechanisms to encourage a change in attitude and behavior). According to Müller-Eie and Kosmidis [92], smart mobility solutions can be divided into mixed-modal access, prioritized clean and non-motorized options and integrated ICT. Holden et al. [7] presented the three grand narratives for achieving sustainable mobility, namely, electromobility, collective transport 2.0 and low-mobility societies (Figure 1).

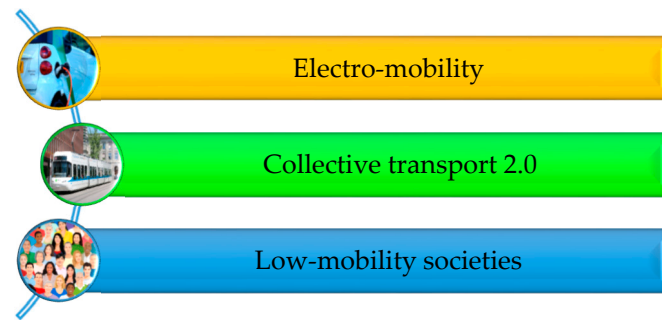


Figure 1. Three grand narratives for sustainable mobility. Source: authors' own elaboration based on [7].

3. Research Methods

The research process of this study included three methods: literature review, case studies and technology mapping to visualize the study results. The aim of the literature review was to present and analyze the challenges facing modern cities and the benefits of implementation of sustainable and smart mobility in the context of urban development from the perspective of officials and academics. The publications were researched in different databases using phrases in titles, key words and abstracts. The search query included the following phrases: "sustainable mobility*" OR "sustainable transport*" OR "intelligent mobility*" OR "intelligent transport*" OR "smart mobility*" OR "smart transport*". Afterwards, the publications were selected according to the topic and finally 158 sources were reviewed (Table 2), among others: 103 scientific publications addressing smart and sustainable mobility including 74 articles in Web of Science and Scopus, 9 books and 30 other articles; 9 strategic European documents; 8 sustainable urban mobility plans in chosen cities; 28 websites.

Table 2. Types of reviewed literature sources.

Source	Number of Publications
Articles in WoS and Scopus	74
Books	9
Other articles	30
Urban mobility plans	8
European documents	9
Websites	28
Total	158

Source: authors' own elaboration.

The literature review was enriched by case studies presenting the good practices of successful implementation of SSUM in selected cities. The authors also examined the literature to identify the SSUM solutions and classified them into three narratives. Finally, a technology mapping method was applied to organize solutions with the use of the Future Wheel tool. Technology mapping, in the broadest sense, is a method of creating visualizations of technology-related elements, including their spatial location, as well as analysis of the relationships between them. A technology map is a representation on a picture plane of a given technology, or related elements, at a particular moment, by means of contractual designations [93]. The final result of this study is a technology map for smart and sustainable urban mobility (Figure 2).

