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Special Issue
Electrification of Urban Transports and the Environment

Edited by
Dr. Matheus Koengkan

MDPI

https://doi.org/10.3390/su14159525

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New Paradigm of Sustainable Urban Mobility: Electric and Autonomous Vehicles—A Review and Bibliometric Analysis

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Abstract: The growing relevance of sustainability, as well as the necessity to replace traditional forms of transportation with sustainable ones, has made sustainable urban mobility an imperative. In order to respond to the ever-increasing need to develop sustainable modes of transport, the importance of electric, autonomous, and electric autonomous vehicles is increasingly emphasized. In addition, as trends of growth and development in electric autonomous vehicle technology are increasing, one of the questions that has appeared is whether autonomous electric vehicles represent one of the mechanisms that will be used to increase the sustainability of urban mobility. With this in mind, the results of a systematic analysis of existing research in the WOS and Scopus databases using the keywords "urban mobility", "electric vehicles", and "autonomous vehicles" was carried out to identify research trends in the use of autonomous electric vehicles in urban areas. The research showed that authors focus on the advantages and disadvantages of autonomous electric vehicles and their usage in the urban mobility system, but an insufficient number of authors consider and define the need to plan the transition towards incorporating autonomous electric vehicles into the urban system. The results of this research also indicate an insufficient number of papers that research and describe the application of autonomous electric vehicles in distribution logistics. This paper provides an overview of existing research related to autonomous electric vehicles and the challenges of transition in the context of infrastructure and the development of a culture of sustainability among urban residents.

Keywords: urban transport; electric vehicles; sustainable urban mobility; autonomous vehicles

Citation: Kovačić, M.; Mutavdžija, M.; Buntak, K. New Paradigm of Sustainable Urban Mobility: Electric and Autonomous Vehicles—A Review and Bibliometric Analysis. *Sustainability* **2022**, *14*, 9525. https://doi.org/10.3390/su14159525

Academic Editor: Matheus Koengkan

Received: 15 July 2022
Accepted: 1 August 2022
Published: 3 August 2022

1. Introduction

The need to create new paradigms and new forms of urban mobility continues to grow as society's concerns related to sustainability develop. The reason for this is the growing number of inhabitants in urban and suburban areas [1,2] and the increasing use of fossil fuel vehicles. The use of such vehicles results in air pollution and the risk of developing a wide range of diseases within the urban population, such as lung diseases. In addition to air pollution, the mass use of fossil fuel vehicles also results in noise pollution, which can reduce the quality of life in urban areas [1,3]. There are also significant problems related to the habits of residents when it comes to traveling, including driving without car sharing with other individuals. Besides car usage, one of the areas that has a significant impact on CO_2 emissions in urban areas is distribution logistics that use fossil fuel vehicles [2]. The use of fossil fuel vehicles emits various pollutants into the atmosphere, such as PM10 and PM2.5, which can cause various allergic reactions, i.e., can affect the quality of the air. In addition, the burning of fossil fuels produces nitrogen oxides, sulfur dioxide, heavy metals, etc., which can cause acid rain, which can have a negative impact on the soil and plants. To reduce these negative impacts, different methodologies have been developed and are used to analyze the emissions of traffic sources and, in accordance with the obtained results, to define measures that will reduce the negative impact [4]. In addition, there are also specialized models that are used to analyze the emission of PM2.5 particles, which are particularly problematic in terms of their negative impact on health [5]. Growing concerns about pollution are based on the fact that urban transport is one of the most significant causes of air pollutants [6] and on the fact that the consumption of fossil fuels is growing due to the growing number of vehicles on roads. This increase in pollution results in unsustainability that has direct and indirect impacts on drinking water sources and food production [7,8]. Additionally, it is necessary to mention the increase in the price of fossil fuel production, which leads to significant increases in the cost of ownership of fossil fuel cars [9]. Solutions to the described problems are creating so-called "Smart Cities", within which one of the areas that is addressed with smart solutions is urban mobility. For the transition from a conventional city to a smart city, it is necessary to conduct a transformation that demands the implementation technological innovations, such as Internet of Things technology [8,9], Artificial Intelligence [10], sensors [11], cyber–physical systems, digital twins, etc. [12]. Implementing such technologies can result in the increased sustainability of a city and can also solve problems such as air pollution. It also results in creating public transport based on electric vehicles. The benefits of creating such systems are recognized by the European Union and the European Institute of Technology, both of which are developing a strategy for reshaping the existing situation, which means reducing the number of fossil fuel vehicles in urban areas and encouraging new modes of transport [3,8,9]. However, urban transport systems are complex and imbued with social and economic characteristics, which means that re-shaping the current situation must include changes in these segments, which may result in resistance, i.e., the dissatisfaction of urban residents [10].

Furthermore, when talking about the need to redefine the existing paradigm of urban transport, it is necessary to highlight the European Union's plan, which emphasizes that by 2035, all newly manufactured vehicles must emit 0 g of CO_2 [13], which means that the existing technologies used to produce fossil fuel vehicles will no longer be able to meet the targeted CO_2 emission levels [12,14]. In other words, after 2035, fossil fuel cars will still exist, but new ones will be produced with the aim of reducing the total global amount of CO_2 emissions.

One of the solutions to all of the described problems is the use of electric vehicles or to define a new organization system for transportation in urban areas that involves sharing vehicles [15,16]. According to simulations, this mode of urban mobility can reduce the amount of exhaust gas by 6.5% compared to the current one mode of urban mobility [6]. However, the introduction of this method of transport organization can bring the resistance of users with it since using one's own car achieves a higher level of comfort compared to sharing a car with other people. On the other hand, when it comes to the production of electric vehicles and their introduction to mass use, there are challenges associated with disposing used batteries [17] and ensuring sufficient resources, such as lithium for battery production [7,18,19]. In addition, one of the challenges is to ensure a sufficient number of charging stations [8] as well as a sufficient energy infrastructure capacity to service numerous electric vehicles [20] as well as to produce a sufficient amount of green electricity [21,22]. Otherwise, the use of electricity from sources that are not environmentally friendly will not result in significant improvements.

It is important to note that in addition to the potential of electric vehicles, there is also the possibility of using autonomous vehicles, which may influence changes in the existing paradigm and in the way urban transportation functions. Autonomous vehicles reduce the need for human intervention, while driving and can have a positive impact on safety if the developed autonomous system is sufficiently reliable [23]. In the case of such a system having insufficient reliability, which can be reflected in an insufficiently developed ability to detect and recognize objects, safety can be significantly compromised, which can result in different kinds of risks [9,24]. Autonomous systems can improve existing public transport services, i.e., they can replace the human component needed to operate a vehicle, which can result in lower costs and the greater accuracy of public transport [10]. Examples of such systems are drones [25], which can replace existing package distribution facilities, and given that such vehicles are powered by electricity, they can reduce CO_2 emissions [26,27].

In addition to all of the above, at the planning level, there is also the development of sustainable urban mobility plans, which include solutions for sustainable mobility that include the transformation of the existing system through the implementation of sustainable solutions. Shared space zones [28], public bicycles [29,30], and encouraging the use of public urban transportation [31–33] as well as paying a fee for vehicle entry into the city center and other similar measures [11] are examples of solutions that can be implemented to increase the sustainability of urban transportation. The described measures can be a phase of transforming urban mobility, and planners, when creating such plans, must be aware of future trends and the technology that future trends will bring so they that they can adapt infrastructure to meet the requirements of such technology in the future.

