

Review

Smart-Mobility Services for Climate Mitigation in Urban Areas: Case Studies of Baltic Countries and Germany

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Abstract: The transport sector is one of the largest contributors of CO₂ emissions and other greenhouse gases. In order to achieve the Paris goal of decreasing the global average temperature by 2 °C, urgent and transformative actions in urban mobility are required. As a sub-domain of the smart-city concept, smart-mobility-solutions integration at the municipal level is thought to have environmental, economic and social benefits, e.g., reducing air pollution in cities, providing new markets for alternative mobility and ensuring universal access to public transportation. Therefore, this article aims to analyze the relevance of smart mobility in creating a cleaner environment and provide strategic and practical examples of smart-mobility services in four European cities: Berlin (Germany), Kaunas (Lithuania), Riga (Latvia) and Tartu (Estonia). The paper presents a systematized literature review about the potential of smart-mobility services in reducing the negative environmental impact to urban environments in various cities. The authors highlight broad opportunities from the European Union and municipal documents for smart-mobility initiatives. The theoretical part is supplemented by socioeconomic and environmental descriptions, as well as experience, related to smart-mobility services in the four cities selected.

Keywords: smart city; smart-mobility services; smart-city planning; climate mitigation



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1. Introduction

Climate change mitigation requires transformative changes in cities. Rapid urban population growth, traffic congestion and related air pollution, as well as ageing infrastructure and energy usage put cities at the center of the climate mitigation agenda. In 2018, 4.2 billion of the world's population lived in cities. This number is expected to reach 6.5 billion by 2050 [1]. Environmental implications are highly related to the consumption of natural resources for energy production and greenhouse gas emissions (GHG), which contribute to climate change. Currently, cities are responsible for 60 to 80% of all energy consumption and approximately 70% of carbon emissions in the world [1]. The transport sector is one of the main contributors to greenhouse gas emissions. At the global scale, transportation accounted for 28% of the global final energy demand and 23% of global energy-related CO₂ emissions in 2014 [2]. The transport sector's emissions, such as particulate matter (PM₁₀ and PM_{2.5}), nitrogen dioxide (NO₂), carbon monoxide (CO) and other gases, mostly depend on the type of fuel used, with diesel and gasoline being the most popular.

In the European Union (the EU) road transportation accounted for 70% of GHG emissions in 2014 [3]. In 2017, the impact from road transport increased by 2% in three years, where 44% were caused by passenger cars [4]. Focusing on urban areas, in 2013 cities were responsible for 23% of all CO₂ emissions from transportation [5]. The latest

data show that urban mobility accounts for 40% of all CO₂ emissions of road transport and up to 70% of other pollutants from transportation [6]. Toledo et al. [7] study found that individual motorized transport causes 59% of greenhouse gas emissions, while the freight and urban services sectors were responsible for 28%. Compared to private vehicles, public transportation produces 95% less CO, 45% less CO₂ and 48% less NO₂ than private vehicles [8]. However, the emissions from public transportation are highly dependable on the energy sources, as well as the age and mileage of the vehicles in question [7]. In addition, the Cooperative information platform for low carbon and sustainable mobility (CISMOB) found that 16% of EU urban population was exposed to PM₁₀, as well as 8% of PM_{2.5} above the EU daily limit value and target value set in the Ambient Air Quality Directive [9]. According to the results of Chen et al. [10] study, urban population growth determines the transportation sector's energy consumption and CO₂ emissions increase.

Moreover, health science studies have revealed relevant results about the impact of air pollution on human health. For example, there are significant associations between traffic-derived air pollution and asthma incidence caused by PM_{2.5} [11,12] and NO₂ [12–14]. Positive but not-significant correlations for PM_{2.5}, PM₁₀, NO_x and NO₂ were found in Hendryx et al. [11] and Mostafavi et al. [15] studies. These results prove that transportation has a negative impact on the environment and human health.

The Paris Agreement, together with the input of Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, called for nations to strengthen the global response for climate mitigation [2]. The smart-city concept is thought to support this response in different fields of urban mobility. Fields of action in the transport sector comprise the demotorization and decarbonization of transportation, including the expansion of electric vehicles and greater use of energy-efficient appliances [2]. Citizens' mobility pattern changes to increase the usage of active, more energy efficient mobility modes also need to be taken in consideration. However, the report [2] stressed knowledge gaps and uncertainties related to smart cities, such as the expansion of electric vehicles; greater use of energy-efficient appliances, autonomous and shared/public mobility systems; and limited evidence on the impacts of electric vehicles and non-motorized urban transportation.

Accordingly, many studies about the environmental impact of smart-mobility applications were performed. Positive results for air-pollution reduction were found by applying mobile monitoring systems [16], traffic performance measurement [17] and bicycle-sharing systems [18,19], as well as of public transport promotion [19,20], shared mobility [21], smart vehicle routing systems [22] and Maas technologies [23]. The potential of reducing GHG emissions by using dynamic trip-planning and ticketing services, on-demand minibuses, and first- and last-mile ridesharing in Mexico City, London and San Francisco has been analyzed by Canales et al. [24]. Moreover, several authors discussed the benefits of real-time location-based shared smart parking systems for large areas [25,26]. Research finds that smart mobility provides solutions for these fields of action, namely for air pollution [27–30], by creating new opportunities for businesses and research institutes [31]. Furthermore, it provides political, social, economic, operational and technical benefits [32–34]. However, more evidence about different types of smart-mobility applications in different cities, their impact on environment needs to be provided.

The issues related to smart-mobility services still remain. Smart-mobility applications are capable of collecting various types of data, but the generation of data without data-based solutions is colloquial and does not prove the intelligence of a city [35]. This requires financial resources for creating and integrating smart-mobility technologies, openness of the data, public and private sectors collaboration, ICT experts and citizens' involvement.

Addressing the issues of sustainable urban development and climate change, specific targets in the mobility area are set in the global Transforming our world: the 2030 Agenda for Sustainable Development strategy [36] and the Paris Agreement [37]. Current long-term vision for climate neutral cities in The European Union is based on smart-mobility solutions for a sustainable future in Sustainable and Smart Mobility Strategy—putting European transport on track for the future COM/2020/789 and the Action Plan [38]. It is

a part of the ambitious European Green Deal COM (2019) 640 [39], which provides wide financial opportunities for creating a background for new foundation opportunities in the EU transport system for green and digital transformation.