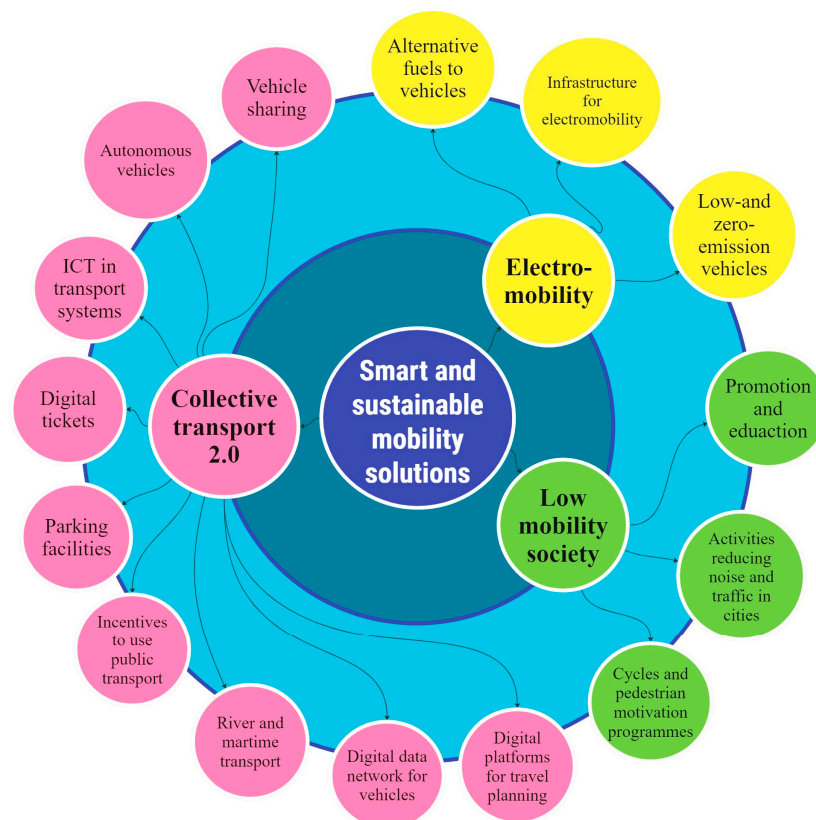


Figure 2. Technology map for smart and sustainable mobility. Source: authors' own elaboration.

4. Research Results and Discussion

Based on the strategic documents concerning sustainable development, scientific literature review and case studies, the smart and sustainable solutions were identified, grouped and finally classified within three narratives: electromobility, collective transport 2.0 and low-mobility societies (Figure 2). Following the current trends in urban development, the authors expended the concept of Holden et al. [7] based on sustainable mobility by adding the dimension of smart mobility. The “sustainable” aspect considers the solutions with the aim to reduce pollution and protect the environment. The “smart” aspect is visible in involving information and communication technologies in urban mobility to improve the quality, comfort and speed of travel. The authors developed the concept, presenting in-depth a wide range of the existing SSUM solutions, but also the new innovative ones, which are still being tested.

4.1. Electromobility

Electromobility, aiming to replace existing fossil fuel vehicles with electric and hydrogen vehicles, implies replacing not only fossil fuel-based private cars, but all existing fossil fuel-based vans, buses, heavy-duty vehicles, rail, ships and short-distance planes with corresponding electric drive-trains [7]. Electromobility seems to be one of the ways to achieve a higher degree of sustainability, in particular based on energy produced from renewable sources [94]. In order to implement electromobility, it is necessary to consider both positive and negative aspects including future challenges. On one hand, electric vehicles provide higher energy efficiency and easier maintenance than fossil fuel-based vehicles, but also reduction of greenhouse gas emissions with a simultaneous decrease in local air pollution [95–97]. On the other hand, electromobility introduces a set of environmental effects regarding the use of rare metals in batteries, pollution from tires, brakes and the road, but that also are much more expensive than fossil fuel-based vehicles. Therefore, national and local actions should be taken to introduce incentives for electric vehicle users

like tax relief, free access to bus and taxi lanes, reduction or exemption from road or parking fees, development of public recharging points, support for R&D projects and field tests [98]. Nevertheless, many Western European countries like Austria, Norway, Spain and Sweden introduced electric vehicles (EVs) successfully, the examples of which are presented in Table 1. However, electromobility deployment encounters problems in Eastern European countries in comparison to other countries, like a relative lack of privileges for users of eco-friendly cars in Poland [94], low public interest in purchasing electric vehicles in Slovakia, mainly due to the high price, an insufficient network of charging stations, short battery life and low social awareness [99].

Electromobility solutions include the following: low- and zero-emission vehicles, infrastructure for electromobility and alternative fuels to vehicles. The below three groups of solutions are presented:

- (a) Low- and zero-emission vehicles:
 - Vehicles powered by hydrogen fuel cells [2,100];
 - Electric vehicles that are battery-powered [2,101,102];
 - Hybrid vehicles [103,104];
 - Energy eco-taxis, solar-powered electric cars to carry passengers, squad solar city cars [5];
 - Electric buses [24];
 - Buses powered by hydrogen [24];
 - Battery-powered minibus [104];
 - E-bicycles [24,104];
 - Cargo bikes [2], powered cargo bikes [104];
 - Electric scooters [24];
 - Electric water transportation [2].
- (b) Infrastructure for electromobility:
 - Filling stations for electric car and autonomous vehicles [104];
 - Swift charging points [104];
 - Installation of pantograph chargers at selected bus loops [105].
- (c) Alternative fuels to vehicles:
 - Electric, hybrid, hydrogen, fuel cells, and compressed natural gas vehicles [106].