Given the complexity of urban transport and the growing demand for a paradigm shift that emphasizes sustainability, the aim of this paper is to conduct a bibliometric analysis of the impact of electric and autonomous vehicles on shaping a new urban transport paradigm. The research questions define in this paper are:

- What are the challenges of the transition towards autonomous electric vehicles in urban mobility?
- What impact do autonomous electric vehicles have on sustainability components?

This paper presents a defined research problem: the current knowledge of scientists and practitioners in the field of using electric and autonomous vehicles in re-shaping the conventional urban transport system.

This research is divided into chapters. The Section 1 presents an introduction to the issue of sustainable urban mobility. The Section 2 provides an overview of the theoretical assumptions of sustainable urban mobility and electric and autonomous vehicles. The Section 4 presents the results of the research and defines the research GAP. The Section 5 describes the discussion related to the issue, while the Section 6 defines the conclusion.

2. Theoretical Framework

2.1. Sustainable Urban Mobility

Sustainable urban mobility is a term that refers to the use of means of transport that do not affect the environment [14] and an approach to the planning of the development of urban areas with sustainability goals in mind [14,34,35]. When creating sustainable urban mobility plans, planners must also have the number of inhabitants in urban areas in mind as well as the need to ensure a satisfactory transportation service for residents located in urban areas [15].

There are a number of challenges in ensuring a sustainable mode of transport. One of the most significant challenges in implementing and enforcing sustainable urban mobility plans is the attitudes of residents [36], which must change significantly, as residents need to adopt new public transport patterns and reduce their use of cars [16].

Since urban areas in the past were planned and built according to the needs of conventional means of transport based on the use of fossil fuel vehicles [37], today's urban areas, with the challenges of space and the availability of financial resources when creating sustainable urban mobility plans, face many other challenges. Identified challenges that require significant financial investments in infrastructure are being overcome by adopting policies to encourage urban mobility, such as increasing parking ticket fees to discourage cars from entering the city center [38], reducing the number of parking spaces in the city center [39,40], reducing speed limits [16], etc. However, despite policies aimed at reducing traffic in urban areas, there are still problems related to freight transport, i.e., distribution logistics, as the cost of the last mile is particularly pronounced in urban areas [41,42] and because a dominant proportion of the vehicles involved in distribution logistics are fossil fuel vehicles in order to achieve payload and autonomy. In this context, there is the possibility of using electric delivery vehicles [17], which may have fundamental limitations related to autonomy and carrying capacity as well as to the area they cover, which is often reduced to inner city areas. Accordingly, there are initiatives to develop sustainable urban logistics plans that include the implementation of infrastructure [18,43,44] that will reduce the need for vehicles and physical delivery as well as increase the use of kiosks to pick up goods, cargo bikes, drones, and similar solutions.

Furthermore, when decarbonizing urban mobility, i.e., transforming the conventional urban transport system into a sustainable one, a special challenge may arise in large cities, while small cities are significantly more agile and have greater potential for complete transformation. This challenge is particularly pronounced in the cities of Central and Eastern Europe, which are on the path towards integration with the European Union and have the obligation to reduce the negative impact of urban transport on the environment [45]. The European Union plays a very important role in the development of sustainable urban mobility plans [46] as well as in co-financing projects for the development of sustainable urban mobility. In such projects, in addition to the exchange of knowledge, the implementation of solutions to increase the sustainability of urban transport is financed, i.e., the purchase of vehicles.

2.2. Electric and Autonomous Vehicles

The importance of the development of electric vehicles is growing with growing concerns about global warming. Unlike vehicles that use fossil fuels, electric vehicles do not emit significant amounts of CO_2, which is why they are considered and are classified as significantly more sustainable [47–49]. However, although they do not emit a significant amount of CO_2, the total amount of CO_2 emitted is determined by the source of electricity, i.e., the way in which the electricity used to charge electric vehicles is produced [20]. In other words, the use of gas plants for the production of electricity or for the production of electricity from coal has a negative impact on the sustainability of electric vehicles since harmful gases are released into the atmosphere during electricity production [50]. However, in addition to electric vehicles, there is also the development of hybrid vehicles that combine electricity and fossil fuels to power vehicles [21]. Such vehicles are significantly more sustainable compared to conventional vehicles that are solely based on fossil fuels and can be a good solution for the transition to fully electric vehicles.

One of the challenges associated with electric vehicles is the battery, which is crucial for the functioning of such vehicles. One of the main concerns is elements such as lithium, which, during production, release harmful emissions [22]. In addition to production, one of the challenges that arises is the disposal of used batteries since the environment in which the battery is disposed of can be endangered in the disposal cycle during battery disintegration [23,51]. Furthermore, the limitations of the batteries used in electric vehicles can be reduced to the time required for charging [51] as well as the availability of infrastructure in urban areas [52,53]. Ensuring that a sufficient number of electric charging stations that will be able to serve electric vehicles in urban areas poses a significant infrastructural, spatial, and financial challenge [9], and there is also the challenge of implementing electric charging stations for vehicles in the urban grid [54].

The emergence and development of Industry 4.0 as well as of technology within Industry 4.0, such as artificial intelligence, enables the creation and production of autonomous vehicles [53,55]. An autonomous vehicle is a vehicle that does not require human intervention to function. The development of autonomous vehicles is particularly important in the context of distribution logistics [56], where autonomous vehicles can transport cargo based on a programmed route without the need for human involvement [57,58]. In addition, the development of autonomous vehicles enables the creation of different forms of public transport that can drive along a defined route continuously, which means the possibility of maintaining permanent lines of public transport [57].

However, until the development of such systems, the reliability of autonomous vehicles needs to be further improved [59,60], as there is a risk of autonomous systems having insufficient reliability, which may result in complete system failure or in the risk of damage to other people and objects [61]. This is also the reason for the development of new concepts of autonomous vehicles based on connecting autonomous vehicles with other systems with which they communicate and from which they take information [62,63] and make adjustments in accordance with the downloaded information. These systems are known as connected and autonomous vehicles [64], and they serve as the foundation for reducing the need for humans as vehicle drivers [65,66]. However, the development and mass use of such vehicles raises legal issues related to compensation and liability for the potential errors made by autonomous vehicles as well as the liability of people in an autonomous vehicle in the case of vehicles transporting people [26].

The functioning of autonomous vehicles is based on sensors that are paired with artificial intelligence. Sensors scan the environment in which the vehicle is located and adjust the speed according to the identified objects [67]. The artificial intelligence systems used in the vehicle as well as the autonomous vehicle itself can be divided into several levels, from level 0 to level 5. Level 0 represents the absence of systems for autonomous driving. Level 1 systems are those that help the driver while driving, but as such, they do not have a significant impact on maneuverability. The driver is still responsible for steering. Level 2 systems have an impact on controllability and can control the vehicle independently, which is the case for systems that are used on highways. Level 3 autonomous driving involves systems that can be activated if there is a need for activation, such as a during a specific event on the road. Level 4 autonomous driving refers to vehicles that have the ability to drive independently and can stop the vehicle if there is a need to stop. The last level is level 5 autonomous driving, which represents autonomous vehicles that can reach a defined location on their own without any driver intervention [68]. It should be emphasized that with the increase in vehicle autonomy comes an increase in the risk if there is an error in the system or a failure of the system itself.