Due to the transport sectors contribution to contamination levels in cities and opportunities for smart-mobility services to reduce air pollution, this article aims to analyze the relevance of smart mobility in the climate mitigation context and provide practical examples from Berlin (Germany), Kaunas (Lithuania), Riga (Latvia) and Tartu (Estonia). Therefore, three main research questions are raised: (1) What is the role of the smart-mobility services in the smart-city concept? (2) What are the specific measures in the Baltics and Germany that contribute to global and regional strategic goals in the smart-mobility area? (3) What could be learnt from smart-mobility examples in the selected cities? Various methods were used in different stages of the analysis, such as the literature review (logical method, systematic analysis and generalization method), document content analysis, case study and secondary data analysis. The results of the study could be useful for decision-makers, public transport companies, private companies, citizens, experts, researchers and innovators.

2. Research Methods

To analyze current scientific findings and the practical application of the smart-city concept focusing on smart urban mobility issues, the study was performed in four stages (Figure 1). The theoretical part is based on literature overview and documents' content analysis, while the case study method is used in the empirical part. The first stage—literature review—was performed by selecting scientific literature (articles, reviews, conference papers, etc.) from the Web of Science Core Collection database, Science–Direct and Google Scholar platforms. Some specific keywords, such as “smart city”, “smart city concept”, “intelligent city”, “sustainable city”, “smart mobility”, “smart urban mobility”, “smart mobility services”, “air pollution” AND “smart mobility”, “smart mobility” AND “air emissions reduction”, “smart mobility” AND “climate mitigation” were used to find the scientific publications. For synthesis and analysis of the results, logical and generalization methods were applied for the generalization, and logical and systematic evaluation of collected facts.

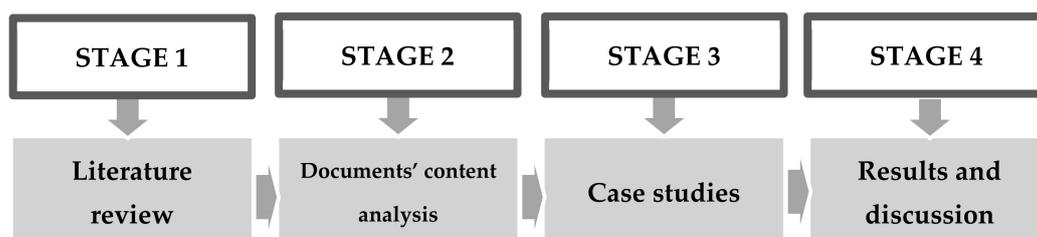


Figure 1. Research stages (prepared by authors, 2021).

In the second stage of the study, a qualitative research method of document analysis was applied. Important strategic documents and agreements were reviewed hierarchically from the global, to the European Union and municipal (city) level, concerning the significant role of the cities, especially the transport sector, in the context of climate mitigation. This type of document analysis helps determine global goals and objectives related to the smart urban mobility topic and, at the same time, understand the specific path and contribution at the municipal level. It is necessary to point out that the number of cities chosen for the study is not four by accident. The study was determined by the scope of the project “Smart Cities for Climate Mitigation”, funded by the EUKI, which comprises four partners from Estonia (Tartu), Latvia (Riga), Lithuania (Kaunas) and Germany (Berlin) (Figure 2). The project addressed several issue areas: (1) governance (smart-city strategies, processes, structures and actors), (2) monitoring and evaluation and (3) transfer of best practices. Therefore, the document review at the municipal level focused on four European cities—Berlin, Kaunas,

Riga and Tartu—identifying the specific plans and actions related to smart-mobility services concept application and compliance to the EU and global goals. The analysis focused on the presence elements—goals, targets and measures for smart-urban-mobility services.



Figure 2. The scope of the study and selected cities (prepared by authors, 2021).

In the third stage, case studies of smart-mobility services were chosen. In the first part of this stage, a quantitative method (secondary data analysis) was applied by providing the main information about socioeconomic characteristics and mobility patterns of citizens. Various sources of data from different periods were used for identification of population size in the city (all of data from 2019 from Statistic Berlin Brandenburg [40], Official Statistics Lithuania [41], Central Statistical Bureau of Latvia [42] and Statistics Estonia [43]). The data from Eurostat in 2019 were used for real GDP per capita analysis [44] and comparison of each countries' contribution to total EU GDP at the national level [45]. In order to understand mobility patterns in each city, the data from 2018 and 2019 were used (Berlin [46], Kaunas [47], Riga [48] and Tartu [49]). Moreover, additional information about the location, city size, public transportation regulations and types of publicly operated public transport modes is provided.

Air quality in selected cities was analyzed by annual mean ($\mu\text{g}/\text{m}^3$) of air pollution from NO_2 , $\text{PM}_{2.5}$ and PM_{10} in four selected cities in 2019 and 2020. The time period was chosen with concern to recent scientific findings on transport impact on air-pollution level reduction on the national and city level for the duration of the COVID-19 pandemic [50,51]. In the case of Berlin, 2019 and 2020 data from the Umweltbundesamt annual tabulation [52] were analyzed by deriving the annual averages from different amounts of air-monitoring stations inside the city (year, number of air-monitoring stations): NO_2 (2019, 24; 2020, 16), $\text{PM}_{2.5}$ (2019 and 2020, 4), PM_{10} (2019 and 2020, 11). Kaunas city air-pollution data from the Environmental Protection Agency [53] were used in 2019 and 2020, from one air-monitoring station. Data about air pollution in Riga city were found only for the year 2019 from the European Environmental Agency Statistics: NO_2 (2 stations), $\text{PM}_{2.5}$ (1 station) and PM_{10}

(1 station) [54]. Annual averages in 2019 and 2020 of the main types of air emissions in Tartu city were derived from daily and hourly rates [55].

In the second part, examples of publicly operated smart-mobility services from the four countries are described, highlighting a variety of smart-mobility solutions which could be adopted in the cities. These cases were used in the project as smart-mobility examples from project partners.

The final stage presents the conclusions of the study and discusses the possibilities for further research.