4.2. Collective Transport 2.0

Collective transport is far beyond public transport. With individual travel patterns becoming increasingly diverse and the number of private cars on the rise, there is a need to look for the forms of collective transport in addition to traditional public transportation. This way of thinking implies a shift from "ownership" to "usership" [107], which has also been defined as a part of the concept of mobility-as-a-service (MaaS) [108]. Collective transport 2.0 narrative is focused on the increase in passenger number and occupancy rates for both public transport and cars as shared mobility [60]. Shared mobility, as an alternative to private cars and traditional public transport, could significantly reduce trip frequencies, travel lengths and emission levels [109–111]. Shared mobility includes five emerging models: peer-to-peer provision of vehicles by a broker, short-term rental of vehicles managed and owned by a provider, companies that sign up ordinary car owners as drivers, on-demand private cars and vehicles shared by passengers going in the same direction or bike-sharing [107,112]. Although shared mobility service means an interaction between businesses and users, there is clearly a need for a regulatory framework and public incentives like restrictions for privately owned vehicles in certain areas, access to bus lanes or tax relief and/or subsidies [107]. Recently, autonomous vehicles have been considered as a disruptive transport innovation, which causes many challenges, but can become a part of the next model of shared mobility service in the future [113,114].

An important change in the management and transport approach has been observed recently to improve the level of service in the context of quality, performance, sustainability

and modernization of the transport system. Some important changes in the incentive system have been made during the last two decades, with increased attention towards achieving cost efficiency [115]. Among identified solutions within collective transport 2.0 are those related to traditional public transport like incentives to use public means of transport (dedicated bus lanes, low fares for public transport tickets, discounts on tickets or other incentives for car owners, on-demand stops, etc.). In this group, the modern technologies are implemented: information and communication technologies (ICTs) used, for example, in the Intelligent Transport System, parking facilities, digital platforms for travel planning supported by Artificial Intelligence (AI), e.g., mobility-as-a-service (MaaS), but also still gaining more popularity—vehicle sharing or autonomous vehicles under tests. Among the above-mentioned solutions, the emerging concept of MaaS is a type of service that, through a joint digital channel, enables users to plan, book and pay for multiple types of mobility service [116]. MaaS is a user-centered form of mobility that combines and integrates material and immaterial services with the aim of offering an alternative to unsustainable mobility, often based on the use of a private car. The pioneer cities that implemented MaaS were Helsinki and Vienna, where all local and regional public transports are integrated into a MaaS market. However, this concept has become popular recently among many cities in Europe, for example, Austria, France, the Netherlands and Italy [117]. It is worth outlining that recently AI has been tested in the context of dynamic mobility management to support the achievement of efficiency and sustainability goals. AI can be used to model alternative mobility system scenarios in real time and to identify network and service configurations by comparing phenomena in similar contexts, so it can be used as a supplement and an extension of MaaS service [118].

Below, the groups of solutions within collective transport 2.0 are presented:

- (a) Vehicle sharing:
 - Car sharing [104,115,119,120];
 - Electric car sharing [24,121];
 - Hybrid car sharing [104];
 - Bicycle sharing [24,121];
 - Ride-sharing services [122–124];
 - Ride hailing [125];
 - Development of rental vehicles: scooters, bicycles, cars (including hybrid ones) and vans (including electric ones) [105].
- (b) Autonomous vehicles:
 - Autonomous cars [126–129];
 - Connected and autonomous vehicle [130,131];
 - Self-driving automated electric shuttle [104,127].
- (c) ICT in transport systems:
 - Automatic vehicle locator [132];
 - Monitoring and evaluation system [77];
 - Intelligent transport system [106,133–135], including intelligent traffic light network [136], intelligent traffic management systems [1] and traffic control system [137,138];
 - Outdoor navigation technologies [139];
 - Optimization of logistics and autonomous vehicles [139].
- (d) Digital tickets:
 - E-ticketing [123,138];
 - Electronic fare payment [132];
 - Flexible tickets [2];
 - Modern system ticketing and integrated fare offer tariffs [105];
 - Klimaticket—all public transport with a single ticket [5];
 - Resident's card [134];

