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International Scientific Conference on the Occasion of the Hungarian Science Festival

Sopron, 2023. november 23.

23 November 2023, Sopron

FENNTARTHATÓSÁGI ÁTMENET: KIHÍVÁSOK ÉS INNOVATÍV MEGOLDÁSOK

SUSTAINABILITY TRANSITIONS: CHALLENGES AND INNOVATIVE SOLUTIONS

Szerkesztők / Editors:
OBÁDOVICS Csilla, RESPERGER Richárd, SZÉLES Zsuzsanna, TÓTH Balázs István

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Influences of Autonomous Vehicles on Sustainability: A Systematic Literature Review

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Abstract
Autonomous driving is an attractive and controversial topic in the field of mobility research. With the continuous technical progress in the field of autonomous vehicles, scientific research in this area is also growing exponentially. This is equally true for the topic of sustainability. Here, too, research interest and the resulting scientific publications have increased significantly in recent years. From the two mutually reinforcing factors, the risk of information overload for researchers can be derived. This paper attempts to address this complex of issues in a systematic manner. To this end, previous research is examined using a systematic literature review. Bibliometric methods and a qualitative content analysis support this approach. This summary is intended to serve as a basis for further research. This includes summarising current research as well as identifying current research gaps. The results of the article show a growing field of research with many special features. Above all, reducing emissions and increasing efficiency are decisive contributions to the sustainability of autonomous vehicles.

Keywords: autonomous vehicles, sustainability, systematic literature review
JEL Codes: R40, Q55, Q56

1. Introduction

1.1. Relevance and problem definition

Global passenger traffic increased fourteenfold between 1950 and 2018. This enormous increase in passenger transport has led the sector to become one of the largest energy consumers and therefore one of the largest CO_2 emitters (Moriarty, 2021). In 2010, the transport sector accounted for 23% of global energy-related CO_2 emissions. This corresponds to 6.7 $GtCO_2$ (Sims et al., 2014).

This increase in CO_2 emissions due to transport sector is also evident in Germany. Emissions from German road traffic have remained constant over the last two and a half decades, despite the continued development of vehicles. In the past, the focus in Germany has been primarily on emission standards for new registrations or the promotion of electric cars. Due to its emissions, the mobility sector plays a decisive role in compliance with international agreements on reducing emissions and, thus, limiting global warming (Gössling & Metzler, 2017). Against this backdrop, new technologies for the transport sector are entering the market. Autonomous driving, which is currently attracting much attention, is one of such technology (Maurer et al., 2016). While autonomous driving is still at an early stage of development, its impact could be considerable. Just as entire industries, social norms, and political landscapes have evolved around the automobile since its introduction 100 years ago, autonomous driving has the potential, to be a fundamentally change of the industry (Brown et al., 2009). This is also shown by current research into the spread of autonomous vehicles. In a market study on the German automotive market, Kaltenhäuser et al. (2020) assumed that 12.4 million privately owned vehicles would be able to drive autonomously in Germany in 2040. They also expected that there would be 2.4 million robotaxis on the roads in Germany by 2040 (Kaltenhäuser et al., 2020). It should be noted that there are different levels and definitions of autonomous driving. In general, autonomous vehicles refer to level 4 or 5 vehicles, which are vehicles that can operate fully without human input in road traffic (Yigitcanlar et al., 2019). The levels of automation can also be seen in Figure 1.

Source	Levels of Automation					
	0	1	2	3	4	5
Federal Highway Research Institute (BASt)	Diver only	Assisted	Partly automated	Highly automated	Fully automated	
National Highway Traffic Saftey Administration (NHTSA)	No automation	Function specific automation	Combined function automation	Limited self-driving automation	Full self-driving automation	
Society of Automotive Engineers (SAE)	No automation	Driver assistance	Partial automation	Conditional automation	High automation	Full automation

Figure 4: Levels of automation

Source: Own illustration (2023), according to Yigitcanlar et al. (2019)

There has been increased interest in the topics of sustainability and autonomous driving in recent years, which has led to a growing number of new publications in this field of research. This increase in publications poses the risk of information overload. It is therefore necessary to present summaries of relevant topics to capture the entirety of a research area.

The aim of this article is to provide a structured and comprehensible overview of the current scientific literature on the topic of autonomous driving and sustainability. To achieve this goal, a systematic search was carried out in relevant scientific databases; the identified literature was assessed in terms of its scope and characteristics and then analysed using qualitative content analysis.

To fulfil the scientific requirements and enable future researchers to understand the steps taken, a systematic literature review was the research method chosen for this article. The aim of this article is summarised by the following research question:

How has the scientific output on autonomous vehicles developed in terms of sustainability?

1.2. Structure of the work

The first chapter of the introduction describes the problem. This forms the basis for the objectives of the article and the research question. The structure of the article is also described. The following chapter describes the methodological approach. Here, the methodology is described in general terms, and the approach is defined. The methods used are then described in more detail in the corresponding chapters. Chapter 3 describes the results of the literature review. The final chapter concludes the article with a discussion of the results and their limitations, as well as further research possibilities.

2. Methodology

A systematic search of the literature serves to collect and analyse all published scientific studies on a specific question in a reproducible manner (Cooper et al., 2019). The integral search, appraisal, synthesis, and analysis (SALSA) (Figure 2) model was developed to ensure the reproducibility and comparability of the literature search. The elements of the acronym represent the essential steps of a review: search, appraisal, synthesis, and analysis (Booth et al., 2016).