3. Role of Smart-Mobility Services in Urban Environment Condition Improvement

Smart-city discourse and its concept application is widely analyzed in scientific literature. The smart-city concept is placed at the center of the urban agenda and is used as a tool for ensuring competitiveness and sustainability in urban areas. In a broad sense, it means a long-term vision, which includes usage of intelligent solutions and knowledge [28,56], information and communication technologies, for efficient natural resource management, environmental impact reduction and better quality of life creation for citizens [27,57]. This definition itself prompts three very important and interconnected aspects—smartness, intelligence and sustainability. The holistic approach to a city as “a system of systems” explains the meaning of “smartness” as the ability to bring together all of its resources to effectively and seamlessly achieve the goals and fulfil the purposes it has set itself [58]. In other words, it is the effective integration of physical, digital and human systems in the built environment to deliver a sustainable, efficient, functional, resilient, livable and equitable future [59,60]. That means that the integration of sustainability into a smart-city concept addresses not only environmental (resource efficiency, energy, mobility, etc.), but also economic and social pillars. As a design paradigm, it uses ICTs to achieve global and universal access to different types of information about the city to achieve collective intelligence [61]. It creates opportunities for different systems in a city (citizens, organizations, finances, facilities, infrastructure) to not only function individually, but also work in an integrated way.

The application of the smart city concept in practice sets a number of challenges. One of the key aspects of a smart city is data, which, through openness, would provide clear benefits for the concept of a smart city. However, openness of data creates a number of institutional, legislative, technological, communicational, etc. barriers. Many authors analyzed and identified the main potential pitfalls of smart-city development [32–34,62]. There are hurdles of system information insecurity, privacy leakage, information incompatibility between different systems and various digital divides. Data privacy remains an issue in many IoT applications, which creates a barrier for increasing citizens’ involvement, while protecting and securing user data [63]. From a positive point of view, the idea of smart cities sounds very promising and optimistic; however, a number of challenges arise during its practical implementation.

In sustainability concept, urban mobility needs to consider improvement of natural environment condition, increase of social cohesion and economic competitiveness. Therefore, specific measures such as transport optimization, co-modality between public and private transport, and development and implementation of sustainable mobility plans could contribute in addressing these sustainability goals [64]. Therefore, smart-mobility services are a complementary layer to conventional transport systems (Figure 3). It includes integrated ICT infrastructures, sustainable transport systems, and logistics to support better urban traffic and mobility [30]. Smart urban mobility uses technology for data generation and sharing; information and knowledge for decision-making; enhancement of vehicles, infrastructure and services; and improvement of transport system operators, users, and stakeholders [65,66]. Moreover, the term “smart mobility” is not only related to sustainable and efficient transport systems based on contemporary technology, but it also contributes to cleaner mobility pattern changes and decision effectiveness in the transport sector.

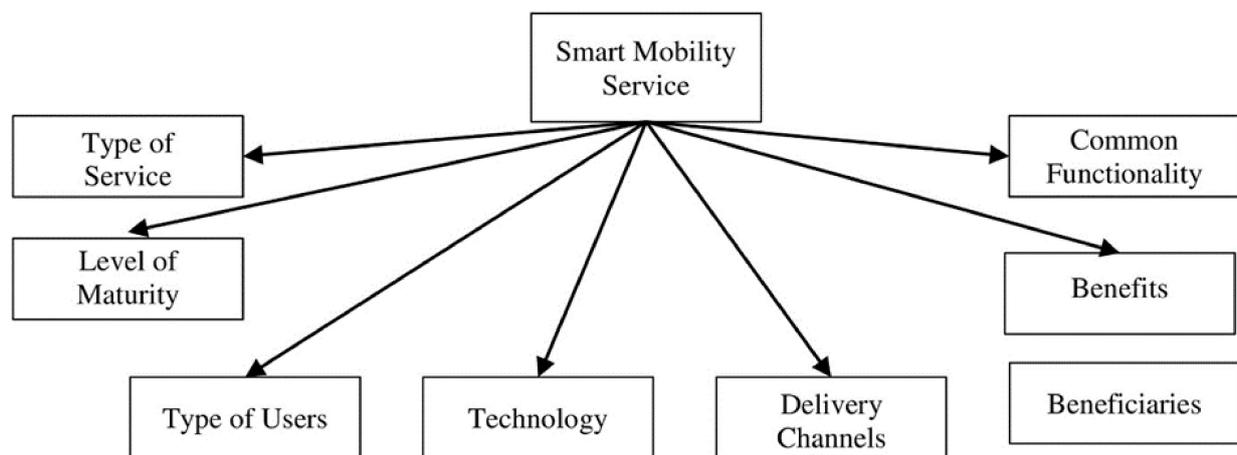


Figure 3. A smart-mobility service taxonomy (Cledou et al., 2018).

Mobility is also a necessary element in creating more resilient cities, which could be able to deliver natural and manmade shocks. The reduction of negative environmental impact of transportation during the COVID-19 pandemic crisis by improving air quality was proved by Feiferytė-Skirienė and Stasiškienė [50], and Pepe et al. [51]. During the same crisis, smart-city systems, IoT sensors and Machine learning were used for timely insights provision, based on a real-time data, for assessing pedestrian levels and traffic volumes, as well as for effective decision making [67]. The crisis has shown the importance of transportation system for being not only sustainable, but also resilient. In this case, urban mobility is used as an element for ensuring a more equitable use of transport system in case of serve disruptions [68]. It means that primary forms of mobility (walking), soft mobility modes (scooters, bicycles, etc.), new digital applications for booking public transport guarantees sustainable, social distancing, as well as the opportunities for transport costs savings for operators and users [69].

Transformative changes in mobility require significant actions in citizens' modal shift. According to Cepeda et al. [70] systematic review about the levels of ambient air pollution by various modes of the transportation, car commuters had higher exposure to all pollutants than did active commuters in 30 (71%) out of 42 comparisons, followed by those who commuted by bus in 57 (52%) out of 109, by motorcycle in 16 (50%) out of 32, by a car with controlled ventilation settings in 39 (45%) out of 86 and by massive motorized transport in 21 (38%) out of 55. Yang et al. [71] gives priority for the development of public transportation, reducing vehicle energy consumption and controlling emission standards to achieve road traffic energy saving and emission reduction. In the case of Auckland, New Zealand, it is planned that the promotion of public transportation (share of total passenger kilometers by public transport from 8% to 33%) greenhouse gas emissions could be decrease by 40% as the outcome of total kilometers travelled and a cleaner modal split [20]. Moreover, in the case of Barcelona's CO₂ reduction for shifting from car to other modes of transportation (bike and public transport) was estimated to be 203,251 t/CO₂ emissions per year [72]. Xia et al. [19] found that by shifting 40% of vehicle kilometers travelled by passenger vehicles to alternative transport, annual average urban PM_{2.5} would decline by approximately 0.4 µg/m³ compared to business-as-usual in 2030 in Adelaide. In the case of Lisbon and Helsinki, full use of shared mobility could lead to a reduction of CO₂ by 62% caused by private cars [21]. MaaS opportunities (journey planning and ticketing app) can support behavior change toward more sustainable modes of transport through better information and service integration [73]. However, the technology still does not assess the environmental impact in air emissions reduction and health [23].

