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Unveiling the Hidden Effects of Automated Vehicles on "Do No Significant Harm" Components

Oana Luca *, Liliana Andrei, Cristina Iacoboaea and Florian Gaman

Faculty of Civil, Industrial and Agricultural Engineering, Technical University of Civil Engineering, 020396 Bucharest, Romania; liliana.capra@phd.utcb.ro (L.A.); cristina.iacoboaea@utcb.ro (C.I.); florian.gaman@utcb.ro (F.G.)

* Correspondence: oana.luca@utcb.ro

Abstract: The deployment of automated vehicles (AVs) has the potential to disrupt and fundamentally transform urban transportation. As their implementation becomes imminent on cities' streets, it is of great concern that no comprehensive strategies have been formulated to effectively manage and mitigate their potential negative impacts, particularly with respect to the components of the do no significant harm (DNSH) framework recently introduced in the EU taxonomy. The methodology employed comprises three steps: (i) An extensive literature review on the impact of AVs on the DNSH components; (ii) exploration of designing a coherent pro-active vision by integrating measures identified in the literature as key elements to mitigate the harm; and (iii) an interdisciplinary focus group (FG) to verify whether the impacts of AVs and potential mitigation measures for Bucharest are similar to those identified by the literature and integrated into the pro-active vision. The results suggest that while there are commonalities, variations exist in focus and perspective, underscoring the necessity of examining the mitigation measures encompassed in the vision through additional focus groups conducted in different cities.

Keywords: automated vehicles; do no significant harm; pro-active vision; interdisciplinary focus group; smart transport and mobility

Citation: Luca, O.; Andrei, L.; Iacoboaea, C.; Gaman, F. Unveiling the Hidden Effects of Automated Vehicles on "Do No Significant Harm" Components. *Sustainability* **2023**, *15*, 11265. https://doi.org/10.3390/su151411265

Academic Editors: Samuel Labi, Hualiang (Harry) Teng, Ali Karimoddini and Sikai Chen

Received: 12 June 2023
Revised: 14 July 2023
Accepted: 18 July 2023
Published: 19 July 2023

1. Introduction

The rapid growth of automated and connected vehicles (CAVs) has the potential to revolutionize urban transport systems [1], offering numerous benefits such as improved safety [2], reduced congestion [3], and increased mobility options [4]. Previous studies have examined specific aspects of AV impacts such as traffic flow optimization [5], energy consumption [6], safety improvements [7], and land use impacts [8]. Detailed papers and reviews have been conducted on health [9], the environment [10], and economic implications [11]. Extensive research has focused on the technical aspects of CAVs development and implementation [12,13], although dedicated research focused on the relationship of AVs with climate change is limited [14], emphasizing four approaches to reduce traffic emissions (encourage car sharing, renewable energy sources, involve stakeholders, and legal regulation implementation for motivating the use of climate-neutral transport).

As the deployment of automated vehicles (AVs) becomes increasingly imminent on cities' streets, it is of serious concern that no comprehensive strategies have been formulated to effectively manage and mitigate their potential negative impacts. This lack of preparedness raises significant questions about how cities will manage the challenges that may arise with the introduction of AVs into their transportation systems. Effective management of negative impacts requires pro-active planning, policy development, and collaboration among stakeholders, including government agencies, transportation planners, urban designers, researchers, and community members.

Moving on, the newly released EU taxonomy has proved to be an ambitious and significant regulation aimed at defining sustainable activities, which is influential in the current global trend of countries developing environmental or ecological taxonomies. In order to qualify as sustainable and to align with the EU taxonomy, an activity must not cause significant harm (DNSH) to the environmental objectives, namely (i) climate change mitigation, (ii) climate change adaptation, (iii) sustainable use of water resources, (iv) transition to a circular economy, (v) pollution prevention, and (vi) protection and restoration of biodiversity and ecosystems. The DNSH principle was established as a qualifying element for the eligibility of an investment for the purpose of accessing more favorable financial instruments in terms of conditionality and costs [15]. By implementing the DNSH principle, the EU aims to ensure that economic activities and investments support the transition to a sustainable and low-carbon economy while avoiding significant harm to the environment and contributing to the achievement of EU environmental objectives and climate goals. Few papers have emphasized its importance so far, mainly in relation to the environmental assessments [16], as a specific case in Singapore [17], or in relation to the energy transition [18]. AVs have the potential to impact climate change mitigation efforts. They can contribute to reductions in greenhouse gas (GHG) emissions by optimizing driving patterns, reducing congestion, and promoting the use of electric or shared vehicles [19]. AVs can also influence climate adaptation strategies. For instance, AV technology can be integrated with intelligent transportation systems to enhance resilience and responsiveness to extreme weather events, such as floods or heatwaves [20]. Understanding the impact of AVs on climate adaptation within the DNSH components allows for the development of a coherent vision and adaptive strategies that minimize vulnerabilities and enhance community resilience in the face of climate change. AVs can contribute to the transition towards a circular economy, where resources are used efficiently and waste is minimized [21]. AVs have the potential to reduce air and noise pollution in urban areas [22] by promoting the use of electric vehicles and optimizing driving patterns. AVs can influence the health and integrity of ecosystems, including urban green spaces, wildlife habitats, and biodiversity [23]. The expansion of AV infrastructure and associated land use changes may impact ecosystems and disrupt ecological processes.

We thus note that while understanding the impact of AVs on each of the components of the DNSH is crucial to ensure their responsible and sustainable implementation, a holistic understanding of the overall impact of AVs on DNSH components (climate mitigation, climate adaptation, water resources, circular economy, pollution prevention, and healthy ecosystems) in the cities and the development of an integrative vision incorporating pro-active mitigation measures is a topic that has not yet appeared on the international research agenda.

Additionally, in Romania, AV research has focused only on understanding future users' perceptions [24,25], or technical aspects [26,27]. The effects of implementing AVs in Romania have not yet been fully understood, and an interdisciplinary approach is still lacking. Furthermore, how the city will change if AVs are deployed and how they are influencing the recently introduced concept of DNSH are matters that have not yet been discussed in Romania, where cities are currently not ready for implementation, requiring mitigation of current unsustainable mobility habits and prevention of further aggravation through the use of AVs [24]. The focus of this research is Bucharest, the capital and largest city in the country, with a motorization rate of 673 vehicles per 1000 inhabitants and a national average of 357 vehicles per 10,000 inhabitants, the highest levels of motorized commuting, and a reluctance of residents to use public transportation [24].

Objectives of the Paper

The main aim of our paper is to build upon the knowledge, by conducting, for the first time in the literature, an exploratory study by (i) identifying the impacts of AVs on DNSH in a comprehensive literature review for each of the six components exploring potential mitigation measures; (ii) developing an integrative vision for the city, should AVs become reality, integrating the measures identified in the literature review; and (iii) exploring experts opinions from an interdisciplinary focus group approach on the impact of AVs on the DNSH components and checking whether the measures suggested to be incorporated into the integrative vision in step (ii) are similar to the ones suggested by FG experts in Bucharest, and thus effective to mitigate potential harms.

The integrated vision is crucial for developing strategies, policies, and practices that maximize the positive impact of AVs while minimizing any harmful effects on the environment, natural resources, and human well-being. The focus group approach encourages collaborative discussions between experts from different disciplines, including urban planning, road engineering, traffic policing, environmental science, economics, public health, and social sciences.

In order to achieve our objectives, we propose the following research questions: (1) What is the current impact of automated vehicles on DNSH components based on existing research and evidence? (2) Can we integrate the mitigation measures into a coherent vision to address the potential harm caused by AVs on each DNSH component? (3) Based on the experts' opinions elicited in the interdisciplinary focus group, can the elements of this integrative vision be considered adequate for Bucharest?

By addressing these research questions, this study seeks to contribute to the existing body of knowledge in the field of automated vehicles by bridging the gap between technical advancements and their broader societal and environmental impacts. The outcomes of this research are verified in the interdisciplinary focus group in Bucharest and will ultimately guide the development of pro-active strategies to ensure a sustainable and responsible integration of AVs within urban environments while adhering to the DNSH principle.

The novelty of the research lies primarily in the comprehensive literature review on each of the DNSH components, as indicated by the EU taxonomy. Additionally, the research offers an innovative aspect through the development of an integrative vision for cities when implementing AVs, in accordance with DNSH principles that serve as the foundation for future strategies. Moreover, the research validates this vision through an interdisciplinary FG conducted in Bucharest. The findings demonstrate similarities between the elements of the proposed vision and the discussions held within the FG, indicating a shared interest in sustainability among Romanian experts. Overall, this research provides a novel contribution by combining the literature review, the development of an integrative vision, and the verification of its alignment with expert perspectives. This approach enhances our understanding of the potential impact of AVs on DNSH components and fosters the development of sustainable strategies for future urban planning.