When talking about other important characteristics of autonomous vehicles, it is necessary to emphasize the legal aspect in the context of traffic accidents. Thus, one of the questions that arises is the responsibility for the consequences of a traffic accident. Since an autonomous vehicle can function without the driver's intervention, questions regarding the driver's responsibility if an autonomous vehicle causes a traffic accident arise [69]. The prevention of such accidents is of particular importance in urban areas due to the possibility of endangering pedestrians, cyclists, and other road users. In this context, the research carried out by [70] identified how a system that controls an autonomous vehicle can make a wrong decision due to wrongly placed road signs or roadside signs, which can result in damage or a traffic accident.

In the context of the adoption of electric cars, the research carried out by [71] analyzes the potential for electric vehicles, either autonomous or electric autonomous vehicles, to replace vehicles powered by fossil fuels. Furthermore, ref. [71] describes a methodology that can be used to assist in making decisions about the implementation of electric, autonomous, or electric autonomous vehicles. The methodology takes into account social, economic, and ecological criteria, and for decision-making, it takes into account the opinions of experts and the set goals that address the observed area. For decision-making and to analyze the profitability of implementing electric, autonomous, or electric autonomous vehicles, AHP (Analytic Hierarchy Process) is used. The use of this or similar methodologies is of particular importance in cases where there is no consensus regarding the implementation of the mentioned vehicles, i.e., when there is no information related to the profitability of implementation.

However, this is not the only challenge associated with the use of autonomous vehicles: autonomous vehicles face risks related to their safety in terms of the risk of a third-party taking control of them through system hacking. This is also one of the most significant risks, since taking control of a vehicle can endanger the life of the passenger as well as the lives of other road users [72]. In addition to the described risks and challenges, the research carried out by [73] identified that autonomous vehicles are attractive to many drivers and that drivers believe that by using autonomous vehicles, they can make better use of their time. However, it should also be emphasized that the attractiveness of using autonomous vehicles can be determined by policies that emphasize the use of such vehicles for public transport [73,74]. However, it should be emphasized that the use of autonomous vehicles can also be viewed according to trends and that the trends of use can change if new innovations appear on the market that are more attractive to drivers.

One significant study that examines the profitability of implementing electric vehicles was carried out by [75]. It analyzes the ecological and economic profitability of implementing electric vehicles. Based on the conducted research, ref. [75] comes to the conclusion that there is significant variability depending on the countries being analyzed. The study identified that electric vehicles are already more ecologically profitable in some countries after 30,000 km (such as in Norway), while achieving economic profitability depends on the distance traveled and differs depending on the context of the country being analyzed (for example, in the Czech Republic, economic profitability is achieved after 335,000 traveled kilometers). However, it is particularly important to emphasize that economic and environmental profitability can differ depending on the country. The basic conclusion of the research conducted by [75] is that electric vehicles must be adapted and that their performance improved in order to become more competitive compared to vehicles that use fossil fuels for propulsion. Furthermore, if we are talking about the situation related to the implementation of electric vehicles and the willingness of residents to buy such vehicles, the research carried out by [76] identifies how attitudes towards the purchase or use of electric vehicles can differ depending on the technical characteristics that the vehicle has, such as battery autonomy, and attitudes towards climate change [77]. However, the research showed that the attitudes of residents towards the purchase of electric vehicles differ depending on the country and that in some countries, such as China, the attitude towards climate change is a variable that affects the consideration of the possibility of purchasing an electric vehicle significantly less.

Ultimately, the profitability of the implementation and use of electric, autonomous, and electric autonomous vehicles depends on the context of the country being analyzed, which means that it can be determined by the attitudes of the inhabitants towards climate change, the characteristics of electric vehicles [78], etc.

3. Materials and Methods

This research is based on a bibliometric review of the literature conducted with R software. The research included papers published in the WOS and Scopus databases in the period from 2005 to 2022.

Figure 1 shows the approach to the research. The keywords used when searching the databases were "urban mobility", "electric vehicles", and "autonomous vehicles". An initial search of the WOS database identified 145 papers, while a search of the Scopus database using the same keywords identified 128 papers. In this bibliometric review, only scientific papers are included, while books and chapters in books were excluded. After filtering, the total number of papers included in the research was 239.

The bibliometric review parameters that were considered were institution productivity, author productivity, corresponding author analysis, analysis of the most cited papers, and co-citation analysis.

Analysis of institutional productivity was conducted by analyzing the total number of papers produced by an individual institution during the observed period.

When it came to analyzing the authors, the parameters that were considered were the total number of papers by an individual author, the country from which the author was from, and articles fractionalized articles, which refers to an individual author's contribution to a published set of papers.

Country productivity analysis is related to the analysis of countries with the largest number of published papers.

Papers were analyzed based on the analysis of the largest number of citations for each paper. The most significant papers were selected, and an analysis of the objective, type of paper, and method was carried out, and the contribution of the paper was clarified.

Co-citation analysis refers to the analysis of mutual citations between authors. The authors were divided into clusters, and the clusters were connected to each other with lines. The thickness of the lines indicates the number of citations, and the size of the circles indicates the significance and influence of the author.

The results are presented graphically and tabularly.

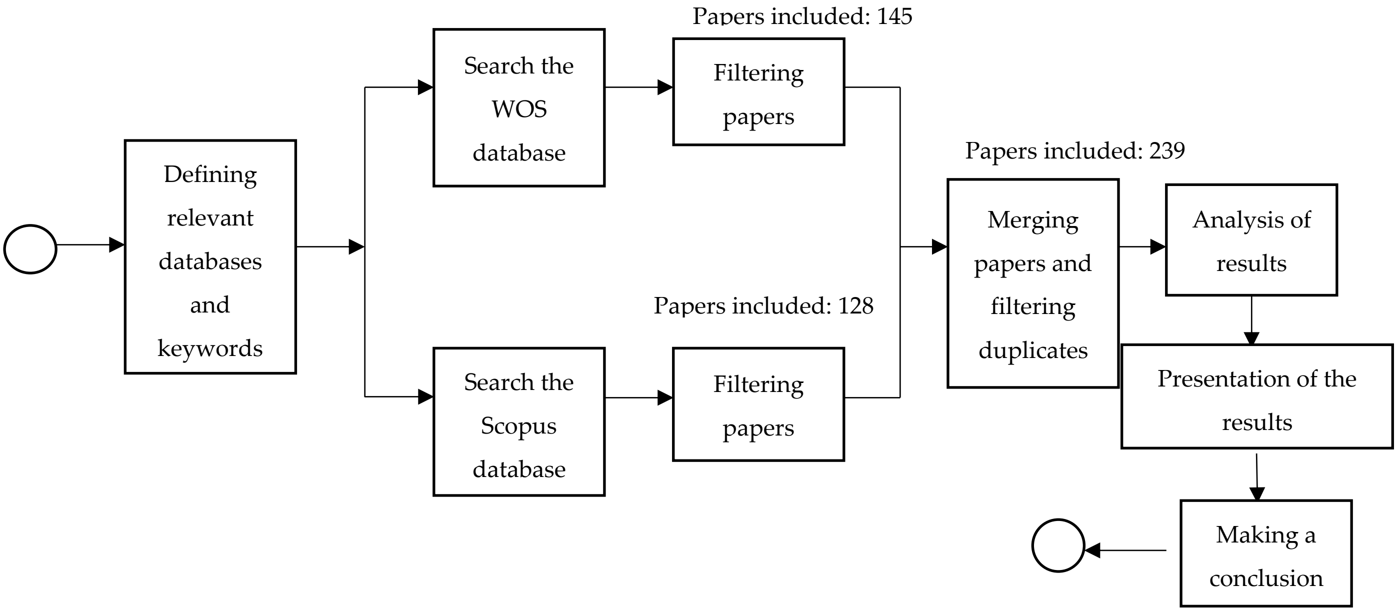

Figure 1. Research methodology.