Sun et al. [16] used a mobile monitoring system for traffic-related carbon-emission data collection consisting of a variety of environmental meters at different special scales. The study improved the IPCC bottom-up model by taking road type into consideration

and quantifying the overall traffic-related carbon emission amount in Shanghai. Barth and Boriboonsomsin [17] applied traffic-performance management-system data in the study about traffic congestion in South California and developed methods for reduction of CO₂ by 7% to 12%. Some necessary insights about real time information about expected impact on CO₂ emissions and energy savings from public transport and electronic bike-sharing systems are counted in the CISMOB study [9]. Moreover, a vehicle smart routing system was a useful tool for assessing how air pollution caused by vehicles could be minimized by taking ecosystem services (green areas) into account [22]. Even if the impact on the environment in a real-time location based shared smart parking system was not assessed, it is found to be useful time saving solution for air pollution and efficient traffic management [25,26].

Cities are already adopting a number of smart-mobility solutions, which could contribute to changes in modal split and citizens' behavior. According to Šurdonja et al. [67] in-vehicle navigation tools, e-parking, e-ticketing, e-pass, info-mobility signage, driverless car, walking bus, bike or vehicle, demand-responsive transport, vehicle pooling, services live tracking, biometric scanning and dynamic queuing management are already integrated in the cities. Investigations were also carried out in order to assess capabilities in measuring and reducing environmental impact of different smart-mobility services. The potential of new mobility applications such as dynamic trip-planning and ticketing services, on-demand minibuses and first- and last-mile ridesharing also were assessed [24]. The study of Canales et al. [24] has shown that dynamic trip-planning and ticketing apps could reduce GHG emissions by 500,000 tons per year in London, Mexico City and San Francisco, while increasing the usage of public transportation. Replacing fixed-route diesel buses with on-demand electric minibuses could reduce GHG and fine-particulate (PM₁₀) emissions by more than 80% and NO_x emissions by up to 95% per bus route in London and Mexico City. Deploying ride-sharing services for first- and last-mile trips to and from public transportation stops could minimize per-journey emissions of GHGs and local air pollutants by 55–80%. The theoretical analysis revealed that smart-mobility services contribute to the reduction of air emissions. The cases of different cities have shown the benefit of modal shift by using active transport modes and public transport, causing a lower CO₂ emissions rate. It is also necessary to point out that various types of smart-mobility services exist, some of which have already been assessed for environmental impact or the ability to make positive behavioral changes in mobility. It is also clear that new types of smart urban mobility services appear constantly and some additional studies could be carried out in order to understand their capabilities to contribute to a cleaner urban environment.

4. Smart-Mobility Strategies for Climate Mitigation: Global, Regional and Local Perspective

Smart-mobility policy framework is very broad. Some parts of it are included in other specific policies, such as climate change, energy, urban, digital, etc. Global strategies and agreements set the main goals, which later are adopted in the EU and municipal policies and strategies, assessing the capabilities of each level (Figure 4). In this study, authors have chosen main documents on the global and EU level and indicated direct and indirect relationship with the smart-mobility topic. Moreover, the analysis focuses on four main European cities—Berlin, Kaunas, Riga and Tartu—where the main strategic documents of these cities are analyzed in order to highlight sustainable mobility objectives, which were/are planned for making the mobility sector in urban areas smarter.



Figure 4. Global, regional and municipal documents related to smart mobility in urban areas (prepared by authors, 2021).

Transforming our World: The 2030 Agenda for Sustainable Development A/RES/70/1 [36] and the Paris Agreement to the United Nations Framework Convention on Climate Change [37] form the basis for reaching the goal of global warming limitation below 2, preferably by 1.5 degrees Celsius, by reducing greenhouse gas emissions in the world. Mobility issues and smart solutions are addressed in a number of European Union documents. The strategic origins for smart cities arise in 2007, when the European Commission adopted the European Union Green Paper as an urban agenda for mobility, which included the solutions for collective transport quality improvement, technologies for clean and efficient energy and protection of passenger rights on public transportation [74]. It also addressed an issue of smarter urban transport and provided options for the integration of Intelligent Transport System applications, traffic and travel data processing for better management of operations and new services (fleet management, traveler information systems, ticketing systems, etc.), and better communication (information for passengers about choice on the mode and time for travel) for planning a journey. The implementation of these actions is based on local authorities and private stakeholders' collaboration and participation. Another important strategy was EUROPE 2020 A strategy for smart, sustainable and inclusive growth COM/2010/2020 [75] published in 2010. Smart and sustainable growth were the priorities. One of the main goals for the EU member states until 2020 was to reach the target of an increase to 30% of emissions reduction. For achieving the 60% GHG emission reduction target in oil dependency, the European Union White Paper on Transport [76] included cleaner, collective transport and intelligent transport systems for traffic management. The Pact of Amsterdam [77] indicates that sustainable, efficient urban mobility and digital transition for better public services provisions in cities are the priorities related to smart mobility. In 2009, 28 of the EU cities signed the Green Digital Charter [78], committing to work together on ICT and energy efficiency ICT, deploying 5 large-scale pilots per city to reduce the carbon footprint of ICT and provide ICT solutions, which lead to more energy efficiency in transport.