This paper is organized as follows: Section 2 provides an extensive literature review; Section 3 describes materials and methods used in research; Section 4 describes the results on AV transportation-related impacts on DNSH components; and Section 5 provides the conclusions.

2. Literature Review

In this section, we reviewed a significant number of studies that analyzed the impact of AVs on each of the six components of the DNSH according to the EU taxonomy [15].

2.1. Climate Change Mitigation

The adoption of connected and autonomous vehicles (CAVs) can have varying effects on the emission costs imposed on society, depending on the market penetration rate (MPR) of these vehicles and associated factors. When considering factors such as AV extra vehicle miles traveled (VMT), value of time (VOT) reduction rate of AVs, and automation cost, the emission rate is lowest when 100% of AVs are present in the network [28]. However, it is important to note that different scenarios may yield different outcomes. One of the literature reviews focused on environmental impacts highlights energy consumption and emissions as the main impacts considered by researchers [29]. In the context of connected autonomous vehicle (CAV) diffusion scenarios, it has been observed that the introduction of EVs in these scenarios can lead to a decrease in CO_2-eq emissions of 6% to 20% [30]. Moreover, a study conducted in the Paris region revealed that the overall rebound effect from ridesharing could cancel out a significant portion of CO_2 emission reductions and social benefits, ranging from 68% to 77% and 52% to 73%, respectively [31].

AVs have the potential to improve urban air quality, as shown in a study in a Portuguese urban area. The introduction of AVs resulted in varied effects, with an increase in NOx and CO_2 emissions in an autonomous scenario but a significant reduction in emissions in an electric autonomous scenario [32]. It is important, therefore, to consider the source of energy used to power AVs, as fossil fuels can contribute to GHG emissions and exacerbate climate change. However, transportation as a service (TaaS) could lead to dramatic reductions or eliminations of air pollution and GHG emissions, along with improved public health. This disruption, combined with concurrent advancements in renewable energy infrastructure, has the potential to create a largely carbon-free road transportation system by 2030 [33]. While AVs show promise in reducing energy demand and emissions, the increase in vehicle primary energy use and GHG emissions due to certain CAV subsystems must be taken into account. Nevertheless, incorporating operational effects such as eco-driving and platooning can result in a net reduction in energy and GHG emissions. In fact, research suggests that the widespread adoption of AVs could cut greenhouse gases by millions of metric tons each year [34]. AVs have the potential to reduce energy use by decreasing vehicle ownership, optimizing vehicle operation through technologies such as adaptive cruise control (ACC) and vehicle-to-everything (V2X) communication, and employing eco-driving strategies. Studies have shown that vehicle-to-infrastructure (V2I)-enabled eco-driving control can result in energy use reductions of up to 40% compared to baseline scenarios [35]. When considering shared autonomous vehicles (SAVs), preliminary forecasting results predict that each SAV could replace up to eleven conventional vehicles, presumably with beneficial impacts on emissions [36]. Significant reductions in energy consumption and emissions can be achieved, particularly when efficient electric vehicles are used [37]. Projections suggest a potential reduction of about 30% in energy use by 2030 compared to 2020 [38] and a reduction of about 56% in 2030 compared to 2016 [39]. However, it is worth noting that the energy consumption of sensors, computing power, and communication related to CAVs can pose emerging challenges [39]. Additional energy consumption from sensors and communication systems can range from 300 to 1400 Wh/km for an average passenger car [40].

2.2. Climate Change Adaptation

Adapting to climate change involves both reducing carbon emissions and preparing for the current and predicted impacts of climate change. It is increasingly recognized that simply reducing emissions is not enough to mitigate the effects of climate change, and countries are now focusing on adaptation strategies. Climate change-induced extreme weather events such as heavy rain, storms, flooding, and heatwaves have a substantial impact on transportation infrastructure, compromising its reliability and safety, including autonomous vehicles (AVs), which can experience operation issues, transportation disruptions, and increased community vulnerability due to power outages, infrastructure damage, and communication failures [41].

Autonomous vehicles (AVs) have the potential to reshape city structures, thus having a major effect on climate adaptation. They can reduce the demand for parking areas, leading to a decrease in the heat island effect. However, AVs may also increase the demand for transport infrastructure and urban expansion [42]. Studies have shown that AVs can increase lane capacity by up to 40% and allow for a reduction in lane widths by 20%, leading to the potential conversion of space into bicycle lanes, pavements, green spaces, or playgrounds [43–45]. In this regard, there is a need to expand research on public bicycle use, which, according to [46], initially leads to a decrease in carbon emissions, but after about 29 months of use, the emission reductions are surpassed and carbon emissions begin to exceed the initial reductions. Further, the concern about urban sprawl led to predictions suggesting a potential increase of up to 68% in the horizontal spread of cities due to AVs [47].

The introduction of AVs can provide new mobility options for people who cannot drive, such as minors or the elderly, and can improve transportation in congested cities. This could result in an increase in average travel distances per person, potentially doubling them in some cases. AVs can address mobility challenges and inconveniences associated with parking, taxes, and congestion [48]. Shared autonomous vehicles (SAVs) have the potential to alleviate congestion by reducing travel time, air pollution, and noise [49]. However, during the transition period when AVs coexist with conventional vehicles, there may be increased congestion rates [10], and in the end, it is unlikely that AVs alone will solve road congestion, as the increase in road capacity may attract more vehicles, leading to a negative overall impact on energy consumption [50].

Adverse weather conditions pose challenges for AV sensors [51]. The market penetration rate of connected autonomous vehicles (CAVs) has a positive impact on traffic efficiency and safety, particularly in rainy and snowy weather conditions. A shorter reaction time for both CAVs and human-driven vehicles (HDVs) can lead to better overall traffic performance [52].

However, the adoption of AVs may create societal disparities. AVs could become a privilege available only to those who can afford them, while vulnerable groups may be encouraged to rely on AVs for living and travel under constant scrutiny [53].

2.3. Sustainable Use and Protection of Water and Marine Resources

Urbanization has significant impacts on hydrogeological systems, leading to changes in water resources and increasing the risk of flooding. The expansion of impermeable built-up areas in urban environments intensifies flooding events, reduces aquifer recharge, eliminates small surface watercourses, alters the permeability of natural terrain, and increases pollutant loads. Moreover, urbanization also escalates the demand for water for the growing population and its services. Research conducted in Beijing, a megacity experiencing suburban urbanization since the 1990s, suggests that the degradation and decline of water resources at such levels may jeopardize the future sustainability of the city [54]. Emerging technologies such as smart buoy networks (SBNs), autonomous underwater vehicles (AUVs), and multi-sensor microsystems (MSMs) offer innovative and cost-effective monitoring solutions for marine environments. These systems, equipped with electronic sensors and adaptable monitoring programs, can learn specific ecological patterns and respond in real time to environmental signals. They have the capability to autonomously adjust their monitoring activities and send alert messages to prompt human intervention when necessary [55]. Water monitoring and cleaning systems integrated into autonomous and teleoperated surface vehicles can overcome the limitations of stationary systems. These vehicles have the ability to sample water at different locations, exchange information with other sensing and acting agents, and collaborate to accomplish required tasks. For instance, fish-like robots have been developed to patrol waters and detect pollutants, while autonomous surface vehicles can contribute to water monitoring and cleaning efforts [56]. Furthermore, AVs can play a crucial role in maintaining and inspecting critical water-related infrastructure, such as dams and water distribution networks. By assisting in regular maintenance and inspections, AVs help ensure the proper functioning of these infrastructure systems and minimize the risk of water-related hazards.

The literature related to the impact of AVs on this component is rather scarce, and future research is necessary to include alternative viewpoints or potential criticisms of the role of automated vehicles and emerging technologies in addressing water-related challenges.

