Review of the sustainability for autonomous driving vehicles

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Abstract: This research paper provides a comprehensive review of the sustainability considerations for autonomous driving vehicles. The purpose of this study is to examine the environmental impact and the social implications associated with the widespread adoption of autonomous driving technology. The approach used in this research involved a thorough literature review analysing existing studies, reports, and academic papers related to autonomous driving vehicles and their sustainability aspects. The findings from these sources were synthesized to provide a holistic understanding of the subject matter. The key findings of this research show that autonomous driving vehicles have the potential to significantly reduce the environmental impact of transportation. By optimizing traffic flow, reducing congestion, and promoting shared mobility, these vehicles can contribute to lower emissions and energy consumption. However, challenges related to battery technology, charging infrastructure, and renewable energy integration need to be addressed to maximize their sustainability benefits. In terms of social implications, autonomous driving vehicles offer improved accessibility and mobility for various populations, while also raising concerns about job displacement and changes in travel behaviour. It is essential to address these social challenges through skill development programs and job creation in emerging industries, as well as fostering social acceptance and trust in the technology. In this research it emerges the importance of policy and regulatory frameworks to address safety, liability, data privacy, and ethical considerations. The establishment of clear guidelines and standards, as well as international collaboration, is crucial for the successful integration of autonomous driving vehicles. The value of this research lies in providing a comprehensive overview of the sustainability considerations for autonomous driving vehicles. It serves as a valuable resource for policymakers, researchers, and industry professionals in understanding the opportunities and challenges associated with this transformative technology and shaping a sustainable and inclusive future of transportation.

Keywords: Autonomous driving; Literature review; Environmental impact; Social implications.

I. INTRODUCTION

Autonomous driving vehicles, also known as self-driving or driverless vehicles, represent a transformative technology with the potential to revolutionize the transportation sector. These vehicles leverage advanced technologies such as artificial intelligence, sensors and connectivity to navigate and operate on roads without human intervention. The emergence of autonomous driving has generated significant interest and raised important questions about its implications for sustainability.

A. Background of Autonomous Driving Vehicles

The concept of autonomous vehicles has been a topic of research and development for several decades. Recent advancements in computing power, machine learning algorithms and sensor technologies have accelerated the progress in this field. Major automotive companies and technology firms have invested substantial resources into developing and testing autonomous driving technologies, aiming to improve road safety, efficiency and user experience.

B. Significance of Sustainability in the Context of Autonomous Driving

As the world faces pressing challenges related to climate change, environmental degradation and resource depletion, sustainability has become a critical consideration in all sectors, including transportation.

The integration of sustainability principles into autonomous driving vehicles can help mitigating the environmental, social and economic impacts associated with transportation (Óscar Silva, 2022).

C. Purpose of the Paper and Outline of the Sections

The purpose of this paper is to provide a comprehensive review of the sustainability aspects related to autonomous driving vehicles. It aims to analyse the environmental, social, and economic

implications of these vehicles. By examining the current state of knowledge and identifying research gaps, this review aims to contribute to the understanding and advancement of sustainable autonomous driving.

To achieve this goal, the paper is organized as follows: Section II examines the relevant contributions already present in the literature on this theme. Section III explains the aims and the objectives of the research. Section IV discusses the key findings on environmental impact of autonomous driving vehicles (focusing on aspects such as greenhouse gas emissions, energy efficiency, air quality and lifecycle analysis) and on social impact, including issues related to traffic congestion, accessibility, commuting patterns, and social acceptance. Section V summarizes the key findings of the review and outlines future research opportunities.

By exhaustively exploring the sustainability dimensions of autonomous driving vehicles, this review aims to contribute to the knowledge base and inform policymakers, researchers, and industry stakeholders about the challenges, opportunities, and considerations for achieving a sustainable future of autonomous mobility.

II. RELEVANT LITERATURE REVIEW

A. Methodology

The literature review pertaining to the environmental impacts of Autonomous Vehicles (AVs) was conducted by utilizing the Scopus and Web of Science search engines.

Initially, a search was conducted using commonly employed keywords associated with AVs, such as "Autonomous," "Automated," "Self-driving," "Driverless," and "Vehicle(s)" or "Car(s)." This search yielded a substantial number of references. Subsequently, the search was expanded to incorporate terms related to environmental impacts.

After this screening, only the notable and relevant contributions have been selected, ignoring all the papers which were out of scope, or which dealt with different aspects.