The current strategic vision for the EU strongly focuses on sustainable and smart solutions in the mobility sector than ever. Another serious step towards Sustainable Development Agenda (2015) implementation in the EU is the ambitious European Green Deal COM (2019) 640. It is a financial tool concerned with climate change and environmental degradation, which sets the goal of no net emissions of greenhouse gases by 2050. As a part of the European Green Deal [39] transformative policies are set in a specialized

strategy, Sustainable and Smart Mobility Strategy—putting European transport on track for the future COM/2020/789 in 2020. It addresses new sustainable mobility services for congestion and pollution reduction, especially in urban areas. Future actions are described in three pillars: (1) sustainable transport modes (increasing the number of passengers commuting by public transport), (2) sustainable alternatives widely available in a multi-modal transport system and (3) right incentives to drive the transition [39]. In this strategy, “smart” means connected and automated multimodal mobility, innovation and the use of data and artificial intelligence (AI) for smarter mobility. It promotes smart and resilient mobility solutions in European cities: (1) the modal shares of collective and automated transport, walking and cycling; (2) connected and multimodal mobility; and (3) transport services based on demand (MaaS) integration. It is planned that modal shares of collective transport, walking and cycling, as well as automated, connected and multimodal mobility, would significantly lower pollution and congestion from transportation. The integration of these solutions would also result in a 100 European cities becoming climate-neutral. In addition, another strategy under The European Green Deal is Shaping Europe’s digital future COM/2020/67 [79]. It is related to the “smartness” of the city and highlights the importance of digitalization in the transport sector in pursuing sustainability objectives of The European Green Deal. These are currently the main documents, which address further EU steps in the context of smart cities.

Depending on local conditions, European cities already integrate smart-city planning goals and measures into their municipal planning documents. It is necessary to point out that this analysis does not focus on national level documents in order to highlight municipal relevance. All following documents by the four countries meet the national planning documents and adopt them on the municipal scale. Therefore, in this part the authors present four main strategies of Berlin (Germany), Kaunas (Lithuania), Riga (Latvia) and Tartu (Estonia).

4.1. Berlin “Urban Development Plan for Mobility and Transport” (2021–2030)

The plan [80] outlines a long term vision for future mobility and transport in Berlin by 2030, defines fields of action, objectives, targets, as well as relates these to specific action plans on local transport, cycling, walking, commercial traffic, traffic safety and air pollution control and noise reduction. The plan also includes specific policy measures for spatial planning, urban structure, organizational aspects of mobility planning, regulatory and economic measures, information activities, infrastructure, walking, cycling, public transport, streets and commercial traffic [81]. The document highlights the importance of mobility for inclusion, the economic sector and social cohesion. It also outlines that mobility has negative impacts on air quality, noise, health and the climate. Accordingly, the plan defines overarching objectives related to a transformation of transport (82% ecomobility by 2030, with 23% cycling, 30% walking and 29% public transport), climate mitigation (42% CO₂ reduction of the transport sector in comparison to 1990), health (reduce NO_x and other air pollutions, as well as noise). Building on these objectives, the plan defines specific targets, related to natural resources, global environment and city-compatible traffic. The development plan also sets target to reduce energy consumption related to traffic by 34% in 2030 and minimize land use related to settlements and traffic infrastructure to 30 ha per day.

According to the urban development plan for mobility and transport, the digital transformation offers potential for efficiency gains in the transport sector, connecting different forms of mobility, e.g., through mobility hubs and city-hubs.

4.2. Sustainable Urban Mobility Plan in Kaunas City (2019–2030)

There are two main documents which address smart-mobility-concept integration in Kaunas City—Strategic Development Plan of Kaunas City Municipality Up to 2022 [82] and Sustainable urban mobility plan in Kaunas city [47]. High quality and safe transport infrastructure is one among the long-term priorities in the city of Kaunas, noted into the

development plan until 2022. The plan sets specific targets and detailed measures for its implementation. High-quality and safe transport infrastructure is ensured by renovation and development of city streets, pedestrian areas and their buildings; development and implementation of intelligent information systems in the fields of public transport, motor vehicle traffic management and parking; establishment of a system of technical traffic regulation measures [82]. Another goal—development of public and non-motorized transport systems—is based on the installation and renewal of pedestrian, bicycle and other non-motorized transport paths, roads and other related infrastructure; implementation of public–private transport interoperability systems; preparation and implementation of the Kaunas City Municipality’s sustainable mobility plan; development of clean transport; installation and renewal of public transportation infrastructure [82]. A serious step towards smart-mobility development in the city was the preparation of a Sustainable urban mobility plan in the city of Kaunas. It contributes to some EU documents (EU Green Paper, EU White Paper) and national strategies. Sustainable urban mobility plan in Kaunas City (2019) until 2030 and Action plan until 2020 aim to solve mobility challenges in Kaunas city, to fulfill the global ecological requirements and make the city comfortable to move around. It assesses the main mobility needs of Kaunas’ residents and businesses, proposes solutions, giving priority to public transport, cycling, walking and low-emission transport. A number of smart-mobility-related actions were planned until 2020, such as intelligent transport, smart-mobility management, intelligent parking, traffic management, pollution control system installation and transport air-pollution control system, sector speedometers, development and promotion of non-motorized transportation.

4.3. Riga Sustainable Development Strategy Until 2030 (2014–2030)

The Riga Sustainable Development Strategy until 2030 sets long-term goals, objectives, measures and indicators. It includes a well-balanced traffic infrastructure and organization regarding convenient, fast, available, safe and ecologically friendly services of the public transport, smart technologies integration and development. Priority sequence in the development of transport infrastructure is formed as follows: pedestrian—cyclist—public transport—car transport—freight transport. Provision of high-quality and safe traffic infrastructure, improvement of the municipal parking system, provision of convenient, fast, available, safe and ecologically friendly services of the public transport, development the system of cycling traffic and its integration within the overall traffic infrastructure, development of a “smart” traffic control system and facilitation of the development of the latest technologies, economically effective transport services are the targets of the strategy [83]. A number of the measures are set in order to achieve the latter targets such as reconstruction and construction of modern traffic infrastructure, development pedestrian traffic infrastructure, pedestrian street network and network of mobility points, improvement of parking service, modernization of public transport, provision of a flexible ticketing system, integration of public transport into a single network of bus and train routes, improvement of the operation of the traffic management center and introduction of smart traffic lights [83]. Moreover, some specific measures are taken regarding energy efficiency such as support programs for the transition to renewable energy for the transport sector, installation of public charging points, electric cars and integration of hydrogen technology and fuel cells in the city’s public transport.

4.4. The Development Strategy “Tartu 2030+” (2006–2030)

Environmentally friendly and energy efficient public transport and intelligent traffic light systems are the priorities for long-term transport system development in Tartu city until 2030. Tartu is a city where public transport and non-motorized traffic are of high priority. The non-motorized road network is continuous and covers the whole urban region; rail transport has been planned and implemented, where possible. For the majority of the day, the city center of Tartu is a lively, pedestrian-friendly, human-dimensioned public space. The Strategy points out that Tartu is the city, where public transport and integrated types

of transport function in harmony. Environmentally friendly public transport and light traffic uses energy economically. The city is integrating a telematic system of monitoring bus transport, which allows to forward information about traffic jams and vacant parking places, to guide traffic with an intelligent traffic lights system, etc. [84]. One of the targets are related to the increase of public transport capacity and environmentally friendly public transport vehicles. The Strategy also highlights the importance of the completion of the construction of main streets, bridges and different level streets and road crossings to guarantee smooth traffic, the organization of an efficient parking system and the development of public and light transport.