2.4. Transition to the Circular Economy, including Waste Prevention and Recycling

Autonomous vehicles play a crucial role in smart cities, particularly in environmental maintenance tasks such as trash removal, recycling, and monitoring [56]. By implementing digitalization and driverless systems, these vehicles can improve fuel efficiency through optimized routes and contribute to shifting the vehicle ownership model towards mobility [57]. In terms of city transportation, assuming that the AVs will be electric, transitioning to electric vehicles (EVs), and achieving a net-zero economy have proved to have complex implications. While EVs offer environmental benefits such as reduced CO_2 emissions and improved air quality, their production involves materials that are scarce and have negative impacts on energy consumption, water usage, CO_2 emissions, and air pollution [58]. Compared to internal combustion engine vehicles, EVs have higher impacts in terms of metal and mineral consumption as well as human toxicity potential; hence, optimizing the energy structure, upgrading battery technology, and improving recycling efficiency are of major importance for the widespread promotion of EVs [59]. The adoption of circular economy models is critical for managing the increasing volume of end-of-life lithium-ion batteries (LIBs) from EVs. These models involve the remanufacturing, reuse, and recycling of waste batteries to extend their life and recover valuable materials [60]. Circular economy practices for EV batteries can create business opportunities, reduce raw material consumption, and increase competitiveness [58]. However, there are challenges in the transition to EVs and circular economy practices. The automotive industry's shift to EVs is expected to lead to a reduction in manufacturing jobs due to automation and simpler engines [61]. Additionally, the circular economy applied to EVs may contribute to "green mission creep," where sustainability goals inadvertently perpetuate resource overconsumption and social injustices [62]. Addressing these challenges requires strategic considerations, supply chain redesign, and policies to support workers' transition and skill development [61].

The European Union is promoting low-emission vehicles to reduce greenhouse gas emissions, but this transition increases the demand for battery raw materials such as lithium, nickel, cobalt, copper, and graphite [63]. Recycling and second-use strategies for spent EV batteries can help meet future raw material demand. The recycling of EV batteries can cover a significant portion of future demand, ranging from 10% to 300%, depending on factors such as battery composition and second-use potential [63].

Battery innovation is vital for advancing circularity and sustainability. While there are signs of progress in battery innovation towards cleaner and more reusable solutions, the focus has been more on re-use and repair features than recycling and material recovery [64]. Embracing technological cosmopolitanism, promoting structural diversity, and exploring non-lithium alternatives can drive the energy transition towards sustainability [64]. Consumer willingness to recycle spent EV batteries is essential for establishing a circular economy. Factors such as perceptions of government policy, environmental attitudes, and perceived benefits influence consumers' intentions to recycle [65].

The [19] research outcomes demonstrate how, contrary to common belief, adopting SAEVs as an alternative to EVs has a negative impact on the environment, first because multiple SAEVs are needed to fulfill the travel requirements of a single EV owner, and second because SAEVs exhibit higher global warming potential (GWP), water footprint, and energy demand due to deadheading and additional power consumption from automation devices. Nevertheless, implementing circular economy practices such as "reduce" and "reuse" can significantly decrease the GWP, water footprint, and energy demand of SAEVs by 21.4%, 18.2%, and 17.3%, respectively, and employing a 100% clean energy mix can mitigate the negative effects.

2.5. Prevention and Reduction of Air, Water, and Soil Pollution

The transportation sector is a significant contributor to urban air pollution, emitting particulate matter, CO_2, and NO_x. In the EU, transportation accounts for a quarter of direct greenhouse gas emissions and a fifth of CO_2 emissions [66]. Diesel traffic in European cities and OECD countries, primarily from road travel, is estimated to be responsible for up to 30% and 50% of particulate emissions, respectively, although the exact figures vary [67]. Air pollution from road transport alone leads to the premature deaths of 500,000 Europeans annually. It contributes to 18% of air pollution, including 39% of NO_x emissions and 10% of particle emissions. The European Public Health Alliance (EPHA), an NGO representing over 90 associations of healthcare professionals, revealed that the healthcare cost of such illnesses amounts to EUR 62 billion per year. This estimation is based on data gathered across nine European countries [68].

Exposure to air pollution is generally higher for individuals traveling in automobiles compared to those walking, cycling, or taking buses [69]. The health consequences of ambient air pollution include lung cancer, acute lower respiratory tract infections, stroke, ischemic heart disease, and chronic obstructive pulmonary disease [70]. To combat traffic congestion and urban pollution, many cities worldwide are implementing "car-lite" policies. One solution being explored is the adoption of SAVs or automated mobility-on-demand (AMOD) systems alongside neighborhood redesign and active modes of transportation [71]. Simulations for Lisbon, Portugal, demonstrated that a system incorporating SAVs and self-driving taxi buses could reduce air pollution by 40% and vehicle mileage by 30% [72]. Under an effective pricing strategy, the deployment of SAVs has the potential to significantly reduce $PM_{2.5}$ emissions and energy consumption by 56–64% and 53–61%, respectively. Furthermore, when combined with vehicle electrification, these reductions can further increase to 76% and 74%, respectively [73].

However, the adoption of AVs may reduce physical activity by diverting travelers from walking, bicycling, and public transit, negatively impacting the health of residents [74]. Additionally, the convenience and affordability of AVs may lead to induced demand, resulting in increased overall trips and decreased use of public transportation [75]. The health impacts of AV use and ownership could be significant, potentially increasing vehicle miles traveled and sedentary behavior, yet they are expected to reduce vehicle crashes and the number of vehicles on the streets [9]. Large-scale deployment of fully automated vehicles in the United States could save approximately 25,000 lives annually, leading to substantial economic savings [76] and alleviating pressure on healthcare resources [77]. Fully automated vehicles equipped with computer vision systems and connected infrastructure are expected to enhance collision avoidance, lane keeping, and overall driving safety. These advancements could reduce crashes involving human error [42]. While [78] estimates a rate of 40% or more, [79] postulates that accident and injury rates would be reduced by 50% and 90% if automated vehicles could have a market penetration rate of 10% and 90%, respectively. In surveys, 98% of respondents [75] believe that AVs can reduce the number of accidents, and 99% believe that AVs can reduce the severity of accidents. Increased driving experience and previous involvement in accidents seem to indicate that AVs could be a safer alternative to the regular car [24], although [80] mentions the lack of control in an accident situation.

Road traffic is the leading cause of noise pollution in urban areas, negatively impacting over 70 million Europeans. Noise exposure can lead to hearing loss, tinnitus, psychological and physiological distress, sleep disturbances, cardiovascular effects, reduced performance, annoyance responses, and changes in social behavior [81,82]. Under the premise that AVs will be electric, they may reduce noise levels, although they are not significantly quieter than conventional cars at speeds above 50 km/h. However, a fully electric car fleet could reduce average urban noise levels by 3–4 dB and reduce annoyance effects by more than 30% [83]. The benefits of noise reduction are limited for EVs at higher speeds due to tire-pavement interactions and rolling noise; hence, noise-absorbing surfaces on roads may be introduced [84]. In a hypothetical scenario with 100% AV penetration, the adoption of AVs in a real road network (e.g., the city of Rome) would lead to reduced noise emissions in the central area despite potentially worsening conditions on specific highway links due to increased traffic volume and speed. Overall, a 100% AV fleet would have a beneficial effect on noise pollution, particularly on intraurban roads [85]. However, studies indicate that AVs may increase vehicle kilometers traveled and decrease the usage of public transport and slow modes [86].

When operating near bodies of water, AVs also have the potential to contribute to noise pollution and disturb aquatic and marine life. The manufacture and disposal of batteries for electric vehicles can have a negative impact on the environment, especially on groundwater and soil, if not properly managed. If the widespread adoption of automated vehicles results in a substantial increase in the total number of vehicles, it may be necessary to expand or modify the existing infrastructure to cope with the higher demand, and construction activities associated with AV infrastructure development can disturb the soil. It is, however, important to acknowledge that the impact on road infrastructure will depend on several factors, including the level of adoption of automated vehicles, transport policies, and urban planning strategies.

2.6. Protection and Restoration of Biodiversity and Health of Ecosystems

The impact of automated vehicles (AVs) on biodiversity and ecosystems is a complex issue, encompassing both potential benefits and concerns. AVs have the potential to contribute to wildlife conservation efforts, particularly by reducing wildlife–vehicle collisions. A conceptual framework has been introduced to explore the intersection between AV technological innovation and wildlife conservation, highlighting the need for research on robust warning systems, animal detection methods, and incorporating wildlife–vehicle interactions into decision-making algorithms [87]. Furthermore, AVs equipped with advanced sensors and imaging technologies can assist in wildlife monitoring by collecting data on species distribution, population dynamics, and habitat quality. These data can aid in identifying biodiversity hotspots, determining conservation priorities, and evaluating the effectiveness of management strategies. However, if AVs operate off-road or in sensitive habitats, they have the potential to disturb wildlife through noise, vibrations, or direct encounters. Such disturbances can disrupt breeding patterns, foraging behaviors, and migration routes, ultimately affecting the fitness and survival of vulnerable species [88]. It is also important to consider the environmental impact of AVs throughout their lifecycle. The production, operation, and maintenance of AVs require substantial amounts of energy and resources. The extraction and processing of raw materials for AV components can result in habitat destruction and pollution. Additionally, careful planning of the charging or fueling infrastructure for AVs is necessary to ensure sustainable energy sources and minimize disruption to ecosystems [88].