4. Results

When talking about general survey data, it was identified that the average annual growth in the number of surveys was 9.25%, while the average age of the surveys was 3.25 years. The average citation rate was 6.37. Out of the total number of papers considered, 13 papers had one author, while there were 412 total authors for the papers analyzed. Furthermore, the average number of authors per paper was analyzed, and it was determined that in the analyzed papers, the average number of authors was 2.26.

Figure 2 shows the research trends. A significant increase in the interest of researchers in the field of influence of electric and autonomous vehicles occurred during 2018, when significant growth was recorded. Growth continued during 2021, while data for 2022 are not yet available.

4.1. Author Analysis

Table 1 shows the analysis of the most important authors in terms of productivity. Chyi Yng Rose Lim from Germany, Susanne Schatzinger from Germany, and James Weimer from the USA stand out as the authors with the largest number of papers. If we look at articles fractionalized, then the authors with the largest number of papers are Chyi Yng Rose Lim, Susanne Schatzinger, and Dimitris Apostolou from Greece.

If we look at the countries from which the authors come, it is evident that the most productive authors come from countries in the European Union, namely Germany and Greece.

4.2. Institutional Analysis

Table 2 presents an analysis of institutions and the productivity of those institutions. The institution with the largest number of papers is "Seoul National University" in South Korea, with a total of 14 papers, followed by "The Ohio State University" from the USA, with a total of 9 papers. In third place are "Purdue University" in the USA and the "Queensland University of Technology" in Australia, with a total of nine papers. All institutions are of equal importance regardless of the order in which they are shown in Table 2.

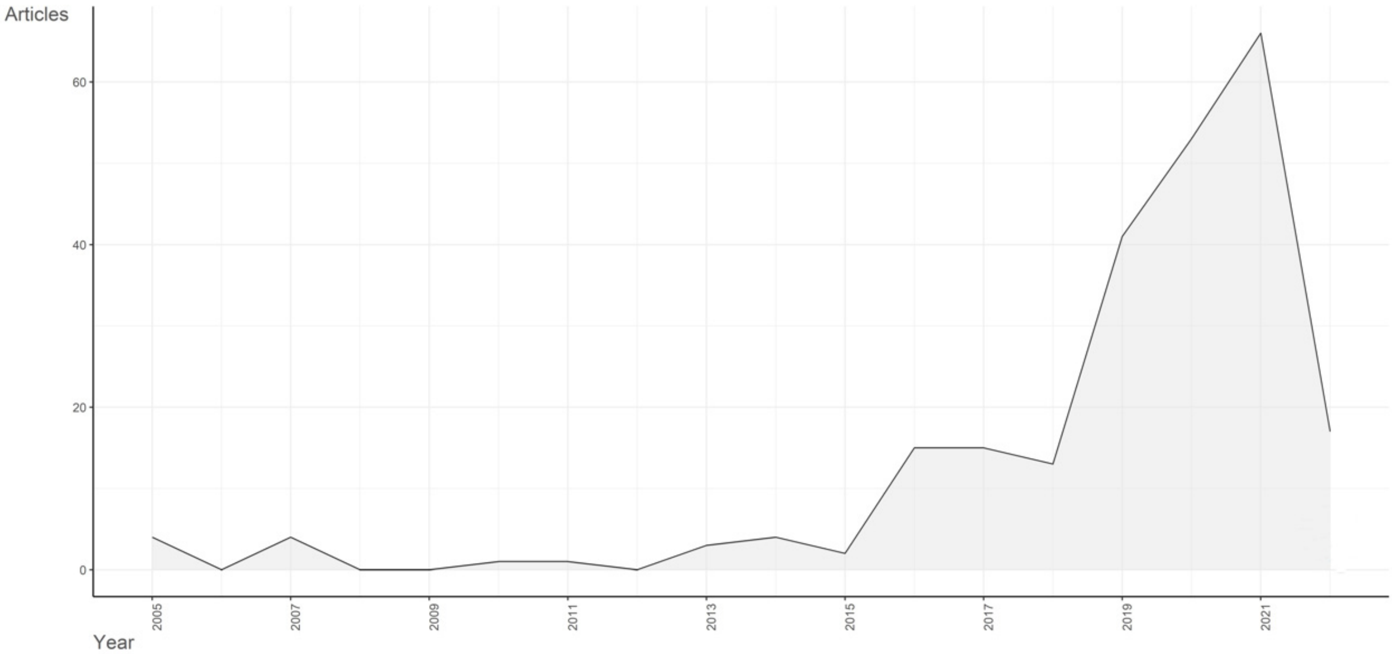

Figure 2. Research trends.

Table 1. Author analysis.

Authors	Articles	Articles Fractionalized	Country
Chyi Yng Rose Lim	3	1.33	Germany
Susanne Schatzinger	3	1.33	Germany
Dimitris Apostolou	2	1.33	Greece
James Weimer	3	1.25	USA
Hussein T. Mouftah	2	1.00	Canada
Bhuvaneshwar Vaidya	2	1.00	USA
Fernando Cesar Barbosa	1	1.00	Brazil
Avishai (Avi) Ceder	1	1.00	Israel
Jingdong Chen	1	1.00	China

Table 2. Institutional analysis.

Affiliation	Articles	Country
Seoul National University	14	South Korea
The Ohio State University	9	USA
Purdue University	9	USA
Queensland University of Technology	9	Australia
National University of Singapore	7	Singapore
Aalto University	6	Finland
Chang'an University	6	China
NYU Tandon School of Engineering	6	USA
Tongji University	6	China
The University of Texas at San Antonio	6	USA

It is evident that most of the institutions are from the USA and eastern countries, which is in line with the fact that those geographical locations have advanced, especially in the context of the technological development of electric and autonomous vehicles, which speaks volumes.

4.3. Corresponding Author's Country

Table 3 shows the corresponding author's country. The country with the largest number of corresponding authors is the USA, with a total of 32 papers, followed by China, with a total of 14 corresponding authors. Germany is in third place, with a total of 11 papers on which the corresponding author is from China. It should be noted that the importance of countries is the same regardless of their position in the table in the case of countries with an equal number of corresponding authors.

Table 3. Analysis of country productivity.