All documents were prepared at different times and follow different principles; therefore, they also differ in content and level of detail. Therefore, comparison of general goals that will further have to be responded to in local action plans or other documents that plan specific measures is outlined in the analysis. Urban development plan for mobility and transport (for Berlin) sets goals and targets with integrated indicators. Development strategy for Tartu is prepared in a similar way: The document outlines goals and targets and only suggests short explanations for each. Riga's and Kaunas' strategic planning documents on the other hand, include specific actions, such as the following: intelligent transport, intelligent parking, traffic-management-system installation, the importance of public transport services and the integration of new technologies for smart-mobility development are the steps, which contribute to the concept of a sustainable and smart city. To conclude, even though the level of detail in the analyzed strategic planning documents differs, all documents are in line with the global environmental goals. Reduction of the environmental impact with the use of locally applicable measures is a common goal in most documents.

The document content analysis is expanded by providing examples of smart-mobility services in analyzed cities: Berlin, Kaunas, Riga and Tartu. These areas were selected to explore the examples of existing smart-mobility services. Table 1 presents main characteristics of fourth study areas related to geographical coverage, socioeconomic characteristics, mobility patterns of citizens, public transport regulation and variety of mobility services. Moreover, Table 2 includes the information about air pollution from NO₂, PM_{2.5} and PM₁₀.

Table 1. Main characteristics of the fourth study areas (prepared by authors, 2021).

Criteria	Level	Berlin	Kaunas	Riga	Tartu
Location	National	Central and Western Europe	Northeastern Europe	Northeastern Europe	Northeastern Europe
Size	Municipal (city)	891.7 km ²	157 km ²	304 km ²	38.80 km ²
Population	Municipal (city)	3.8 million (2019)	0.28 million (2019)	0.63 million (2019)	0.1 million (2019)
Real GDP per capita (euros)	National	35,840 (2019)	14,010 (2019)	12,510 (2019)	15,760 (2019)
Modal split	Municipal (city)	High usage of non-motorized (walking, cycling) and public transport (2018)	High private car usage for traveling to work (2018)	High private car usage (2019)	High private car usage (2018)
Public transport regulation	National	Public transport regulated	Public transport regulated	Public transport regulated	Public transport regulated
Types of publicly operated public transport modes	Municipal (city)	Buses, tram, subway, ferries, ridesharing	Buses, trolleybuses (electric), buses	Buses, tram, trolleybuses (electric), microbuses	Buses, bicycle-sharing (electric), electric car rental

Table 2. Annual mean of air pollution from NO₂, PM_{2.5} and PM₁₀ in four selected cities in 2019 and 2020 (prepared by authors, 2021).

Pollutant/City	Berlin		Kaunas		Riga		Tartu	
Year	2019	2020	2019	2020	2019	2020	2019	2020
NO ₂ (µg/m ³)	31.2	22.7	20.0	16.0	22.5	NA	9.8	6.9
PM _{2.5} (µg/m ³)	12.8	11.5	11.0	10.6	12.1	NA	5.7	5.1
PM ₁₀ (µg/m ³)	19.6	17.8	34.0	23.0	27.4	NA	12.1	13.2

Berlin is the capital of Germany, located in Central western Europe, and has a population of 3.8 million [40]. By the total area, it is the biggest city compared to other selected areas. Germany has the highest real GDP per capita compared to the other analyzed study areas, which is bigger than the average of 27 EU member states [44]. Moreover, Germany's contribution to the total EU GDP was the highest in 2019 (24.7%) [45]. Citizens' mobility patterns in 2018 indicate that the majority of trips in Berlin is conducted by active mobility (30% by foot and 18% by bike) and public transport (27%), while 26% of citizens use cars [46]. Public transport in Berlin is regulated at the State of Berlin (Gesetz zur Neuregelung gesetzlicher Vorschriften zur Mobilitätsgewährleistung—Berliner Mobilitätsgesetz) and federal levels (e.g., Allgemeines Eisenbahngesetz and Personenbeförderungsgesetz). There are a number of types of public transport modes such as buses, tram, subway, ferries and ridesharing. When comparing air-quality data in the four selected cities, we see that Berlin has the highest rates of air pollution from NO₂ and PM_{2.5} [52]. According to the municipality, NO₂ emissions were caused by traffic, heating and industry; PM_{2.5} was mainly caused by traffic (diesel vehicles and tire abrasion), heating, industry, the building sector [85]. Due to COVID-19 pandemic restrictions, the emissions from the main pollutants decreased in 2020 (Table 2).

Kaunas is one of the biggest cities in Lithuania, located in Northeastern Europe. According to current statistics, the population is slightly decreasing and 0.28 million citizens lived in the city's area in 2019 [41]. Lithuanian real GDP per capita is in third place compared to the selected countries and its contribution to the EU's total GDP is lower than 1% (0.3%) [44,45]. Based on 2018 statistics, Kaunas city residents are highly dependent on private cars (57%), 19% use public transport and only 14% travel to work in an active way (4% by bicycle and 10% by foot) [47]. In Lithuania, as well as in Kaunas, public transport is regulated by national law acts, for example, the Law of the Republic of Lithuania on the Framework of Transport Activities. Buses, trolleybuses (electric) and buses are publicly operated transport modes, which currently exist in the city. Kaunas has the highest PM₁₀ levels, it was the third from the four cities in NO₂ emissions' concentrations in 2019 [53]. The Environmental Protection Agency provides the data from one air-monitoring station located in the industrial part of the city. Due to the lack of more air-monitoring data in different parts of a city, it is hard to determine what impact transport has in relation to other polluting activities, such as industry and construction. In 2020, due to mobility restrictions in the entire country, air quality became better (Table 2).