It is worth noting that no previous research has presented a comprehensive and integrated perspective on the effects of AVs on DNSH framework components. Therefore, our paper aims to bridge this research gap by providing key elements in an integrated, pro-active vision of a future city, incorporating the AVs' impact on the DNSH framework.

3. Materials and Methods

The research methodology is outlined in Figure 1. In Section 2, we reviewed the available scientific studies on each DNSH component recognized in EU taxonomy, namely (i) climate mitigation, (ii) climate adaptation, (iii) sustainable use and protection of water and marine resources, (iv) circular economy, (v) pollution prevention, and (vi) healthy ecosystems. We have additionally identified, in the existing body of knowledge, measures to address the negative impacts on each of the components. The second step was, based on the authors' experience, to integrate these measures as key elements of a pro-active vision, revealed in Figure 2, anticipating the potential impacts of AV deployment. Finally, the last step included the case study for Bucharest, which investigated, in an interdisciplinary focus group, the perspectives of eight experts on the impact of AVs on the six DNSH components for Bucharest and was followed by the compilation of key elements of the vision, as shown in Figure 3.

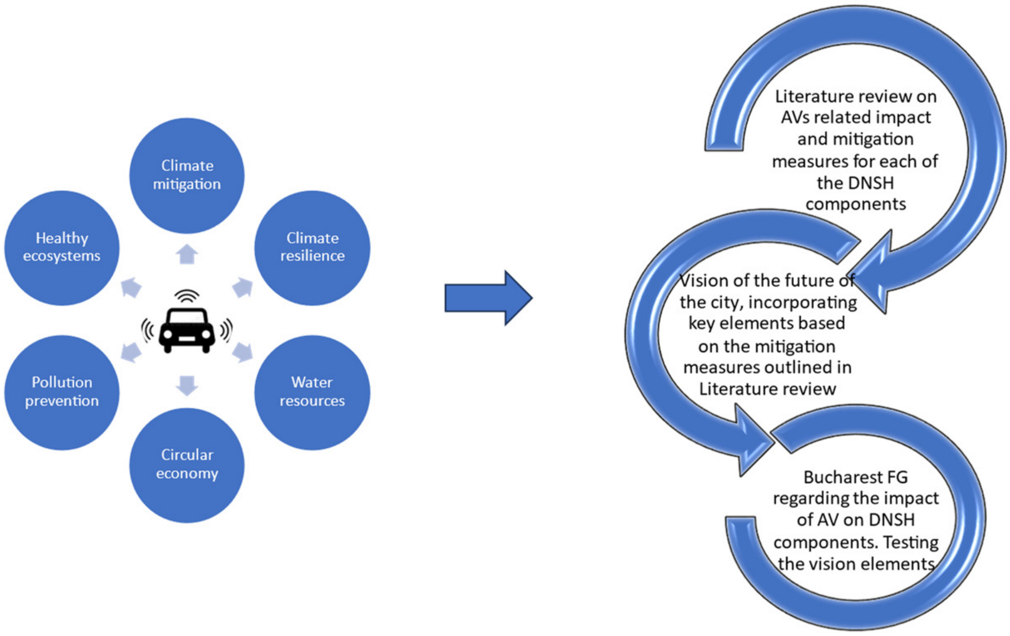

Figure 1. Research methodology for exploring the connection between automated vehicles and DNSH components. Source: elaborated by the authors.

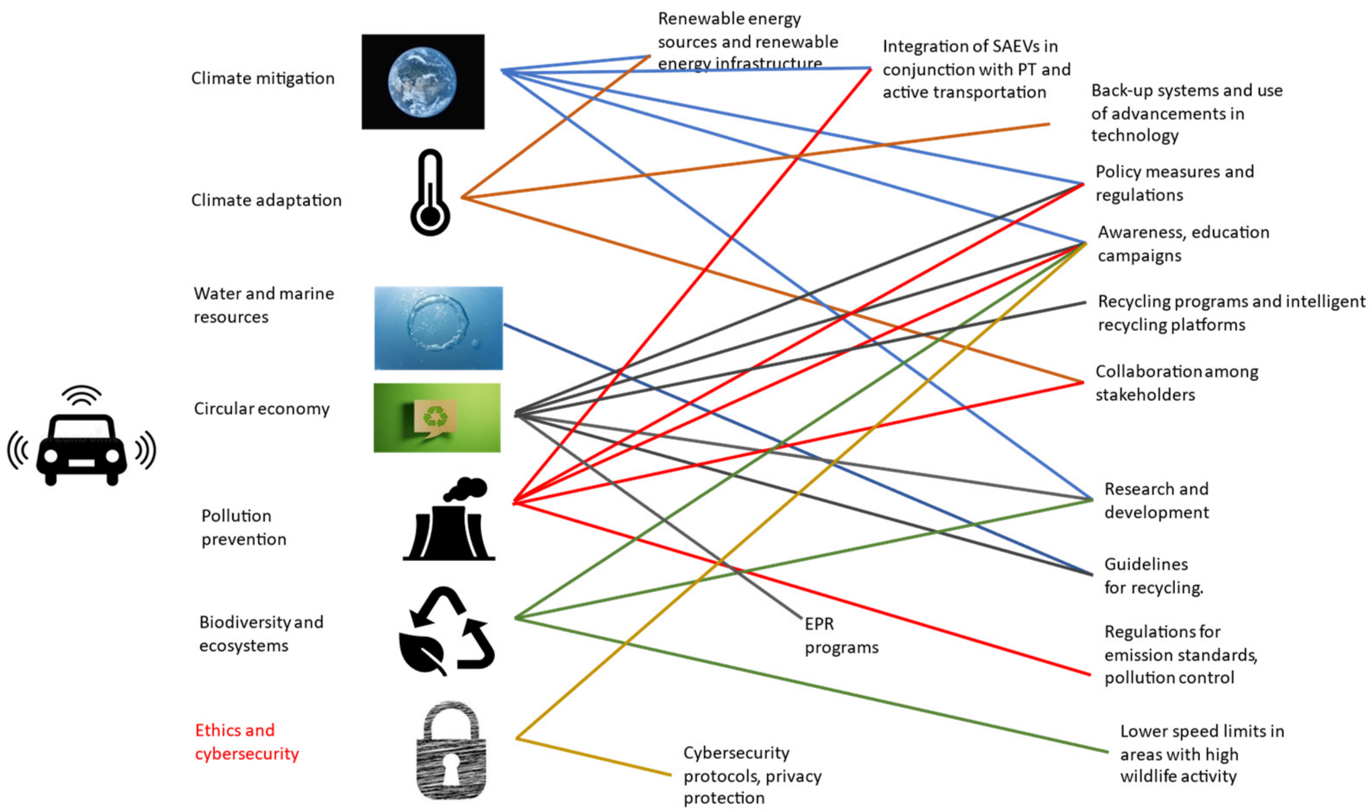

Figure 2. The "spider" vision encompassing pro-active mitigation measures. Source: elaborated by the authors.

Figure 3. Bucharest vision following compilation of interdisciplinary focus group discussions. Source: elaborated by the authors.

3.1. Focus Group Set-Up and Characteristics

The participants were selected among the professionals the authors of the article have worked with in prior collaborations and who had participated in a previous survey [24] related to AVs perceptions. Following email communication, eight interdisciplinary specialists agreed to participate in the focus group session held in March 2023 at the Technical University of Civil Engineering of Bucharest, Romania. Participants were asked to join the FG discussions on a voluntary basis.

At the beginning of the session, one of the authors, who was also the moderator, provided participants with information about the aims and objectives of the meeting, obtained their consent to participate in the study, and provided confidentiality statements for their signature.

According to [89], using focus groups (FG) is valuable for exploring people's knowledge and experiences and introducing the researcher and other group members to new ways of thinking about an issue or topic [90]. This method has been successfully used to achieve a more in-depth understanding of transport research [91,92], allowing flexibility in collecting ideas [80,93].

The socio-economic and demographic characteristics of the participants are outlined in Table 1.

The participants in the FG consisted of interdisciplinary experts (Table 2). While their understanding of the potential implications of autonomous vehicles (AVs) was largely derived from attending conferences or reading about them rather than their own research, they were informed on the subject.