- Introducing a common ticket that allows the use of public transport and train connections within the city [105].
- (e) Parking facilities:
 - Smart parking [104,138,140];
 - Park&Ride [24,105,141];
 - Kiss&Ride [121,142].
- (f) Incentives to use public transport:
 - Dedicated bus lanes [106,143,144];
 - Low fares for public transport tickets [106];
 - Discounts on tickets or other incentives for car owners [106];
 - Public transport vehicles enter zones with restricted or excluded traffic [106];
 - Tele-bus [145];
 - Clean bus Europe platform for eco-friendly buses [24];
 - Conversion of selected stops (with the lowest number of passengers) into “on-demand” stops [134];
 - Replacement of tramway rolling stock and bus fleets (including zero-emission) to be accessible to people with limited mobility [105].
- (g) River and maritime transport:
 - The use of rivers as a transport channel [105];
 - Waterways including both inland waterways (rivers, lakes and canals) and maritime transport and all types of water vehicles including cruise boats, ferries, motorboats, sailboats, rowing boats, etc. [2].
- (h) Digital platforms for travel planning:
 - Mobility-as-a-service (MaaS) [123,139,146,147];
 - Multimodal passenger applications with available configuration of transport connections or parking spaces [1,24,123];
 - Programs or applications to plan and optimize travel [123,137];
 - Smart mobility application assisting elderly and/or disabled persons to move in an urban setting [77];
 - Creation of a common European mobility data space [2];
 - AI used for dynamic mobility management [115].
- (i) Digital data network for vehicles:
 - Internet of Vehicles (IOVs) [39,135,143,148];
 - Vehicular Ad Hoc Networks (VANETS) [149–151];
 - Mobile Ad Hoc Networks (MANETS) [150,152];
 - Blockchain-based Internet of Vehicles (BIOV) [150,153].

4.3. Low-Mobility Societies

The concept of low-mobility societies is a response to the high and growing number of cars and plane trips, but also increasingly acknowledged global oil depletion and adverse climate change. Low-mobility actions address the need of reducing the negative consequences of car use for citizens, such as congestion, noise and environmental pollution. Thinking in “car-free” terms means fewer and/or shorter trips by cars and planes, preferably electric ones [7]. Car-free cities mean banning cars of residents, employees and visitors from significant areas, including housing, shops, restaurants and work places. Due to higher population density and generally shorter distances to private and public services, people in cities have reasonable alternatives to cars, such as walking, cycling and well-functioning public transport systems. Although car-free zones are implemented in many European cities (Table 1), this idea is rarely considered by academia. Nevertheless, according to Khreis et al. [154], there is a need to get more knowledge to describe rational

requirements, facilitators and barriers for creating car-free cities and finally get public acceptance for car-free areas.

Among solutions used within low-mobility societies are actions related to promotion and education about the benefits of sustainable mobility, activities reducing noise and traffic in cities and cycle and pedestrian motivation programs. Below, these groups of solutions are presented:

(a) Promotion and education:

- Information and promotional campaigns [105,132,155];
- Education about public transport [156];
- Expert events in the field of sustainable mobility [77];
- Discussion meetings [105];
- Training for elementary school teachers on active mobility [134];
- Promotion of urban transport—timetables in local media [134];
- Distribution of maps [155].

(b) Activities reducing noise and traffic in cities:

- Speed limits up to 30 km/h [5,77];
- Traffic-calmed zones, low-emission zones and zero-emission zones [63,134,157];
- Creation of parks and green infrastructure in the city [105];
- Transit traffic out of the functional downtown area [105];
- Polluter pays rule [2];
- Fees for infrastructure access [2] like paid parking zone [105,134] and increasing parking fees [105];
- Public transport enters zones with restricted or excluded traffic [106];
- The use of drones for commercial applications [2].