Riga is a city in Northeastern Europe and the capital of Latvia. It is the second city by area and population size from the four cities [42]. However, Latvia's real GDP per capita is the lowest, financial contribution to the total EU GDP was only 0.2% in 2019 [44,45]. As well as in Kaunas, most of the city's residents (more than half) use cars (52%), 32% travel by public transport and only a small minority choose to travel by foot (12%) and bicycle (4%) [48]. In Latvia, public transport is regulated by the Law On Public Transport Services. Currently, public transport modes in the city include buses, tram, trolleybuses (electric) and minibuses. Comparing all selected cases, Riga was the second city according to air emission rates (NO₂, PM_{2.5} and PM₁₀) in 2019. A majority of residents prioritize private transport for travelling inside the city, therefore, it could be presumed that the emissions could be caused by vehicles, which are powered by diesel and have a long period of use. However, it is not possible to indicate air-quality changes in 2020, as the data are not provided.

Tartu is the second largest city in Estonia, located in Northeastern Europe. It has the lowest population (0.1 million) compared to the other selected cities [43]. As a country, Estonia is in the second place regarding its real GDP per capita results in Table 2, however, its share of EU GDP is also among the lowest (0.2%) [44,45]. The majority of trips in the city was conducted by car (46%), 21.5% by public transport and foot, while only less than 10 of residents chose cycling (8%) and other transport modes in 2018 [49]. As well as in the other analyzed cities, public transport in Tartu is regulated by the national Public Transport Act. Types of publicly operated public transport modes include buses, tram, subway, ferries and

ridesharing. Tartu is the most environmentally-friendly city taking the lowest rates or main air emissions used in the study. Since the beginning of 2020, public transportation vehicles were fully powered by renewable fuel—biomethane—produced by recycled bio-waste. Moreover, active transport modes are becoming more common in the city—Tartu is one of the most progressive cities in terms of using bicycles and developing a bike-sharing system in Estonia.

Mobility patterns of the three (of four) selected cities prove citizens' attachment to cars for travelling purposes in urban areas. Many smart-mobility solutions could transform residents' behavior by being attractive, comfortable, safe (data) and cost effective. The data received by the users should be used as an informative source in order to not only follow behavioral changes in mobility patterns, but also find effective real-data-based solutions for cities' challenges. As smart-mobility services are an important component of smart urban mobility, the article presents the examples of publicly operated smart-mobility services in Germany and the Baltic countries: Berlin mobility service "Jelbi", Kaunas public transport ticketing app "Žiogas", Tartu "Smart bike share" and "Mobility point" in Riga.

4.5. Berlin Mobility Service "Jelbi"

In 2019, the mobility service "Jelbi" was introduced in Berlin by the public transport company "BVG" (Berliner Verkehrsbetriebe). The service consists of a smartphone application that was developed together with the Latvian company "Trafi". The idea behind "Jelbi" is to facilitate the transition from motorized individual transport to public and sharing transport, thereby contributing to GHG emissions reductions in the city. This mobility service connects existing services in one application. These services include the car-sharing company MILES (Berlin, Germany), as well as DB Flinkster, cambio, mobileeee, greenwheels, e-scooter of the companies TIER (Berlin, Germany), Voi and e-mopeds from Emmy and TIER; a ridesharing service of BVG called BerlKönig, bikesharing by nextbike, public transport (bus, tram, subway and S-Bahn), as well as taxis. Users can plan and book their journey with the application comparing prices and expected travel time. In addition, part of "Jelbi" are mobility hubs that are installed in the neighborhoods, as well as next to subway stations, where users find cars, bicycles and scooters. Currently, more than 200,000 people downloaded the application. In the future, additional companies providing mobility services are planned to be included.

4.6. Kaunas Public Transport Ticketing App "Žiogas"

Kaunas public transport company "Kauno autobusai" (Kaunas, Lithuania) introduced a ticketing app "Žiogas" (Kaunas, Lithuania) for traveling by public transport in the city of Kaunas. The main goal of the "Žiogas" app is to make it easier for travelers to pay for trips. Therefore, the app is an additional way to purchase transport ticket along with e-tickets (cards) and physical tickets. A new user of the app must download the app, create an account, connect their bank card and select a valid discount if applicable. When on a bus/trolleybus, travelers must scan a designated QR code, which can be conveniently found in several locations on the bus to confirm the purchase of their ticket. The ticket is valid for 30 min, during which the passenger can switch to another route without being additionally charged. The app will stop charging for traveling if the person reaches the cost of a monthly ticket. The app is available in both Lithuanian and English. According to "Kauno Autobusai", in the period before the pandemic, around 215 thousand trips were made using the app every day [86]. Before the pandemic, trips paid for using the app made up around 7% of all trips, in 2020 the share of app users grew to 15%. In 2020, public transport in Kaunas was used by 28 million travelers and there were 94 thousand app users [86]. The app collects depersonalized data about use patterns and ticket types. The collected data can be used to improve public transport routes and identify problems. However, there is no possibility yet to see and track public transport routes on the app. One of the challenges of apps like this is that the person needs to have a charged smartphone and a bank account. Not all passengers can meet these conditions, therefore integration of

different ways to pay for trips is important. Integration of different ticketing types to one system and adding functionality such as trip planner or route maps would be aspects that could be included in the app in the future. Moreover, investment into digital infrastructure and convenience of use for public transport are important drivers to encourage sustainable mobility and reduce negative impact to the climate in cities.

4.7. "Mobility Point" in Riga

In 2020, the Riga Municipal Agency "Riga Energy Agency" launched the first mobility point in Riga and Latvia, connecting different sustainable modes of transport and offering convenient access to micro mobility and public transport opportunities. The mobility point also serves as a pilot area for deployment of innovative, data-based solutions, with both a bicycle and pedestrian counter and a testbed for smart-city solutions. The mobility point infrastructure offers convenient bicycle parking spaces, a bicycle repair station, an electric scooter and bicycle-sharing rental point, as well as a smart solar bench, providing free Wi-Fi and solar charging for smart devices. It has been implemented to promote sustainable transportation by connecting the public transport system with shared transport modes and a cycling network. The overall strategic objective for development of the mobility points network in Riga is to provide unlimited opportunities for fast, convenient, safe and comfortable commuting in the city without the use of conventional fossil-fueled vehicles, contributing to the achievement of the climate neutrality goals of the City of Riga. Compared to other mobility points in Europe, the solution developed in Riga is unique in terms of target audience, as it has taken into consideration not only the mobility needs of citizens, but also the interest of scientists and entrepreneurs involved in data collecting, opening up and promoting innovative data solutions. Thus, the Riga mobility point solution provides easy-to-access, open public infrastructure for testing innovations with the requirement for the users to open all the gathered data in machine-readable format. However, currently, data repository data.gov.lv collects only state and municipal data, and due to regulation and technical limitations, it is unable to serve non-public bodies. Therefore, collaboration between the private and public sectors should be ensured to make the open data usable.