The focus group meeting lasted for approximately 2 h, and the discussions were transcribed by the moderator and another author of the paper.

Table 1. Characteristics of participants in the interdisciplinary focus group.

Gender	**Number**	**%**
Woman	5	62.5
Man	3	37.5
Age	Number	%
18–34	2	25
35–54	3	37.5
55–69	2	25
+70	1	12.5
Educational level	Number	%
University	3	37.5
Postgraduate	1	12.5
Doctoral	4	50

Table 2. Background and experience of the participants.

Feature	**Participant**	**%**
Professional profile	Urban planner	12.5%
	Traffic engineer	12.5%
	Traffic police representative	12.5%
	Environmental expert	12.5%
	Economist	12.5%
	Public health specialist	12.5%
	Sociologist	12.5%
	Engineer, representative of local authority	12.5%
Degree of knowledge about AVs	I have prior familiarity with this topic from previous exposure through reading or hearing about it	37.5%
	I attended conferences dedicated to this topic/ I have actively conducted research and investigation into the topic/ I have published relevant work on the subject	62.5%
	None the above	0%

3.2. Focus Group Discussion Structure

During the semi-structured FG discussions, participants were asked to anticipate whether AVs could have a positive or negative impact on climate mitigation and adaptation, water resources, the circular economy, pollution prevention, and healthy ecosystems, and to think about potential measures that could be taken to mitigate negative impacts and possibly maximize the positive ones.

In the FG discussions, we considered AVs to be fully automated (i.e., level 5 according to SAE International standards, 2016 [94]), available for private use, or shareable. A general introduction to AVs and these assumptions was presented to participants in a short, animated video at the beginning of the session, and a brief introduction to DNSH components was also performed by the moderator. The questions (see Table 3) were related to the anticipation of the potential impact of the implementation of AVs in Bucharest for each of the six DNSH components outlined above and possible pro-active measures that could be implemented.

Table 3. Focus group questions.

1. Do you think that AVs will contribute to climate change mitigation, especially on GHG emissions? What measures will be effective in reducing impacts? 2. Do you consider that AVs can have an impact on climate change adaptation? In particular, what do you think about the potential changes in the urban structure of? What measures would be necessary in case of negative impacts? 3. How do you perceive the impact of AVs on the sustainable use and protection of water resources? What measures would be needed? 4. Do you think that AVs will be beneficial for the transition to the circular economy, including waste prevention and recycling? If not, what measures will be needed to improve the situation? 5. Do you think that the use of AVs will have an impact on air, water, and soil pollution? Please also consider noise pollution. What measures will be needed to mitigate the negative effects? 6. Imagine the impact of introducing AVs on the protection of biodiversity. Do you think that the introduction of SAE 5 vehicles will be beneficial or not for biodiversity and healthy ecosystems? What measures will be needed? 7. What do you think about the introduction of cybersecurity and ethics as components of the impact of AVs—additional question if not acknowledged by experts.

4. Results

4.1. Key Results of Literature Review

Based on the comprehensive analysis of the existing literature (refer to Table 4), it is evident that extensive research has been conducted on the positive and negative effects of AVs on the six components of the DNSH framework, including mitigation measures.

It is observed that the literature outlines that automated vehicles require sophisticated algorithms and artificial intelligence systems to make decisions on behalf of humans [95]. Ethical considerations are needed to ensure that these vehicles make choices that prioritize human safety and well-being [96,97]. In addition, ethical discussions can provide insight into the potential risks, vulnerabilities, and unintended consequences of automated systems. This approach can help identify and address potential hazards, ensuring that automated vehicles do not cause significant harm to people, pedestrians, or other road users [98,99]. Further, ethical considerations play a key role in shaping public perception and acceptance of this technology. By incorporating ethical principles, we can promote transparency, accountability, and responsible behavior among developers, manufacturers, and policymakers [100]. This approach builds trust and addresses concerns about privacy, fairness, and the potential negative impact of automated vehicles. Introducing cybersecurity in the "do no significant harm" framework when discussing the impact of automated vehicles is equally scientifically important. It ensures the safety and reliability of these vehicles, builds public trust and acceptance, protects data privacy, maintains system integrity and reliability, and mitigates potential harm to human life and infrastructure [101,102]. By considering and implementing robust cybersecurity measures, the overall resilience and security of automated transportation systems can be enhanced.

We believe introducing cybersecurity and ethics into the discourse on the impact of automated vehicles on the "no significant harm" components is scientifically justified. Ethics is needed for the development of responsible and safe automated systems, social acceptance and trust, equitable access, environmental concerns, and guiding decision-making processes to prioritize human welfare and societal benefits.

Summarizing, the positive and negative impacts of AVs on the DNSH components are outlined in Table 4.

Table 4. AVs compliance with DNSH concept.

Components of DNSH Principle	AVs Positive Impact	AVs Negative Impact
Climate mitigation	Significant reduction in emissions in an autonomous electric sharing scenario; V2I-enabled eco-driving control can result in energy use reductions of up to 40%.	Increase GHG if powered by fossil fuels; energy consumption of sensors, computing power, and communication related to CAVs can pose emerging challenges; may add more travel distance.
Climate adaptation	Potential to reshape city structures may lead to a decrease in heat island effects; SAVs have the potential to alleviate congestion; CAVs have a positive impact on traffic efficiency and safety, particularly in rainy and snowy weather conditions.	Transportation disruptions and increased vulnerability of communities during critical times; adverse weather conditions create major issues for AV sensors; may increase the demand for transport infrastructure and urban sprawl; during the transition period, there may be increased congestion rates; adoption of AVs may create societal disparities.
Sustainable use and protection of water and marine resources	Autonomous underwater vehicles offer innovative and cost-effective monitoring solutions for marine environments; autonomous surface vehicles can contribute to water monitoring and cleaning efforts; can facilitate the maintenance and inspection of critical infrastructure.	Any negative impact is not clearly revealed in current research.
Circular economy, including waste prevention and recycling	Trash removal, recycling, and monitoring; business opportunities for EV battery recycling and second-use.	Demand for battery raw materials such as lithium, nickel, cobalt, copper, and graphite.
Prevention and control of air, water and soil pollution	Air pollution is reduced if SAV systems are integrated with existing public transportation; implementation of fully automated vehicles could reduce accidents, save lives, and result in substantial economic savings, alleviating pressure on healthcare resources; used as EV can reduce noise levels.	Health impacts of AV use and ownership could be significant; safety risks for pedestrians with visual impairments; limited benefits of noise reduction at higher speeds; contribute to noise pollution and disturbance of aquatic and marine life when operating near bodies of water; construction activities associated with AV infrastructure development can disturb soil.
Protection and restoration of biodiversity and ecosystems	Reducing wildlife–vehicle collisions; AVs equipped with advanced sensors and imaging technologies can assist in wildlife monitoring.	If AVs operate off-road or in sensitive habitats, they have the potential to disturb wildlife; extraction and processing of raw materials for AV components can include habitat destruction and pollution.

The first objective of our study, which was to identify the impact of AVs on the DNSH components, has been successfully accomplished, effectively addressing research question 1.

4.2. Pro-Active Vision for the Future City Integrating Measures for Mitigating the Negative Impacts of AVs on the DNSH Components

The vision of a city deploying AVs and complying with the DNSH principle must be guided by a strong commitment to mitigate their negative impacts, as highlighted in the previous section, by prioritizing sustainability, shared mobility, including public transport, climate governance, community engagement, and ethical implementation of technology. This vision, integrated into a coherent strategy [103], may serve as a guiding framework to shape the future of cities, harnessing the transformative potential of automated vehicles while pro-actively mitigating their potential adverse effects.

Several key elements are encompassed in the study of the existing literature, merged in a panoramic view, and emphasized in the "spider" vision in Figure 2:

The city is fostering a culture of environmental responsibility and sustainable transportation practices through educational campaigns, outreach programs, and initiatives that promote sustainable transportation choices, encouraging behavioral changes and a shift towards greener mobility options. The public is informed about the benefits and potential risks associated with AVs so they can make informed decisions and adopt healthy behaviors while using and interacting with AV technologies.