B. Results

The environmental impact of AVs has been extensively studied, with a focus on emissions reduction.

One key factor that influences AVs' energy consumption and emissions consists in their design, including the driving systems and additional equipment. Zhang (2019) found that accelerating and overcoming frictional resistance account for 53.4% of the total energy consumption of an electric AV. Improving driving efficiency can lead to lower consumption and emissions. For instance, simulations using the Motor Vehicle Emission Simulator (MOVES) estimated emission reductions of up to 14% by replacing human-driven vehicles with AVs (Liu, 2017). Cooperative driving systems, such as Cooperative Eco-driving at Signalized Intersections and Cooperative Adaptive Cruise Control (CACC) and Platooning, offer the highest environmental benefits (Wang, et al., 2020).

Numerous studies propose models that explore different operational concepts under various scenarios. Many of these studies focus on traffic improvement at intersections through vehicle-to-vehicle and vehicle-to-infrastructure connections, resulting in emission reductions ranging from 13.8% to 59% [(Bento, et al., 2019), (Bichiou & Rakha, 2017), (Chen & Liu, 2019) & (Feng, et al., 2018)].

Cooperative models (Ma, et al., 2019) and variable speed strategies (Guo, et al., 2020) also show potential for significant emissions reduction of over 40%.

The introduction of dynamic routing systems and eco-driving strategies can further improve traffic and reduce emissions [(Djavadian, et al., 2020), (Liu, et al., 2019), (Ma, et al., 2019) & (Tu, et al., 2019)]. Different studies analysing different traffic conditions and driving behaviour parameters indicate that emissions can decrease by 26% or increase by 35% depending on the programming of AVs (Stogios, et al., 2019). Dynamic double-parking is another advanced possibility that increases parking capacity and reduces emissions (Estepa, et al., 2017). Additionally, it is important to consider the entire lifecycle of AVs, as electric AVs can generate 35% more emissions than conventional internal combustion vehicles when considering construction, maintenance, and end-of-life phases (Patella, et al., 2019).

As AVs penetration is expected to be gradual, studies focus on mixed traffic scenarios with both conventional and autonomous vehicles. In closed-loop field experiments, even a low percentage (5%) of AVs stabilizes traffic and reduces emissions (Stern, et al., 2019). The presence of connected AVs improves traffic flow stability and can prevent shockwaves, while AVs show higher

throughput than connected vehicles at similar market penetration (Talebpour & Mahmassani, 2016). However, in real traffic modeling with human drivers, the presence of AVs does not always improve traffic conditions: in high-density traffic, non-connected AVs tend to slow down.

III. AIMS & OBJECTIVES OF THE RESEARCH

This research paper aims to provide a comprehensive examination of the sustainability considerations for autonomous driving vehicles. The primary objective of this study is to investigate the environmental impact and the social implications associated with the widespread adoption of autonomous driving technology.

By addressing these key areas, the research aims to contribute to the existing body of knowledge on autonomous driving vehicles and shed light on their potential for promoting sustainable transportation.

Specifically, the research aim is to explore the environmental impact of autonomous driving vehicles by analysing their potential to reduce emissions, energy consumption and congestion through advanced traffic optimization and shared mobility. It also aims to investigate the challenges related to battery technology, charging infrastructure and renewable energy integration, with the goal of identifying potential solutions to maximize the sustainability benefits of autonomous driving vehicles.

In terms of social implications, the research aims to examine the impact of autonomous driving vehicles on accessibility, mobility, and travel behaviour. It seeks to investigate the potential societal benefits and challenges associated with the integration of autonomous vehicles, including concerns related to job displacement and changes in commuting patterns. By addressing these social considerations, the research aims to provide insights on how autonomous driving vehicles can be effectively integrated into society in a socially inclusive manner.

Overall, the aims of this research are to provide a wide-ranging understanding of the sustainability considerations for autonomous driving vehicles and to contribute to the ongoing discourse on their potential for promoting sustainable and efficient transportation systems. By addressing the aims outlined above, the research aims to offer valuable insights and recommendations to policymakers, researchers, and industry professionals working in the field of autonomous driving technology.