4.8. Tartu "Smart Bike Share"

The Tartu Smart Bike Share is operated by the municipal public service coordinator Tartu Linnatransport. It is a newly formed entity that coordinates public transport services in Tartu: city bus and bicycle-sharing services. Infrastructure was developed in cooperation with Bewegen Technologies Inc (Canada). On 8 June 2019, Tartu launched the first Estonian cross-city bike-share service, which includes 240 bicycles and 510 electric bikes in a total of 69 car parks/loading docks across town. The bike-share service can be used with the electronic bus card (an additional contract is required) or smartphone, supported by a mobile application which allows users to look up the locations of car parks, the condition of parked bikes, service times, distance covered, consumed energy, etc. The service is also supported by a public online map application. In 2020 and 2021, bike-share was developed further inside and outside of the city borders with additional bicycles added to the system. In total, 1,621,650 rides have been made since the beginning of the service in 2019, covering the distance of 4,300,603.73 km. Bike-sharing is reducing the need for fossil fuels in the city, where most services are within reach of a 15 min. bicycle ride. Electric bicycles only use green electricity. The cycling infrastructure, especially the roads and cycle paths, require further development, including redesigning the crossings in the city's streets and separating the fast and slow (aka pedestrian) travelers. Proper seasonal maintenance is a challenge both for the cold snow-heavy and mild winters just below and above the freezing point. Financial sustainability and moving away from the subsidy model will be a challenge in the future.

5. Discussion

The results of the literature review showed that smart mobility is an important component of the smart-city concept. Smart mobility is a vision, based on the smart-city concept, and could result in a more sustainable future of cities. The installation of new smart-mobility innovations may reduce the negative environmental impact from the transport system; stimulate new (healthier and cost-effective) citizens' mobility patterns; and contribute to more efficient decision-making, urban-mobility policy planning and implementation. The involvement of decision-makers, public transport companies, private companies, citizens, experts, researchers and innovators is a necessary component in the planning process (both in top-down and bottom-up initiatives) to form realistic and clear goals, targets and measures. It creates opportunities for new businesses; public-private cooperation models; alternative methods of transport integration; new market players; and stakeholders' involvement, development of technologies and international collaboration. Specific attention is required from local governments to create effective policies designed for greenhouse gas emissions reduction, efficient financial support and cost-effective public services.

According to the results of the document content analysis, all strategies relate to global environmental goals. However, the empirical question could be raised about planning documents contribution in achieving environmental goals. Many of them focus on the reduction of environmental impact in urban zones by adopting specific policy measures, which are based on cities' circumstances. All of the four strategies differ with regard to principles and focal points. Tartu development strategy also points out the important goals and targets with short explanations. Riga's and Kaunas' planning documents differ from Tartu by clear strategic plans, where the actions towards smart-mobility development are clearly laid out. Intelligent transport systems installation, intelligent parking systems, traffic management systems, the importance of public transport services and integration of new technologies for smart-mobility development are important parts for rendering smart cities sustainable. The cities already integrate smart technologies such as intelligent transport systems installation, smart-mobility management platform, intelligent parking system, telematics systems, traffic management system, pollution control and transport air-pollution-control-system sector speedometers. Even if the real impact of smart technologies is not assessed, smart technologies must provide the value and solutions, based on real-time data, in order to achieve global, the EU and municipal goals. The European Green Deal is a promising financial tool for cities to integrate more additional intelligent technologies in urban areas in the future.

The analysis of four selected cities—Berlin, Kaunas, Riga and Tartu—provided examples of different smart-mobility services in European cities. Modal split results in the cities revealed a high citizens' dependence on private cars in Kaunas, Riga and Tartu, non-motorized transport modes (walking, cycling) are more preferred in Berlin. It also showed that public transport is one of the preferred modes of mobility. Regarding these findings, the examples of smartphone application, mobile ticketing app, smart bike-sharing and mobility point provided by the public sector could change these mobility patterns in a more sustainable way. Moreover, the data are not yet accessible that could be used for real contribution to CO₂ and greenhouse gas reduction assessment. Therefore, it is necessary not only to provide smart-mobility services, but also use the beneficial output generated from/by these services in an intelligent way, to further benefit the smart-city system. The air-pollution data showed that, when comparing the four selected cities, Berlin had the highest levels of NO₂ and PM_{2.5} emissions, while Kaunas had the highest rates of PM₁₀ emissions in 2019. The best air-quality results were found in Tartu.

The study provides descriptions about socioeconomic characteristics, mobility patterns and air-pollution situation in 2019 and 2020. Systematized results of previous research on the possible widespread use of smart-mobility services and their impact on air-pollution reduction are presented in the theoretical part. However, the research did not analyze the environmental impact of smart-mobility services in the selected cities. Moreover, due to lacking air-quality data in Riga, it was not possible to compare pollution changes in a given

time period. While it is easier to assess how smart-mobility services (apps and other digital platforms) change, the accessibility to mobility services does not automatically lead to a positive environmental impact. They need to be analyzed in relation to the conventional services that they aim to improve or substitute. Therefore, there is a need to search for a systematic assessment methodology to better understand how smart-mobility services contribute to the overall improvement of sustainable urban mobility services.

The pandemic and its repercussions arguably altered the context in which sustainable mobility strategies operate. It impacted the demand for transportation modes, e.g., whereas public transport usage fell strongly in many cities, bike-sharing systems were less affected and perceptions changed on the health safety of public transport [87]. Moreover, travel restrictions—within and between—urban areas had positive environmental effects, improving local air quality and reducing greenhouse gas emissions. These effects highlighted both the impact of transport on the environment and the capacity of governments to act swiftly.

Future strategy adaptation needs to take this changing context into account. In particular, sustainable mobility strategies should focus on aligning ambitious climate mitigation with pandemic recovery measures, by investing in environmentally friendly mobility, i.e., biking, walking and public transport infrastructure, as well as ensuring universal and affordable access to urban mobility services. Furthermore, emphasis should be placed on rendering public transport more resilient for future crisis situations. Smart-mobility solutions should be integrated within overall mobility decarbonization to ensure that solutions that minimize transport's climate footprint in cities are replicated.

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