Automated vehicles are integrated into a multimodal transportation network that encourages active modes of transportation such as walking, cycling, and the use of public transport. AV infrastructure is designed to avoid urban sprawl, prioritize, and support active transportation options, such as pedestrian and cycling paths, encouraging physical activity, reducing sedentary behavior, and improving cardiovascular health [104]. By promoting active modes of transportation and reducing private vehicle usage, the city minimizes congestion, decreases greenhouse gas emissions, and improves air quality. A key aspect of the vision is the widespread adoption of electric and shared mobility services enabled by automated vehicles and, following future research, their integration with the public transport system, seamlessly connecting AVs with other modes, which can significantly mitigate GHG emissions [105,106]. Car-sharing programs, ride-sharing platforms, and on-demand public transportation options are seamlessly integrated, ensuring convenient and accessible mobility for all residents. By encouraging shared mobility, the city reduces the number of private vehicles on the road, alleviating congestion and reducing the demand for parking spaces.

The city leverages the potential of automated vehicles to optimize resource utilization. Through advanced data analytics, smart routing algorithms, and efficient traffic management systems, the city maximizes the capacity and usage of vehicles, reducing the overall number of vehicles required. This approach minimizes energy consumption, optimizes infrastructure usage, and reduces the urban footprint associated with parking spaces and road networks.

Automated and connected vehicles are powered by renewable energy sources, shifting away from fossil fuel-based energy sources [10]. They are integrated with the electric grid, further reducing greenhouse gas emissions. Policies that encourage the deployment of renewable energy technologies are established, encouraging energy-efficient technologies to mitigate the urban heat island effect and the development of electric vehicle infrastructure. Incentives are provided for the purchase of electric vehicles, and investments are made in research and development for advanced battery technologies [21].

In case of adverse weather conditions, backup systems, redundant communication channels, and redundant power sources for automated vehicles are in place. Advancements in technology, such as satellite monitoring, infrastructure integration, and mobile control centers, help overcome these challenges and improve collision avoidance [51]. The city has incorporated green infrastructure features, such as permeable pavements, bioswales, and rain gardens, to support the management of the urban heat island [107].

Guidelines for proper disposal are developed, ensuring that AV components are handled and disposed of in a way that minimizes the risk of water pollution and that valuable resources can be recovered and reused, thus reducing the need to extract new materials. Extended producer responsibility (EPR) programs for AVs are implemented, thus incentivizing manufacturers to design products for recyclability, establish take-back systems for end-of-life vehicles, and fund recycling initiatives. Battery recycling programs and promoting circular economy practices and strategies, including de-manufacturing and end-of-life activities such as reuse, repair, and recycling, are implemented to reduce primary demand for raw materials, waste production, and dependency on limited resources [65]. Research supports developing alternative battery chemistries that rely on more abundant or environmentally friendly materials, decreasing the dependence on critical raw materials, and enhancing the overall sustainability of battery production [108]. Efficient and scalable recycling infrastructure is established, allowing valuable materials such as lithium, nickel, cobalt, copper, and graphite to be recovered from used batteries and reused in the production of new batteries [108]. Practices on improper disposal or recycling of potentially harmful substances such as heavy metals, toxic chemicals, and hazardous materials are appropriated by the relevant stakeholders to avoid the release of these substances into the environment and the risk of water contamination. Artificial warning sounds are installed for electric AVs for road safety improvements, especially for pedestrians with visual impairments [109].

Ecological sensitivity mapping to identify areas of high biodiversity and wildlife activity is guiding AV deployment and infrastructure planning, avoiding sensitive areas and minimizing potential disruptions to wildlife habitats. Wildlife underpasses, overpasses, and fencing are being implemented to enable safe wildlife movement across roadways, reducing the risk of collisions and habitat fragmentation. Lower speed limits are enforced in areas with significant wildlife activity. Automated vehicles are equipped with sensors and advanced algorithms for detecting and responding to wildlife presence, prioritizing their safety, and minimizing the risk of collisions.

Transparent and accountable ethical frameworks, robust cybersecurity protocols, privacy protection mechanisms, continuous vulnerability assessment, user awareness and education, collaboration and information sharing, regulatory frameworks, and independent auditing and certification processes are established to address privacy concerns, cybersecurity risks, and ethical dilemmas associated with autonomous systems. The city promotes ongoing research, development, and dialogue to ensure that automated vehicles operate in a manner that aligns with societal values, safety standards, and the protection of human rights [110–112].

The implementation of automated vehicles is accompanied by comprehensive stakeholder engagement processes that involve (i) public authorities and agencies, (ii) manufacturers, (iii) healthcare institutions, (iv) emergency services, and (v) various stakeholders in the transport ecosystem as vital elements for effectively addressing the health impacts of AVs and mitigating disruptions. The city ensures that the benefits of automated vehicles are accessible to all residents by providing equitable access to shared mobility services, promoting affordability, and addressing potential disparities in digital connectivity.

This section brings us to achieving the second objective of our study and the affirmative answer to the second research question on the feasibility of integrating mitigation measures into a unified vision of the future city that addresses the potential harm.

It is essential to underline that the above vision, which includes measures for minimizing the negative impacts of AVs on DNSH, is not a one-size-fits-all solution. Different regions, jurisdictions, and cultural contexts may require tailored approaches to address specific challenges. This is the reason we are proceeding to check this vision against a case study, highlighted in the next step.

4.3. Bucharest Case Study, Regarding the Impact of AV on DNSH Components: Results of the Focus Group

4.3.1. AVs Impacts on Climate Change Mitigation and Response Measures

When asked about the potential impact of AVs on climate mitigation, the local authority representative highlighted that Bucharest will be ready for the introduction of electric AVs that will have a positive impact on climate mitigation, as one of the key advantages of AVs is their potential to reduce greenhouse gas emissions compared to conventional vehicles. The representative of the traffic police pointed out that in 2021 Bucharest had the highest motorization rate in the country, with 49% of all new car registrations nationwide, an average age of the fleet of 12.9 years, and the highest density of the public road network with 50 km/100 km^2 of territory. Under these conditions, climate mitigation will be negatively impacted by the increasing trend in the number of vehicles. The urban planner emphasized that "*Bucharest is a car centric city*", hence there is a major need to implement AVs only as public transport and shared electric vehicles to be powered by renewable sources, for example, electric and hydrogen fuel cell vehicles. GHG emissions can increase if AVs are predominantly privately owned and used for single-occupancy trips. Being stuck in a traffic jam with autonomous cars is no better than being stuck in a traffic jam with traditional cars. "*Streets full of autonomous cars are just as uninviting and risky for children as streets crowded with petrol cars*". But shared mobility can lead to reduced vehicle ownership and increased utilization rates, as vehicles can be continuously in service, reducing the overall number of vehicles on the streets. This can help decrease congestion, lower emissions, and make transportation more efficient, enhancing climate mitigation. The economist suggested "*encouragement of sustainable transport modes*". The urban planner pointed out that the implementation of SAV could be the perfect opportunity to reconfigure streets and park areas in Bucharest in favor of more sustainable modes. The sociologist underlined that there will be a strong desire for families to benefit from at least one AV, even if it will be very expensive, due to the "*social symbol that the car still represents in Romanian society*". Given the 20-year time horizon in which AVs are likely to emerge in Romania, he proposed the development of strong awareness campaigns and solid educational programs in schools, universities, companies, and organizations to ensure that AVs are used more as SAVs and less as private cars. The traffic engineer reinforced that traffic congestion, which will have a negative impact on greenhouse gas emissions, will be a reality if public transport and SAV measures, as well as awareness and education measures, are not implemented. Finally, the urban planning expert stressed the importance of integrating AVs into broader climate action plans.

4.3.2. AVs Impact on Climate Change Adaptation Component and Mitigation Measures

The traffic engineer highlighted the importance of designing AV infrastructure with climate resilience in mind, taking into consideration, for example, intelligent routing during severe weather conditions. The urban planning expert noted that AVs have an indirect effect on climate adaptation. For example, AVs could lead to changes in travel patterns, reducing the need for large parking areas and potentially enabling the repurposing of urban spaces, which can facilitate the development of nature-based solutions (NBS), such as parks, green corridors, and permeable surfaces. AVs can "*make a difference by replacing the grey with green infrastructure, which is a good thing for sustainability reasons*". These, in turn, can mitigate heat island effects, which are present during the increasingly hot summers in Bucharest. The traffic expert pointed out that if on-demand service is to serve residents door-to-door and operate in the city, street capacity should be evaluated to accommodate the safe movement of automated vehicles. At the same time, infrastructure upgrades are needed, including the implementation of dedicated AV lanes, intelligent traffic management systems, and communications infrastructure. These are costly measures for Bucharest unless additional sources of funding can be accessed. The environment expert indicated that infrastructure development and upgrades can have environmental consequences, including habitat destruction, increased impervious surfaces, and disruption of natural ecosystems. The sociologist expressed the view that encouraging dialogue and knowledge sharing to identify best practices and innovative solutions would be useful for Romanian cities, especially Bucharest, which is potentially an early adopter. The public health expert stressed that this component needs to include the impact on public health, especially the potentially reduced number of accidents, but "*despite the sense of comfort*", the occurrence of mental health issues and sedentary lifestyles.

