Sustainable Urban Mobility

Subjects: Transportation

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Sustainable urban mobility is a term that refers to the use of means of transport that do not affect the environment and an approach to the planning of the development of urban areas with sustainability goals in mind. 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. 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.

urban transport electric vehicles sustainable urban mobility autonomous vehicles

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].

2. Sustainable Urban Mobility

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 [28], 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 [29], 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 [30], reducing the number of parking spaces in the city center [31][32], 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 [33][34] 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][35][36] 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 [37]. The European Union plays a very important role in the development of sustainable urban mobility plans [38] 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.

3. 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 [39][40][41]. 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 [42]. 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][43]. Furthermore, the limitations of the batteries used in electric vehicles can be reduced to the time required for charging [43] as well as the availability of infrastructure in urban areas [44][45]. 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 [46].

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 [45][47]. 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 [48], where autonomous vehicles can transport cargo based on a programmed route without the need for human involvement [49][50]. 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 [49].

However, until the development of such systems, the reliability of autonomous vehicles needs to be further improved [51][52], 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 [53]. 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 [54][55] and make adjustments in accordance with the downloaded information. These systems are known as connected and autonomous vehicles [56], and they serve as the foundation for reducing the need for humans as vehicle drivers [57][58]. 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 [59].

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 [60]. 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 [61]. 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 [62] 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 [63] analyzes the potential for electric vehicles, either autonomous or electric autonomous vehicles, to replace vehicles powered by fossil fuels. Furthermore, ref. [63] 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 [64]. In addition to the described risks and challenges, the research carried out by [65] 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 [65][66]. 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 [67]. It analyzes the ecological and economic profitability of implementing electric vehicles. Based on the conducted research, ref. [67] 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 [67] 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 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 [68] 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 [69]. 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 [70], etc.

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