Country	Articles
USA	32
China	14
Germany	11
Korea	10
Italy	9
Canada	8
Australia	6
United Kingdom	6
France	5
India	5

4.4. Analysis of Papers

Table 4 shows the analysis of the most significant papers, i.e., papers with the largest number of citations. Pendleton et al.'s paper "Perception, planning, control, and coordination for autonomous vehicles" has 211 citations and is the most cited paper in this field of research. The authors analyze the advantages of using autonomous vehicles in urban mobility and mention advantages such as the reduction of vehicle ownership costs, less environmental pollution, less noise at work, and greater safety [79]. The second paper with the highest number of citations is the paper by Narayanan et al. called "Shared autonomous vehicle services: A comprehensive review". With a total of 146 citations, the authors provide an overview of existing the research related to the application of autonomous vehicles in urban mobility. The authors pay special attention to the economic benefits of such vehicles [80]. The paper with the third highest number of citations is the work by Asvadi, A., Premebida, C., Peixoto, P., and Nunes, U., entitled "3D Lidar-based static and moving obstacle detection in driving environments: An approach based on voxels and multi-region ground planes", with a total of 99 citations. In the paper, the authors describe the 3D perceptions of an autonomous vehicle and emphasize that 3D perception is of importance for driving autonomous vehicles; that is, they emphasize how such a system affects the safety of the vehicle itself. In their work, they conduct an experiment using a vehicle on which they test the LIDAR-3D system and come to the realization that such a system significantly increases the safety and controllability of the vehicle [78]. Mounce, R. and Nelson, J.D.'s paper "On the potential for one-way electric vehicle car-sharing in future mobility systems" has a total of 77 citations. The authors describe the increasing importance of electromobility and emphasize that its importance is growing due to the increase in the number of organizations that offer the possibility of car-sharing with electric cars. They emphasize the advantages of this form of transport and how this form of transport is particularly important for tourists. Furthermore, they look at the role that autonomous vehicles play in the functioning of urban areas [81].

Table 4. Analysis of the most cited papers.

Paper	Authors	Total Citations	Reference
Perception, planning, control, and coordination for autonomous vehicles	Pendleton, S.D., Andersen, H., Du, X., Shen, X., Meghjani, M., Eng, Y.H., and Ang Jr, M.H	211	[79]
Shared autonomous vehicle services: A comprehensive review	Narayanan, S., Chaniotakis, E., and Antoniou, C.	146	[80]
3D Lidar-based static and moving obstacle detection in driving environments: An approach based on voxels and multi-region ground planes	Asvadi, A., Premebida, C., Peixoto, P., Nunes, U.	99	[78]
On the potential for one-way electric vehicle car-sharing in future mobility systems	Mounce, R., Nelson, J.D.	77	[81]
How can autonomous and connected vehicles, electromobility, BRT, hyperloop, shared use mobility and mobility-as-a-service shape transport futures for the context of smart cities?	Nikitas, A., Kougias, I., Alyavina, E., and Njoya Tchouamou, E.	61	[82]
Blockchain based autonomous selection of electric vehicle charging station	Pustišek, M., Kos, A., and Sedlar,	46	[83]
Distributed real-time IoT for autonomous vehicles	Philip, B.V., Alpcan, T., Jin, J., and Palaniswami, M.	35	[84]
Who will drive the transition to self-driving? A socio-technical analysis of the future impact of automated vehicles	Marletto, G	34	[85]
Can autonomous vehicles enable sustainable mobility in future cities? Insights and policy challenges from user preferences over different urban transport options	Acheampong, R.A., Cugurullo, F., Gueriau, M., and Dusparic, I.	33	[86]
The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature	Golbabaei, F., Yigitcanlar, T., and Bunker, J.	18	[87]

Among other papers, it is necessary to highlight the paper by Nikitas et al. entitled "How can autonomous and connected vehicles, electromobility, BRT, Hyperloop, shared use mobility, and mobility-as-a-service shape transport futures for the context of smart cities", with a total of 61 citations, in which the authors describe new technologies that can replace and shape the existing urban mobility system [82]. However, it should be emphasized that almost all of the technologies described by the authors are conceptual, and their application in practice from the aspect of return on investment is questionable. Therefore, it is evident through the review of the most important papers, i.e., the papers with the largest number of citations, that the authors primarily deal with autonomous electric vehicles as a new form of urban mobility that will replace existing passenger cars and on accompanying technologies that allow for the more efficient use of autonomous vehicles.

Furthermore, in addition to the analysis of citations, Table 5 shows the analysis of the most significant papers as well as a defined contribution for each paper. A total of 10 papers were selected from the total number of papers included in the analysis. It should be noted that the papers are primarily concerned with reviewing existing research, that is, how the authors attempt to identify future scenarios through simulations that may affect the development of urban mobility.

Table 5. Analysis of the most important papers.

Reference	Goal of Paper	Type of Paper/Method	Contribution of the Paper
[88]	Analyzes new innovations that can affect urban mobility	Review	The paper defines six fundamental innovations that can affect urban mobility, namely intelligent transport systems; vehicles that use alternative fuels for propulsion; autonomous vehicles; the sharing of mobility services; on-demand transport; and finally, an integrated mobility system.
[73]	Analysis of the possibility of using autonomous vehicles as a taxi service	Article/case study	The authors describe the development of an autonomous taxi vehicle system that is used within the campus and describe the process of developing an autonomous vehicle for use in the context of a taxi service, the challenges related to the application, and the acceptance of such a vehicle by users. They conclude that the use of an autonomous vehicle as a taxi service has significant advantages and reduces the number of vehicles on campus, which also means less disruption to the research operations carried out within the campus.
[89]	Investigates the necessary changes in the infrastructure for the introduction of autonomous electric vehicles	Article/simulation	The authors analyze the performance of charging stations for electric vehicle batteries. They conclude that the best chargers in the context of charging speed are those chargers that combine fast chargers with normal chargers. In addition, the authors come to the realization that it is necessary to reduce the distance between battery charging stations to reduce the load on the charging station and to thus increase the quality of service for users.
[90]	To investigate the carbon footprint of electric autonomous vehicles in an urban area	Article/simulation	In this paper, the authors look at the carbon footprint of autonomous electric vehicles in different conditions of use: driving in an urban area and driving on the highway. From the research, the authors conclude that from the aspect of autonomy, vehicles used within the city have a limited weight that they carry in relation to highways. On the other hand, the authors conclude that autonomous electric vehicles have a significant impact on the release of greenhouse gases during their production, maintenance, and recycling. However, the use of such vehicles can ultimately result in a decrease in pollution in the long term.
[91]	Defining the method by which the impact of shared automated electric vehicles will be measured	Article/conceptual model	The authors provide a brief overview of existing research on the impact of autonomous vehicles on urban mobility. In addition, the paper defines 20 indicators that can be used to analyze the impact that autonomous electric vehicles have on urban mobility. Examples of indicators provided by the authors include safety, accessibility, noise pollution, economic profitability, etc. In addition to the defined indicators, the authors also define ways to measure each of the indicators.
[92]	Analysis of the potential application of air mobility in urban areas	Review/meta-analysis	In this paper, the authors look at the potential and the possibility of applying air mobility in urban areas and state that the development of air mobility in urban areas will become a disruptive technology. The authors come to the realization that despite the potential for the application of air urban mobility, there are challenges associated with the problem of securing parking space, restrictions in the context of using air space for a larger number of vehicles, and the development of charging stations for the vehicles that would be used for this type of transport.
[93]	Looking at the potential of the application of shared mobility in urban environments	Review	The authors look at the minimum number of vehicles that should be included in a fleet of shared vehicles to ensure satisfactory service. They raise issues related to strategies for assigning vehicles to passengers who require transportation as well as a strategy that will ensure that the vehicles are optimally distributed in the urban area to ensure optimal accessibility to users.