4.3.3. AVs Impact on Water Resources Component and Mitigation Measures

The environmental expert noted that, in general, the potential decrease in emissions due to AVs may lead to a better quality of water resources. The reduction in vehicle emissions can indirectly minimize the deposition of pollutants onto land surfaces, thereby reducing the runoff into water bodies. The urban planning expert also pointed out that an indirect impact may be considered if, "*beyond our imagination, the AVs are used for remote monitoring and maintenance of water infrastructure*", helping to identify leaks or inefficiencies in the water supply network. This component has been discussed the least, and no negative impacts have been identified in this FG; hence, further discussions with experts specialized in water pollution would be needed for a more detailed view.

4.3.4. AVs Impact on Circular Economy and Waste Management Component and Mitigation Measures

The economist outlined that it is crucial to analyze the overall economic impact when discussing the role of AVs in the circular economy. The environmental expert stressed that there will be problems with the waste that will be generated from AV components, requiring proper management. In the long term, recycling will be an issue that needs to be addressed because there are physical limits to what can be recycled at scale; modern composite materials and alloys are becoming increasingly complex to efficiently recycle; collection infrastructure is lacking; and rates are low. It will probably be necessary for the authorities to collaborate with battery manufacturers and recycling industries to optimize battery recycling technologies and minimize the environmental impact of battery disposal. From his experience, it would be useful to implement extended producer responsibility (EPR) programs for AVs to "*hold manufacturers accountable for the entire life cycle of their products, including waste management and recycling*". At the same time, EPR programs can incentivize manufacturers to design products for recyclability, establish take-back systems for end-of-life vehicles, and fund recycling initiatives. This approach encourages manufacturers to adopt circular economy practices. The local authority representative responded that there are currently major challenges related to waste and its management and that the transition to a circular economy will take longer than the lifetime of AVs. The environmental expert echoed the need for investment in the development and expansion of recycling infrastructure to support the recycling of AV components and materials. This requires collaboration with recycling industries and local authorities to ensure adequate infrastructure and processes for the recycling of AV-related waste. However, "*setting up a recycling system for the batteries in Romania is miles away*". The planning expert stepped in to explain that raising awareness among consumers, operators, and industry stakeholders about the importance of waste prevention and recycling in the context of AVs is imperative. The local authority representative stressed the need for policies and regulations to support the circular economy and encourage waste prevention and recycling in the AVs sector while promising that "*local authorities will be part of this process*".

4.3.5. AVs Impact on Pollution Prevention Component and Mitigation Measures

In terms of pollution prevention, the traffic engineer outlined that with automated vehicles communicating and coordinating with each other, we can expect "*smoother traffic patterns*", which in turn can lead to fuel savings and reduced emissions. The local authority representative emphasized that, in Bucharest, policies have to remain focused on trying to diminish the use of private cars for short urban trips and stimulate walking, cycling, public transport, and, eventually, carpooling. The urban planning expert supported this opinion by arguing that if public transportation replaces car trips, the shift could lead to a reduction in air pollution emissions, specifically if the public transportation fleet relies on electricity or hybrid energy. The environmental expert stressed the need for promoting proper storage and handling of hazardous materials, such as lubricants, coolants, and cleaning agents, to prevent accidental spills or leaks. The urban planner expert indicated that without alternative transportation options and regulations on automated vehicles, private ownership will increase. To be compliant with the pollution prevention component, Bucharest of the future "*has to prioritize people over cars*". This would also minimize congestion-related noise. Additionally, the environmental expert emphasized the need for a holistic approach that balances the benefits of AV technology with the preservation of a peaceful and harmonious acoustic environment in urban settings. The sociologist pointed out that noise pollution will impact stress levels, sleep quality, and overall well-being within urban populations. Avs, particularly electric ones, have, nevertheless, the potential to reduce noise pollution compared to traditional combustion engine vehicles, indicated the environmental expert, advocating for the necessity of developing noise reduction technologies for AV components.

4.3.6. AVs Impact on Healthy Ecosystems Component and Mitigation Measures

In terms of healthy ecosystems, the urban planner suggested that it is an opportunity to incorporate nature-based solutions such as green roofs to support biodiversity and ecosystem connectivity, roadside vegetation, native plantings, and green spaces along AV corridors to provide habitat, support pollinators, and enhance ecological connectivity. She advised the public authority representative to implement this type of measure "*without any delay*" before the AVs deployment. In fact, the environmental expert underlined that it is necessary to develop guidelines for designing AV infrastructure that consider the needs of wildlife and ecosystems, integrating these nature-based solutions into AV development. The urban planner underlined that if there was political will, measures could be taken to reduce traffic pollution and congestion in Bucharest without AVs, especially if "*public transport would work properly and we can enjoy comfortable travel conditions*", if there would be car sharing opportunities, and if micromobility was encouraged by building infrastructure with low awareness and education costs. The automated electric car will not "*save*" us, but investments in multimodal infrastructure will allow residents to avoid car ownership. "*Fewer cars mean a better city, as cars consume a disproportionate amount of space*". Nevertheless, the introduction of AVs is an opportunity per se to redesign streets and the city, in particular, to become more sustainable. However, if the steps are not correct, there are high chances of failure.

The experts did not explicitly mention ethics and cybersecurity as components of the DNSH principle, although, when asked, they acknowledged that these are key components to ensuring responsible and safe deployment of automated vehicles. Ethical considerations help address potential societal impacts and "*fairness concern*", while cybersecurity measures protect against malicious attacks and ensure system integrity.

Bucharest's vision, as compiled according to the focus group discussions, is depicted in Figure 3.

This vision may constitute the initial stage for developing strategies for preparing the cities for future AV deployment while adhering to the DNSH framework. We have thus achieved the first part of our third objective, which is to explore the views of experts participating in the interdisciplinary FG.

Table 5, below, provides an insightful comparison of key elements that can shape the vision of a city embracing the deployment of automated vehicles (AVs) and compliant with DNSH framework components, based on (a) a thorough literature review and (b) the invaluable input from experts in the interdisciplinary focus group.

In terms of climate mitigation, both opinions prioritize sustainability and the integration of AVs in the multimodal transport network. The literature places more emphasis on renewable energy sources and specific policies, while in the specific case of Bucharest, experts focused on integrating AVs into existing transportation systems and climate action plans. For climate adaptation, the literature primarily discusses technological advancements and collision avoidance, but experts in Bucharest take a broader perspective, considering climate resilience, infrastructure upgrades, and public health implications. Water resources literature discusses the role of AVs in maintenance and inspections, while experts in the FG provide an overall positive assessment of AVs' influence on water resources. In terms of the circular economy, the literature focuses on specific measures such as battery recycling and alternative chemistries, and experts provide a broader perspective, advocating for comprehensive actions. For pollution prevention and biodiversity components, the literature indicates measures to mitigate water and noise pollution risks; experts recognize the significance of sustainable practices; and ethics and cybersecurity are elements that can be integrated into the DNSH framework.

Table 5. Comparative analysis of literature review findings and focus group members' opinions.