IV. KEY FINDINGS

A. Environmental Impact of Autonomous Driving Vehicles

One of the key environmental benefits associated with autonomous driving vehicles is the potential reduction of greenhouse gas (GHG) emissions. With the integration of advanced technologies, autonomous vehicles can optimize fuel consumption, reduce idling time, and employ efficient driving patterns. These factors contribute to lower carbon dioxide (CO2) emissions, which play a significant role in mitigating climate change. Additionally, the electrification of autonomous vehicles can further reduce emissions when coupled with renewable energy sources (Liu, et al., 2019).

Studies have shown that autonomous driving systems, through their ability to optimize acceleration, deceleration, and route selection, can potentially achieve significant fuel savings compared to conventional human-driven vehicles. The reduction in fuel consumption directly translates to lower CO2 emissions, leading to a more sustainable transportation system. Autonomous driving vehicles have the potential to enhance energy efficiency in several ways. By leveraging sensor technologies and real-time data, these vehicles can optimize energy usage through adaptive cruise control, predictive speed adjustments, and intelligent traffic management. Additionally, the implementation of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication enables coordinated driving patterns, which reduce unnecessary stops and starts, and thus improving fuel efficiency (Wu & Zhao, 2011).

Moreover, the integration of hybrid or electric powertrains in autonomous vehicles presents an opportunity for further energy savings and reduced dependence on fossil fuels. Electric autonomous vehicles produce zero tailpipe emissions and can contribute to overall emissions reduction when powered by renewable energy sources.

Beyond greenhouse gases emissions, autonomous driving vehicles can positively impact air quality. The optimization of driving patterns and the reduction of stop-and-go traffic, enabled by autonomous systems, can reduce local air pollutants such as nitrogen oxides (NOx) and particulate matter (PM). These pollutants have

detrimental effects on human health and contribute to air pollution-related issues in urban areas.

By promoting smoother traffic flow and reducing congestion, autonomous vehicles have the potential to mitigate air pollution hotspots, particularly in urban environments where vehicle emissions are a major concern. This improvement in air quality not only benefits human health but also enhances the livability and sustainability of cities (Patella, et al., 2019).

To fully evaluate the environmental impact of autonomous driving vehicles, a comprehensive lifecycle analysis is necessary. This analysis considers the environmental implications at different stages, including vehicle manufacturing, operation, and end-of-life disposal (Kontar, et al., 2021).

During the manufacturing phase, the extraction of raw materials, energy consumption, and production processes contribute to environmental impacts such as resource depletion and pollution. Efforts should be made to minimize the environmental footprint of autonomous vehicles through sustainable manufacturing practices, material selection, and recycling strategies.

Furthermore, the operation phase of autonomous vehicles should consider factors such as energy consumption, emissions, and maintenance requirements. Regular maintenance and efficient energy management systems can optimize vehicle performance and extend their lifespan.

Lastly, the end-of-life phase of autonomous vehicles raises considerations for proper disposal, recycling, or repurposing of components. Implementing strategies for recycling and environmental-friendly disposal can minimize waste and maximize resource recovery.

By conducting a thorough lifecycle analysis, policymakers, researchers, and industry stakeholders can gain a holistic understanding of the environmental implications of autonomous driving vehicles and develop strategies to enhance their sustainability.

B. Social Impact of Autonomous Driving Vehicles

Autonomous driving vehicles have the potential to significantly impact traffic congestion and urban planning. By leveraging advanced sensors, connectivity and real-time data, these vehicles can optimize traffic flow, reduce bottlenecks, and minimize the time spent in traffic. The ability of autonomous vehicles to communicate with each other and adapt their speed and routing can lead to smoother traffic patterns, thereby reducing congestion and improving overall transportation efficiency.

With improved traffic flow and reduced congestion, cities may be able to allocate road space more efficiently, potentially reducing the need for extensive parking infrastructure and promoting the development of pedestrian-friendly urban environments (Ye & Yamamoto, 2018). The repurposing of parking spaces for public amenities, green spaces or cycling infrastructure can contribute to more sustainable and livable cities.

Autonomous driving vehicles hold great promise in enhancing accessibility and mobility for various populations. Individuals who are unable to drive due to age, disabilities, or other factors can benefit from autonomous transportation services. These vehicles can offer increased independence and mobility options for older adults, people with disabilities, and those who are unable to obtain a driver's license (Cordts, et al., 2021).

Furthermore, autonomous driving technology has the potential to improve transportation access in underserved areas, including rural communities or areas with limited public transportation infrastructure. Mobility-as-a-Service (MaaS) models, where autonomous vehicles are integrated into on-demand transportation systems, can provide cost-effective and convenient mobility solutions for individuals who lack access to private vehicles.