Table 5. *Cont.*

Reference	Goal of Paper	Type of Paper/Method	Contribution of the Paper
[82]	Analysis of the impact of new transport technologies on smart cities	Review	In this paper, the authors describe how technologies such as hyperloop, connected autonomous vehicles, or services such as mobility as a service have a significant impact on changing the existing perceptions of mobility in cities. They point out that it is necessary to transform user awareness towards the use of such technologies and services, but on the other hand, to adapt existing legislation to the emergence of new forms of mobility.
[94]	Analysis of scenarios and technologies that can affect urban mobility	Review/scenario analysis	In the paper, the authors review the most significant technologies that have the potential to influence and shape future trends in urban mobility. The authors conclude that autonomous vehicles, electric vehicles, and vehicle sharing with other users have the greatest influence on the development of urban mobility.
[95]	Analysis of air mobility	Review/conceptual model	In this paper, the authors analyze the costs that may arise with the implementation of a vehicle for air mobility. The authors conclude that there is an extremely high potential for the application of air mobility services and that such services offer significantly better quality and faster service compared to the current model of helicopter transportation. The paper emphasizes that the development of autonomous vehicles, that is, the development of electric vehicles for air mobility, is particularly important.

4.5. Journal Analysis

Table 6 shows the journal analysis. *Advances in Intelligent Systems and Computing* stands out as the journal with the largest number of papers, with a total of five papers published, followed by *Transportation Research Part A: Policy and Practice* with a total of 4 papers published. In third place are the journals *Energies*, *Integrated Communications, Navigation and Surveillance conference*, *SAE Technical Papers*, *Sustainability (Switzerland)*, *Transportation Research Part C: Emerging Technologies*, and *Transportation Research Part D: Transport and Environment*, with a total of three published papers each. The journals in third place are equally important regardless of their position in the table.

Table 6. Analysis of the most significant journals.

Journal Name	Number of Articles
Advances in Intelligent Systems and Computing	5
Transportation Research Part A: Policy and Practice	4
Energies	3
Integrated Communications, Navigation and Surveillance Conference	3
SAE Technical Papers	3
Sustainability (Switzerland)	3
Transportation Research Part C: Emerging Technologies	3
Transportation Research Part D: Transport and Environment	3

4.6. Citation Analysis

Figure 3 shows the analysis of the co-citations indicating the influence that an individual author and their research has on other authors, i.e., other research. The authors and their papers are shown in circles. The larger the size of the circle, the greater the citation, i.e., the greater the influence of the author and their paper. On the other hand, all of the circles, i.e., all of the authors and their papers, are interconnected with lines. The greater the number of lines and the thickness of the lines, the more significant the influence of the paper and the author. The authors are divided into two clusters, red and blue, and the clusters are defined according to similarity, i.e., the field of research the authors deal with.

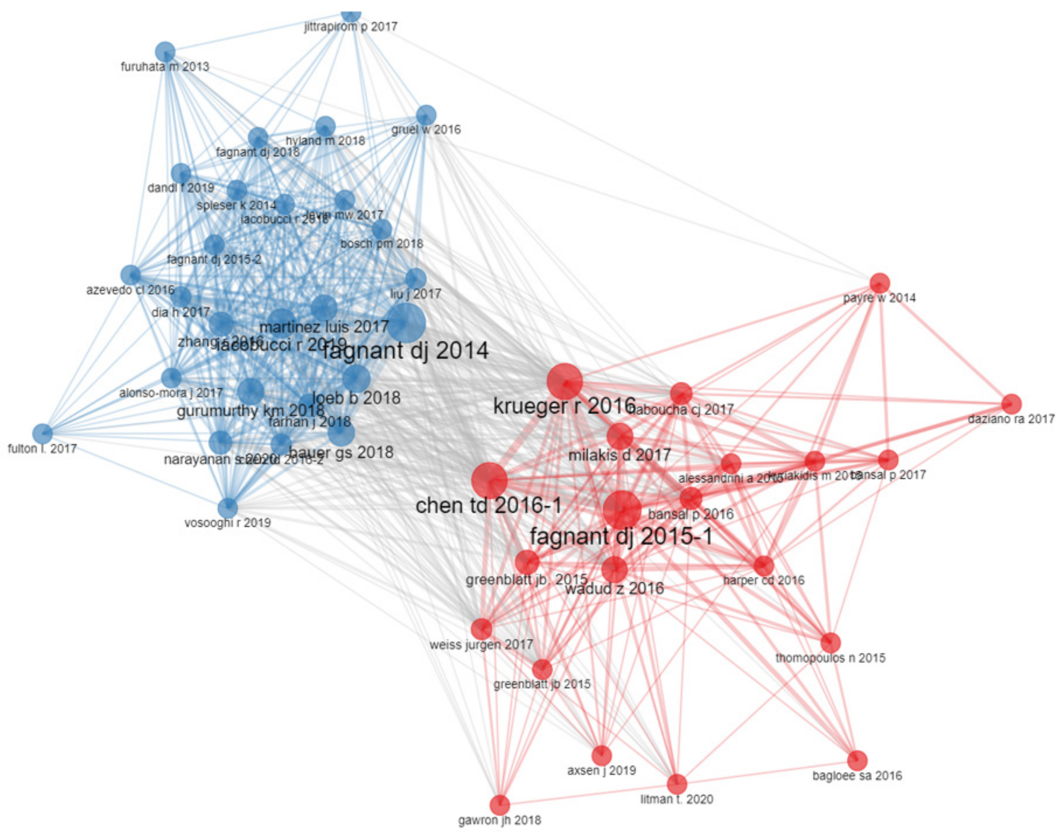

Figure 3. Interrelationship of authors.

In other words, in order to identify the link between research and the impact that research results have on other research, it is necessary to look at the sizes of the circles. The greater the number of lines leaving each circle, the greater the impact that that research has on other authors. It should be emphasized that each circle has the name of the first author and the year of publication.

Based on the conducted analysis, it was identified that the authors can be categorized into two clusters, red and blue. In the red cluster, Fagnant, D.J. and Kockelman, K. stand out as the most significant authors with the paper "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers, and Policy Recommendations". The authors describe the advantages of using autonomous vehicles and point out that the advantages are related to savings due to the possibility of calling a car to come to a precisely defined location at a precisely defined time. Furthermore, other advantages are related to the possibility of saving fuel and time in the car, meaning that passengers can use their time differently instead of spending it driving the vehicle. On the other hand, the authors emphasize the high cost of testing and developing autonomous systems as the main disadvantage [96]. In addition, other relevant authors within the red cluster are Krueger, R., Rashidi, T.H., and Rose, J.M. with the paper "Preferences for shared autonomous vehicles". In this paper, the authors consider the possibility of sharing autonomous vehicles as well as the development of a vehicle sharing system called "Shared autonomous vehicles" (SAVs). The authors point out that the application and development of such systems can significantly increase sustainability, i.e., by applying these systems, the portion of society that uses such systems can record the benefits of use in the context of reducing vehicle ownership costs [97].