Vision Elements on	Literature Review Pro-Active Measures	Interdisciplinary FG Members Opinions
Climate mitigation	AVs are powered by renewable energy sources integrated with electric grid. Municipality promotes educational campaigns to promote sustainable choices. Policies encouraging the deployment of renewable energy technologies have been established. AVs are integrated into a multimodal transport network, encouraging active mobility.	Experts emphasize the significance of integrating AVs into public and shared transportation systems, promoting the use of electric vehicles, and creating incentives for adopting sustainable transportation modes. It is crucial to implement education and awareness programs, along with incorporating AVs into comprehensive climate action plans.
Climate adaptation	Backup systems, redundant communication channels, and redundant power sources are in place. Advancements in technology, such as satellite monitoring, infrastructure integration, and mobile control centers, help overcome these challenges and improve collision avoidance.	Experts stress the importance of incorporating climate resilience into the design of AV infrastructure and systems. This includes considering intelligent routing strategies to navigate extreme weather events, promoting the replacement of grey infrastructure with green alternatives, upgrading existing infrastructure, and fostering dialogue and knowledge sharing. Additionally, it is crucial to address the potential negative impacts on public health, such as mental health issues and sedentary lifestyles, by implementing innovative measures to mitigate these effects.
Water Resources	AVs are used as monitoring and cleaning solutions for water environments. They maintain and inspect critical water-related infrastructure.	The experts outlined the potential to improve the quality of water resources and identified no negative impacts.
Circular Economy and Waste Management	Circular economy approach is promoted by battery recycling programs; EPR programs are implemented; research supports developing alternative battery chemistries; and efficient and scalable recycling infrastructure.	Experts highlight the need for EPR programs, investments in the development and expansion of recycling infrastructure, fostering partnerships with recycling industries, raising awareness, and policies and regulations.
Pollution prevention	Environmentally friendly materials for batteries; artificial warning sounds are installed for electric AVs, especially for pedestrians with visual impairments. Noise-absorbing road surfaces are introduced. SAEVs are integrated with public transport. Guidelines for proper disposal are developed, minimizing the risk of water pollution.	Experts underline the importance of reducing dependence on personal vehicles, ensuring proper disposal and manipulation of dangerous materials, and adopting a holistic approach. In addition, they stress the need to incorporate noise reduction technologies into autonomous vehicle components.
Biodiversity and healthy ecosystems	Ecological sensitivity mapping; lower speed limits; and AVs equipped with sensors and advanced algorithms prioritizing wildlife presence.	Experts highlight the need for incorporating green infrastructure elements that support healthy ecosystems, improving public transport, and investing in multimodal infrastructure.
Ethics and cybersecurity	Transparent and accountable ethical framework, robust cybersecurity protocols, and privacy protection mechanisms.	Key components to ensure responsible and safe deployment of automated vehicles

Consequently, we have now accomplished the second part of objective 3, where the measures identified in the literature mostly align with those proposed by the interdisciplinary FG participants in Bucharest. Moreover, in addressing research question 3, we find that the elements identified in the literature are considered broadly appropriate, with the experts highlighting the necessity of resolving existing issues through a more sustainable approach.

5. Conclusions

This study exposed the impact of AVs on DNSH components and highlighted the importance of developing a coherent vision that incorporates pro-active measures to mitigate potential harm. Using an interdisciplinary FG, experts from various fields and local authority representatives were engaged in discussions to critically examine the implications of AVs implementation on each DNSH component and identify Bucharest-specific mitigation measures. These were then compared with those identified in the literature, previously integrated into a single vision. This integrative approach has never been discussed so far.

Our study has successfully achieved its primary aim of identifying the impact of AVs on each of the components of the DNSH framework.

Additionally, we have accomplished the second objective by integrating mitigation measures into a unified vision of the future city compliant with the DNSH framework, providing an affirmative response to research question 2. Furthermore, our study has fulfilled the first part of the third objective, which involved exploring the perspectives of experts participating in the interdisciplinary FG. We also achieved the second component of objective 3, with the measures identified in the literature partly aligning with the proposals put forth by the FG participants in Bucharest. In response to research question 3, we find that the elements identified in the literature are considered mostly appropriate, with the experts emphasizing the need to address existing issues through a more sustainable approach.

The impact of adopting AVs on climate change mitigation varies, with research indicating that achieving 100% AV presence leads to the lowest emission rate. Incorporating eco-driving and efficient electric vehicles can contribute to further reducing energy consumption and emissions. In the context of Bucharest, experts emphasize the importance of integrating AVs into existing transportation systems and climate action plans. AVs can reshape cities and improve transport when adapting to climate change, but there are concerns about urban sprawl, congestion, access disparities, and managing challenges in adverse weather conditions. Experts in Bucharest take a wider perspective, considering climate resilience, infrastructure upgrades, and public health implications. Further research is needed to explore the role of AVs on water resources, as the literature provides some innovative solutions for monitoring and cleaning aquatic environments and maintaining critical water-related infrastructure, while experts in Bucharest provide a positive brief assessment of the influence of AVs on water resources. In terms of the circular economy, the literature focuses on specific measures such as battery recycling, as even the transition to SAEVs can have a negative environmental impact, with the experts in Bucharest acknowledging the need for expansion of recycling infrastructure, fostering partnerships with recycling industries, raising awareness, and implementing policies and regulations. Regarding pollution prevention and biodiversity components, the literature indicates mitigation measures for air, water, and noise pollution and acknowledges potential benefits in wildlife monitoring and conservation. However, the adoption of SAV can have implications such as reducing physical activity and inducing demand. Experts stress the importance of reducing reliance on personal vehicles but also the need to incorporate elements of green infrastructure that support healthy ecosystems and generally take a holistic approach. Lastly, according to the literature but also according to experts' opinions, ethics and cybersecurity are elements that can be integrated into the DNSH framework. While there are similarities in priorities between the literature and the experts' opinions in the FG, there are also differences in focus and perspective, highlighting the need for a comprehensive approach to address the environmental challenges associated with AVs.

Overall, our study contributes to the understanding of AVs' impact on DNSH components, provides a unified vision for mitigating harm, and highlights the experts' opinions on adopting sustainable approaches to address the new urban challenges.

The findings of this study underline the importance of assessing the impacts of AVs on the DNSH components to ensure responsible and sustainable integration into the urban environment. By considering the DNSH principle, which encompasses climate change mitigation, climate change adaptation, water resources, the circular economy, pollution prevention, and healthy ecosystems, we can identify the potential risks and benefits associated with the implementation of AVs. For the specific analysis of the impact of AVs, ethics and cybersecurity are proposed to be included within the DNSH components.

The interdisciplinary approach of the focus groups proved to be valuable in capturing diverse perspectives and expertise, allowing for a holistic understanding of the impacts of AVs and providing the opportunity to verify the vision proposed by the authors, incorporating mitigation measures available in the literature. The participation of experts from urban planning, traffic engineering, traffic police, environmental science, economics, public health, and social sciences enriched the discussions and contributed to the formulation of the vision that addresses the unique context of Bucharest (Figure 3). In general, the FG experts identified major elements of the previously established vision, although they initially did not acknowledge certain elements related to ethics and cybersecurity.

The knowledge generated from this research, especially the elements of vision developed in Section 4.2, can be transferred through scientific publications and city networks to inform policymakers, urban planners, and relevant stakeholders in developing informed strategies and policies for the responsible implementation of AVs. By integrating proactive measures identified through focus group discussions in Bucharest, potential harms associated with AV implementation can be effectively mitigated while maximizing benefits to the environment, economy, public health, social equity, and overall quality of life.

The present research has inherent limitations because it did not intend to be an extensive review of all publications that include relevant information on the impact of AVs on DNSH components, yet it is the first approach to the relationship between these two elements in a scientific paper, contributing to a general vision for the future city that was verified in the specific case of Bucharest. It is important to acknowledge that a limitation of our research is the inclusion of only one focus group, which may limit the representativeness of the findings. The authors stress the iterative nature of this research. As AV technology continues to evolve, ongoing monitoring and evaluation of DNSH components will be necessary to adapt mitigation strategies and measures accordingly. Future research can build on this study through an in-depth review of future papers, further exploring specific aspects of AVs impacts, such as their influence on specific DNSH components, new mitigation techniques, the integration of AVs with other emerging technologies, and examining the impact of AVs in terms of operation and driving, along with their advantages and disadvantages. In addition, research on the emission characteristics of AVs and key factors influencing their emissions may be the subject of future research. Moreover, the inclusion of multiple FGs from different cities and regions is a future step in the research, allowing a broader range of expert opinions and local context considerations and potentially uncovering additional insights and recommendations for mitigating harm and promoting sustainability.

In conclusion, this paper demonstrates the importance of understanding the overall impact of AVs on the DNSH framework, developing an integrated proactive vision, and encompassing key measures to ensure responsible and sustainable implementation of AVs. By addressing the challenges and capitalizing on the opportunities presented by AVs, we can move towards a future where cities and urban transport are reshaped, minimizing harm and optimizing community well-being.

Author Contributions: Conceptualization, O.L.; methodology, O.L., C.I., L.A. and F.G.; validation, O.L., C.I., L.A. and F.G.; formal analysis, O.L.; investigation, O.L., C.I., L.A. and F.G.; resources, O.L. and F.G.; data curation, L.A.; writing—original draft preparation, O.L.; writing—review and editing, C.I., L.A. and F.G.; visualization, L.A. and O.L.; supervision, O.L.; project administration, C.I., L.A. and F.G.; funding acquisition, O.L. and F.G. All authors have read and agreed to the published version of the manuscript.

Funding: This paper received funding for scientific research dedicated to researchers from Technical University of Civil Engineering Bucharest.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from the Focus group participants.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are grateful to the Romanian experts who participated in the interdisciplinary Focus group discussions.

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

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