(c) Cycle and pedestrian motivation programs:

- Bike to work action [145];
- Action “bike may” [145];
- “World Bicycle Day” [158];
- “Kidical Mass” [158];
- “Cycle Friendly Employer (CFE) Certification” in Bucharest [158];
- “Bicycle Track Priority Plan” [56].

5. Conclusions

Over three decades ago, the first formal document referring to sustainable mobility, the European Commission’s Green Paper on the Impact of Transport on the Environment, identified transport as the source of negative environmental damages in cities. It noted that the future of passenger and freight transport should undergo electric transition, which can reduce emissions and noise. However, the authors argued that in order to make the shift towards sustainable mobility, human behavior, consumption habits and values towards the environment require fundamental changes [17]. According to the European Green Deal, the way to sustainable transport lies in putting passengers’ needs first; they need to be offered cheaper, more accessible, healthier and cleaner options than the ones they currently use most [1]. The main aim of implementing sustainable and intelligent mobility solutions is to use modern urban technological solutions and to improve the standard of living of city dwellers in their space. Implementing the initiatives to improve urban mobility requires not only significant investment, but also a change in the behaviors and habits of the population, which have been formed over generations. The practice of introducing sustainable and intelligent mobility solutions has shown that the implementation process is not simple and requires the involvement of many stakeholders [157]. The development and implementation of sustainable mobility projects should engage all sectors including public administration, business, research institutions and local communities. Therefore, there is still a need to provide knowledge on innovative and ecological solutions, improving urban residents’ mobility, which is the gap addressed by this article.

The scientific contribution of this study is the complex review of existing, innovative and future SSUM solutions and their classification within the three narratives given by Holden et al. [7]: electromobility, collective transport 2.0 and low-mobility societies. Electromobility is related to low-and zero-emission vehicles, infrastructure for electromobility and alternative fuels to vehicles. Among the identified solutions within collective transport 2.0 are those related to the incentives to use traditional public transport, but also the still not so popular—vehicle sharing and autonomous vehicles. Low-mobility society concept includes actions related to promotion and education on alternatives to cars for mobility, activities reducing noise and traffic in cities like traffic-free zones, polluter fees or of drone usage in transport. It is worth outlining that only the compilation of various solutions from each of the three narratives would lead to sustainable transport systems [7]. Many of the solutions classified under the three narratives are generally complementary and influence each other, but some of them can be classified under more than one narrative; for example, electric buses, which are part of electromobility, can be seen as a sustainable means of collective transport 2.0 and a low-mobility society. Bicycles and pedestrian incentive programs as part of a low-mobility society strategy are closely related to shared mobility as part of collective transport 2.0.

This article is based on the concept of the three grand narratives for sustainable mobility and expands it by outlining the aspect of smart mobility supported by the variety of example solutions, case studies and good practices in European cities. The initiatives developed in the analyzed projects may be replicable and enable wider dissemination of proven solutions. Sustainable and intelligent urban mobility should be achieved through the implementation of chosen solutions and their combination suitable for a particular city. Only coordinated action in these areas will achieve long-term benefits. From a practical point of view, the study results can be used by different stakeholders engaged in developing and introducing the sustainable mobility strategies in cities. Based on the catalogue of SSUM solutions and presented case studies with good practices, the city authorities and other stakeholders may gain necessary knowledge, consider the possible options, activities and initiatives towards green transformation in cities and finally adjust them to the citizens' need. As far as the limitations of this study are considered, this article focuses on developed European cities, presenting positive examples of SSUM implementation, omitting the negative ones and poorer countries inside or outside Europe. Considering the fact that this study is just a preliminary part of the research project, future research will consider the identification of factors determining the social acceptance of SSUM solutions in large and middle-sized Polish cities. Other possible research directions would cover the analysis of failures related to SSUM strategies, as well as review the factors determining successful transformation towards eco-mobile cities.

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