Unveiling the Hidden Effects of Automated Vehicles

Subjects: Transportation

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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.

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

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.

2. 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 [24]. 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 [25]. 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% [26]. 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 [27].

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 [28]. 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 [29]. 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 [30]. 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 [31]. 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 [32]. Significant reductions in energy consumption and emissions can be achieved, particularly when efficient electric vehicles are used [33]. Projections suggest a potential reduction of about 30% in energy use by 2030 compared to 2020 [34] and a reduction of about 56% in 2030 compared to 2016 [35]. However, it is worth noting that the energy consumption of sensors, computing power, and communication related to CAVs can pose emerging challenges [35]. Additional energy consumption from sensors and communication systems can range from 300 to 1400 Wh/km for an average passenger car [36].

3. 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 [37].

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 [38]. 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 [39][40][41]. In this regard, there is a need to expand research on public bicycle use, which, according to [42], 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 [43].

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 [44]. Shared autonomous vehicles (SAVs) have the potential to alleviate congestion by reducing travel time, air pollution, and noise [45]. 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 [46].

Adverse weather conditions pose challenges for AV sensors [47]. 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 [48].

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 [49].

4. 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 [50]. 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 [51]. 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 [52]. 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.

5. 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 [52]. 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 [53]. 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 [54]. 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 [55]. 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 [56]. Circular economy practices for EV batteries can create business opportunities, reduce raw material consumption, and increase competitiveness [54]. 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 [57]. Additionally, the circular economy applied to EVs may contribute to "green mission creep," where sustainability goals inadvertently perpetuate resource overconsumption and social injustices [58]. Addressing these challenges requires strategic considerations, supply chain redesign, and policies to support workers' transition and skill development [57].

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 [59]. 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 [59].

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 [60]. Embracing technological cosmopolitanism, promoting structural diversity, and exploring non-lithium alternatives can drive the energy transition towards sustainability [60]. 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 [61].

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.

6. 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 [62]. 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 [63]. 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 [64].

Exposure to air pollution is generally higher for individuals traveling in automobiles compared to those walking, cycling, or taking buses [65]. The health consequences of ambient air pollution include lung cancer, acute lower respiratory tract infections, stroke, ischemic heart disease, and chronic obstructive pulmonary disease [66]. 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 [67]. 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% [68]. 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 [69].

However, the adoption of AVs may reduce physical activity by diverting travelers from walking, bicycling, and public transit, negatively impacting the health of residents [70]. Additionally, the convenience and affordability of AVs may lead to induced demand, resulting in increased overall trips and decreased use of public transportation [71]. 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 [72] and alleviating pressure on healthcare resources [73]. 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 [38]. While [74] estimates a rate of 40% or more, [75] 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 [71] 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 [76], although [77] 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 [78][79]. 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% [80]. 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 [81]. 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 [82]. However, studies indicate that AVs may increase vehicle kilometers traveled and decrease the usage of public transport and slow modes [83].

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.

7. 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 [84]. 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 [85]. 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 [85].

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