The introduction of autonomous driving vehicles is likely to influence commuting patterns and travel behavior. With the ability to operate autonomously, individuals may perceive driving time as productive or leisure time, enabling them to engage in work, entertainment, or just relax during their commutes. This shift in perception could impact travel choices, with people opting for longer commutes or choosing to live farther away from urban centers.

Additionally, shared autonomous vehicles can alter travel behavior by encouraging a shift away from private vehicle ownership. The availability of convenient and cost-effective autonomous ride-sharing services may reduce the need for individual car ownership, leading to changes in travel patterns, reduced congestion, and a potential decrease in the total number of vehicles on the road (Mohammadzadeh, 2021).

The successful integration of autonomous driving vehicles into society relies on social acceptance and trust. Public perception and attitudes towards autonomous vehicles play a crucial role in their adoption and deployment. Concerns about safety, reliability and ethical considerations need to be addressed to foster trust among potential users and stakeholders.

Effective public education campaigns and transparent communication about the benefits, limitations, and safety measures of autonomous vehicles can contribute to increase social acceptance. Additionally, well-defined regulations, standards, and rigorous testing procedures are essential to ensure the safety and reliability of autonomous driving technologies.

Public engagement and participation in the decision-making processes related to autonomous driving can also promote social acceptance: involving the public in discussions regarding ethical considerations, data privacy and the broader societal implications of autonomous vehicles can help address concerns and ensure that the technology aligns with societal values.

By exploring and addressing the social impacts of autonomous driving vehicles, policymakers, researchers, and industry stakeholders can develop strategies that maximize the positive outcomes and minimize potential negative consequences (Huang, et al., 2019).

V. CONCLUSIONS

The rapid development and integration of autonomous driving vehicles have the potential to revolutionize the transportation landscape, with significant implications for sustainability, safety, and societal well-being. In this paper, we have examined various aspects of autonomous driving vehicles in terms of environmental impact and social implications. By exploring these key areas, we have gained insights into the opportunities and challenges associated with the widespread adoption of autonomous driving technology.

Autonomous driving vehicles offer significant potential for reducing the environmental impact of transportation. Through advanced sensors, connectivity and intelligent algorithms, these vehicles can optimize traffic flow, reduce congestion, and minimize emissions. However, challenges such as battery technology, charging infrastructure and renewable energy integration must be addressed to maximize their sustainability benefits.

In terms of social impact, autonomous driving vehicles hold promise in enhancing accessibility and mobility for various populations. They can improve transportation access for individuals who are unable to drive and promote shared mobility solutions that reduce the need for private vehicle ownership. Understanding changes in commuting patterns, travel behavior and addressing social acceptance and trust are crucial for ensuring the successful integration of autonomous vehicles into society.

Advantages aside, we could have also serious drawbacks: first of all, the really high initial costs related to the development and to the deployment of autonomous driving technology which make really challenging for some communities to adopt them initially; then there are ethical and safety concerns related to decision-making in critical situations which require rigorous testing, regulation, and public acceptance; another potential disadvantage is the job displacement for drivers in various sectors, requiring measures to address the social and economic impacts of automation; and finally the existing autonomous driving systems have limitations in handling complex driving scenarios, adverse weather conditions, and unexpected events, necessitating further advancements in technology.

In the light of this inner complexity, it is fundamental to explore some future research areas to cover some of these aspects: A comprehensive lifecycle analysis would be necessary to fully assess the environmental impact of autonomous vehicles, looking at manufacturing, operational and end-of-life phases; then it is fundamental to pursue a full integration of autonomous vehicles with renewable energy sources, crucial to maximize their sustainability benefits; concluding with a focus on Mobility-as-a-Service (MaaS) models which can lead to increased accessibility and reduced vehicle ownership, positively impacting congestion and the overall transportation efficiency.

In conclusion, autonomous driving vehicles offer promising opportunities to create a more sustainable transportation system. By addressing challenges related to emissions, energy efficiency, social acceptance, and job displacement, policymakers, researchers, and industry stakeholders can work towards maximizing the benefits of autonomous mobility while minimizing potential drawbacks. Continued research, public engagement, and collaboration across various

sectors will be essential for shaping a future where autonomous driving technology can contribute to a more sustainable and efficient transportation landscape.

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