Third in importance is the paper written by Chen, T.D., Kockelman, K.M., and Hanna, J.P. entitled "Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle and charging infrastructure decisions". The authors emphasize that electric vehicles have limitations in terms of autonomy and of the time required to charge the vehicle to be ready for driving. Furthermore, the paper emphasizes the possibilities offered by so-called shared autonomous electric vehicles (SAEVs), which refer to the sharing of autonomous electric vehicles similar to shared autonomous vehicles (SAVs), with the difference being that vehicles are electric [98]. Other authors within the red cluster include Milakis, D., Van Arem, B., and Van Wee, B., who, in their paper "Policy and society-related implications of automated driving: A review of literature and directions for future research", describe the consequences of using autonomous vehicles, which they divide into three phases: the first phase is related to purchase and purchase costs; the second phase is related to maintenance; and the third is related to resources and resource use. The authors describe how these phases have an impact on society and society's attitudes towards the use of autonomous vehicles [99]. Furthermore, Litman, T., in the paper "Autonomous vehicle implementation predictions: Implications for transport planning", analyzes the impact of the mass introduction of autonomous vehicles on society and describes how the primary benefit is related to the possibility of easier mobility in urban areas [100].

The blue cluster makes a significantly higher contribution to the topic. Two of the most significant authors in the blue cluster are Fagnant, D.J. and Kockelman, K.M. with their paper "The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios," in which the authors describe the use of the urban mobility systems Car2Go and ZipCar. These systems are based on the so-called principle of mobility on demand, i.e., mobility as a service that advocates for the use of rented vehicles instead of owning one. The authors emphasize that additional benefits are gained through the introduction of autonomous vehicles, primarily through safety, reduced negative impacts on the environment, etc. [101].

Martinez, L.M. and Viegas, J.M., as the second most important authors within the blue cluster, describe the possibilities of using autonomous public transport in medium-sized cities. The paper analyzes two scenarios, and in the first scenario, the current situation, which refers to the fact that all residents have their own private vehicles, prevails, while in the second scenario, residents only use public transport vehicles. The authors identify that the second scenario is significantly better in the context of reducing negative impacts on the environment and suggest the implementation of such systems in practice [102]. Furthermore, with a view of emphasizing the use of electric autonomous vehicles and highlighting their benefits, Loeb, B., Kockelman, K.M., and Liu, J. conducted the study described in "Shared autonomous electric vehicle (SAEV) operations across the Austin, Texas network with charging infrastructure decisions." The mentioned paper seeks to identify a potential solution to the autonomy problems of electric autonomous vehicles. The authors come to the conclusion that by increasing the battery capacity of such vehicles, i.e., reducing the time required for charging, limiting effects can be achieved, and that it is necessary to balance between the mentioned parameters [103]. In this regard, Iacobucci, R., McLellan, B., and Tezuka, T. describe optimization practices from Japan in the paper "Optimization of Shared Autonomous Electric Vehicle Operations with Charge Scheduling and Vehicle-to-Grid", in which they describe and present a methodology that could solve problems related to the speed of charging and the availability of electric vehicles in urban transport without overloading the electrical grid. The methodology presented by the authors was created as a solution obtained using a mixed-integer linear program. Particularly, significant research on the applicability and potential of autonomous electric vehicles was conducted by Gurumurthy, K.M. and Kockelman, K.M., whose results are described in the paper "Analyzing the dynamic ride-sharing potential for shared autonomous vehicle fleets using cellphone data from Orlando, Florida". The authors conclude that through the sharing and introduction of autonomous electric vehicles into urban transport, there would be a significant reduction in emissions, and the cost of owning a vehicle would be significantly reduced since such vehicles would be used with other passengers [104].

4.7. Research GAP

The authors in the described studies mostly focused on researching autonomous electric vehicles and the development of autonomous electric vehicle sharing systems [105–109]. However, the cost of development and implementation of such vehicles is not considered, nor are the risks associated with the use of such vehicles in urban areas, where losing control of the vehicle could result in significant damage. Additionally, there is a lack of research aimed at analyzing the willingness of the population, or users of such transport, to share vehicles with other users.

A particularly important area not covered is the area of safety in the event of a pandemic outbreak, as was the recent case with the SARS-CoV virus, which completely stopped public transport in order to reduce the possibility of spreading the infection. Due to the small space inside autonomous electric vehicles, it is not possible to maintain social distance, which also means a higher risk of spreading the virus in the event of a new pandemic. This risk is particularly significant if we are talking about carpooling and car sharing systems, which are also two of the types of public city transport considered in this paper. In other words, sharing vehicles with others as well as carpooling without adequate disinfection can significantly affect the risk of spreading a virus.

In addition, not owning a car and relying on public transport only, i.e., autonomous electric vehicles as a type of public transport, could result in a complete inability to achieve mobility if measures such as social distance are defined during a pandemic situation. This risk is less pronounced in other means of transport, such as buses and trains, due to the larger amount of space, which is not the case with cars.

One of the particularly significant problems that is not covered by research is the production of electricity from clean sources: sources that do not pollute the environment through the production process. In other words, the authors of the research try to overcome the problems related to the autonomy and speed of charging electric vehicles. They consider the possibility of reducing greenhouse gas emissions by reducing the number of personal vehicles, but they do not consider the significant need for electricity. The complete elimination or reduction of fossil fuel vehicles also means increased demands for electricity, and recent developments related to the political crisis in Eastern Europe have shown that all countries are mostly dependent on imported energy as well as electricity. With the inability to ensure a sufficient amount of electricity, there may be risks related to reductions in the functioning of electric vehicles, as such energy is used for other purposes, not only for the purposes of charging electric vehicles. Likewise, the constant emphasis on the imperative need to reduce fossil fuels in electricity generation places emphasis on solar cells, wind farms, and hydropower plants, which may have capacity constraints. The potential that nuclear energy could have to meet electricity needs is not stated, as nuclear energy is one of the cleanest sources of energy in terms of greenhouse gas emissions.

In addition, it should be emphasized that none of the authors considered distribution logistics or the possibility of using electric and autonomous vehicles in distribution logistics, which is essential since the development of passenger transport alone will not result in the systematic improvement of urban mobility.

5. Discussion

The development of sustainable urban mobility is imperative due to the growing urban population, but also due to growing concerns about the environment and reducing the negative impact of transport. One of the solutions is the development of sustainable urban mobility, for which it is necessary to carry out planning. However, when planning and addressing the challenges of urban mobility, it is necessary to involve all stakeholders and to analyze their needs and views [110–112]. Otherwise, the implemented measures will not result in the desired effects, as there will be resistance related to the use of the implemented solutions.

One of the particularly emphasized measures that the authors point out is car sharing systems, i.e., the use of cars owned by the city or another individual. This approach may result in fewer individuals needing to own their own cars. However, with this approach, the autonomous public transport approach is emphasized [113]. The research conducted by [38], which examines the potential of public transport to increase the sustainability of urban mobility and the attitudes of users towards it, identified four prototypes in this context: technical enthusiasts who accept innovative approaches to public transport, social skeptics who doubt the applicability and acceptance of such a form of transport, skeptics of the service and opportunities offered by this mode of transport, and technological skeptics who doubt the possibility of application and efficiency of such transport [38]. This is where the need to plan the previously mentioned stakeholder analysis and stakeholder attitudes more precisely comes to the fore, as attitudes can be a fundamental obstacle.

However, in addition to attitudes and opinions, one of the obstacles is infrastructure investment as well as investment in the purchase of autonomous electric vehicles [114–116]. The use of such vehicles requires an adapted infrastructure in terms of the availability of electric charging stations in the city and the suitability of electric chargers themselves as well as changing user habits since charging stations are not available in all places [117–119]. In other words, planning and the need to analyze the current situation as well as analyzing potential places where the charging points themselves can be located are again highlighted here, which can be a significant problem when it comes to populated urban areas.

There is no doubt that the potential of using autonomous and electric vehicles as well as autonomous electric vehicles to increase the sustainability of urban mobility is extremely high. However, the implementation of such solutions must include feasibility studies before they can be included in the development of a sustainable urban mobility plan [120–122]. Furthermore, the development of sustainable urban mobility based on the use of electric and autonomous vehicles implies a global initiative, i.e., an initiative that will cover a larger geographical area, or at least an entire country. The reason for this is the need to provide clean sources of electricity, as otherwise, the same problems associated with the application of fossil fuel cars will arise [123–127].

The implementation of autonomous electric vehicles as a means of urban mobility, i.e., public transport, has a significant impact on the social component of sustainability, which can be seen through potential inequality, primarily in the context of the price of electric autonomous vehicles. In other words, considering that the price of such vehicles can be high, the possibility of mass purchasing such vehicles is significantly reduced. However, a particularly significant impact is the increase in the quality of life due to a smaller negative impact due to reduced pollution due to the use of electric vehicles. In addition, the need to increase the production and development of autonomous electric vehicles can result in an increased need for specialized labor, which means greater employability, which raises the standard of living. This alone affects the economic segment of sustainability, since the introduction of new jobs and new production plants positively affects the economic situation from the point of view of starting new companies.

It should also be emphasized that the use of autonomous electric vehicles, despite the risk of loss of control, can have a positive impact on reducing the total number of traffic accidents, which affects safety as well as reduces the economic consequences caused by traffic accidents [128–132].

Furthermore, when considering the impact that the application of autonomous electric vehicles has on the economic pillar of sustainability, the application of electric vehicles requires the aforementioned adaptation of the infrastructure to new requirements. In other words, the application of autonomous electric vehicles can indirectly have a positive effect on the economic segment of sustainability, but it is important to note that there is a risk of the need for financial debt so that the existing infrastructure can be adapted to new requirements.

A particularly challenging area is the development of sustainable urban logistics plans, which must be part of a plan to transform the conventional system of urban mobility and transport towards sustainability [133–136]. It is worrying that none of the authors, i.e., of the papers included in the analysis, do research this phenomenon, which is of particular importance since urban logistics provides all of the necessary resources for the normal functioning of an urban area.

The basic goal of every urban environment should be transformation towards sustainability through opportunities and the implementation of solutions arising from the development of Industry 4.0 [137] or the transformation to the so-called smart city. As smart cities are one of the mechanisms for ensuring compliance and achieving the goals of sustainability defined by the United Nations, smart cities also unite all of the principles of sustainable urban mobility.

However, given that autonomous electric cars are in their infancy and their reliability must be tested and proven, primarily in terms of safety, it is necessary to emphasize that existing urban areas must begin to adapt their infrastructure and analyze opportunities for improvement through an analysis of user attitudes. In addition, one of the possible ways to shape the culture of sustainability in an urban area is the use of public electric bicycles, public electric scooters, or public electric motorcycles while using and encouraging the use of the same requirements for investment in infrastructure and reshaping existing infrastructure to the needs of such vehicles. Since the European Union has set a deadline of 2035 for the complete cessation of the production of CO_2-emitting cars [138,139], urban areas must develop plans and begin to adapt in order to respond to the challenges that will arise with the introduction of more electric cars, i.e., autonomous cars. The proposal for the adaptation and preparation phases is shown and described in Table 7.

Table 7. Preparation phases for developing sustainable urban mobility.

Phase	Description
Phase 1	Changing the culture of urban residents and education on the benefits of using electric vehicles as well as developing funds to encourage the use of electric vehicles; at this stage, it is necessary to strategically consider the construction of power plants for the production of electricity from clean sources that will later be used to charge electric vehicles as well as to begin to think about adapting existing infrastructure to future needs. Furthermore, this phase includes an analysis of the current situation and attitudes of users in order to plan the infrastructure.
Phase 2	Disincentives for the use of fossil fuel vehicles and beginning to stimulate the use of electric and hybrid vehicles through measures such as restricting parking, paying fees for entry into urban areas, and the conversion of existing parking spaces into tracks intended for electric vehicles such as electric bicycles and scooters. At this stage, it is necessary to start building the infrastructure for the transition to electric vehicles as well as to intensify education and the development of a culture of sustainability.
Phase 3	The transition of the urban area exclusively to the use of electric vehicles as well as the consideration of future challenges related to changes that may arise in the future due to the development of new modes of transport such as hyperloops or similar modes of transport as well as the development of sustainable urban logistics in the context of the use of drones and autonomous night delivery systems in order to relieve the burden on roads and to enable the smoothest possible flow of autonomous electric vehicles during peak loads.

It is necessary for urban areas to start adapting to these new conditions as soon as possible because without adaptation, they will not be able to meet the new requirements that will become legal requirements in the future [140,141]. The challenges of the transition to the use of electric autonomous vehicles need to be addressed at the state level, as urban areas do not have sufficient financial strength to develop the infrastructure needed for an established system to function independently.

6. Conclusions

The presented research is based on a systematic review of the literature the WOS and Scopus databases found according to the keywords defined in Chapter 1. Based on a systematic review of the literature, it was identified that an insufficient number of researchers research the challenges of transitioning to autonomous electric vehicles. In other words, the authors describe the need to develop sustainable urban mobility, but, at the same time, do not define measures and mechanisms for dealing with challenges such as the availability of electric charging stations and sources of clean electricity. Given the relatively short period of adaptation given to urban areas to meet the defined requirements to increase their sustainability, it is necessary to approach the development of planning and transformation methodologies and to start with them. Furthermore, the research identified that the use of autonomous electric vehicles is one of the possible optimal solutions that will reduce noise pollution or pollution that may occur due to the operation of internal combustion engines.

In addition, this paper identifies that the largest number of authors dealing with sustainable urban mobility comes from the European Union, primarily Germany, Italy, and Greece, while a smaller number of authors come from the United States and China. It was also identified that the authors who have the greatest influence on the development of sustainable urban mobility are Chii Yng Rose Lim from Germany, Susanne Schatzinger from Germany, and James Weimer from the USA. If we look at the articles fractionalized, then the authors with the highest amount are Chyi Yng Rose Lim, Susanne Schatzinger, and Dimitris Apostolou from Greece, and we are also able to observe how there is a significant link between the researchers studying autonomous electric vehicles and their application in sustainable urban mobility.

The conducted research has limitations. The basic limitation of the research refers exclusively to the focus on the WOS and Scopus databases without taking into account other databases in which there are papers dealing with similar issues.

Future researchers in this field are encouraged to conduct an analysis of urban areas and citizen attitudes toward the use of autonomous electric vehicles as well as an analysis of the use of existing electric vehicles. In addition, we recommend that future studies analyze the current capacity of the electricity system against future requirements for the production of sufficient green electricity. Additional recommendations are to include books and book chapters in future research on this subject.

Author Contributions: Conceptualization M.K. and M.M.; methodology, M.K and M.M.; software, M.K. and M.M.; validation, M.K. and M.M.; formal analysis, M.K. and M.M.; investigation, M.K. and M.M.; resources, M.K. and M.M.; data curation M.K. and M.M. writing—original draft preparation, M.K. and M.M.; writing—review and editing M.K. and M.M.; visualization, M.K. and M.M.; supervision, K.B.; project administration, K.B.; funding acquisition, K.B. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by University North, Republic of Croatia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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