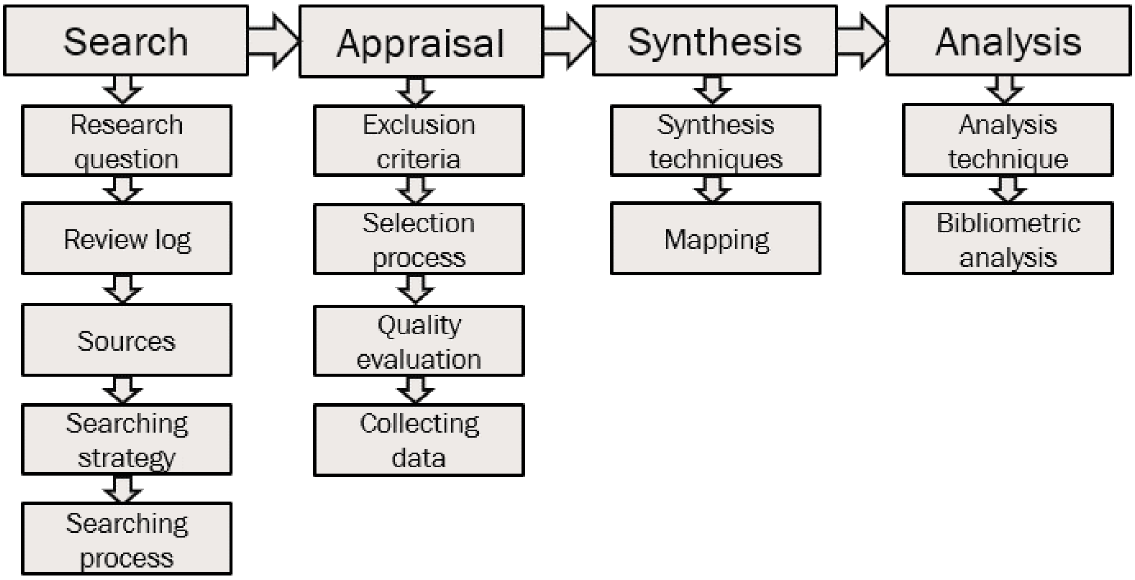

Figure 5: SALSA process model

Source: Own illustration (2023), according to Booth et al. (2016)

As outlined above, the SALSA process identifies four steps in conducting a systematic review of the literature. The first part of the research process consists of defining the research question. The question for this review was defined in Chapter 1.1. Based on the research question, the databases to be searched and the search strategy are determined (Booth et al., 2016). The Scopus database was selected for this article. The search was carried out over the period from November 1, 2023 to November 15, 2023. Within the database, the following keywords were used for the search query: 'autonomous' AND 'vehicles' AND 'sustainability'. Within the articles, the title, abstract, and keywords were searched. This approach was chosen to maximise the number of hits and avoid losing any articles in the search. As English is the predominant language used in scientific research, only English-language literature was authorised for the search, and the following exclusion criterion was used: Limit To: Language: English. Further restrictions regarding elements such as authors and publication form were not used.

The next step in the SALSA process is appraisal. In this step, it should be clearly stated which articles were included in the review and which exclusion criteria were applied. In addition, the scope of the collected data is documented (Booth et al., 2016). To make this step as comprehensible and transparent as possible, the PRISMA process (Figure 3) was also integrated into this step. This process is characterised by a transparent visualisation of all steps. The items found are displayed, checked for duplicates, and sorted. At the end of this process, the articles that are contained in review remain (Page et al., 2021).

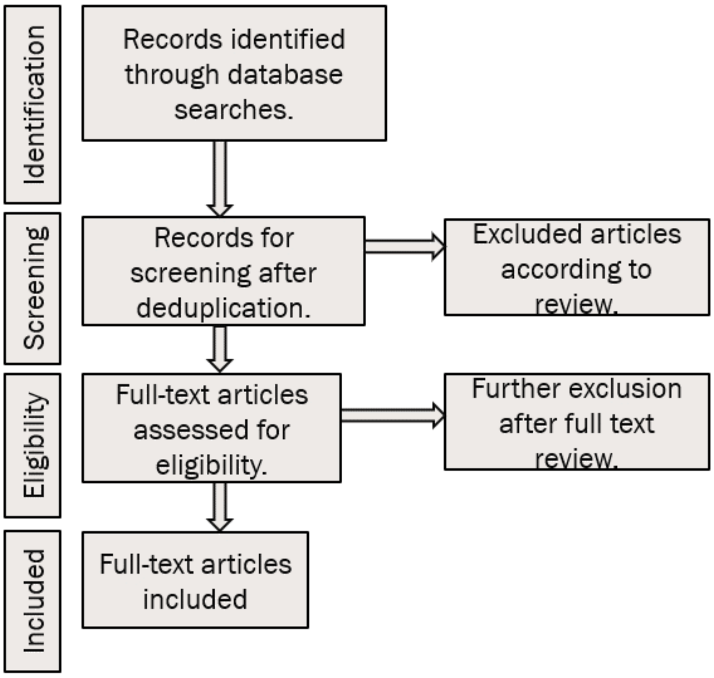

Figure 6: PRISMA 2009 flow diagram

Source: Own illustration (2023), according to (Page et al., 2021)

For this study, 596 articles were found in the Scopus database in the first step of the identification process. After this step, five articles were excluded because they were duplicates. In the next step of the screening, 497 articles were excluded because they did not contribute to the objective of this article. This resulted in the selection of 99 articles for the next step. The next step was eligibility, or checking the full texts of the articles for their suitability. After a full-text check, a further 47 articles were excluded. The remaining 52 articles are discussed in this paper (Figure 4).

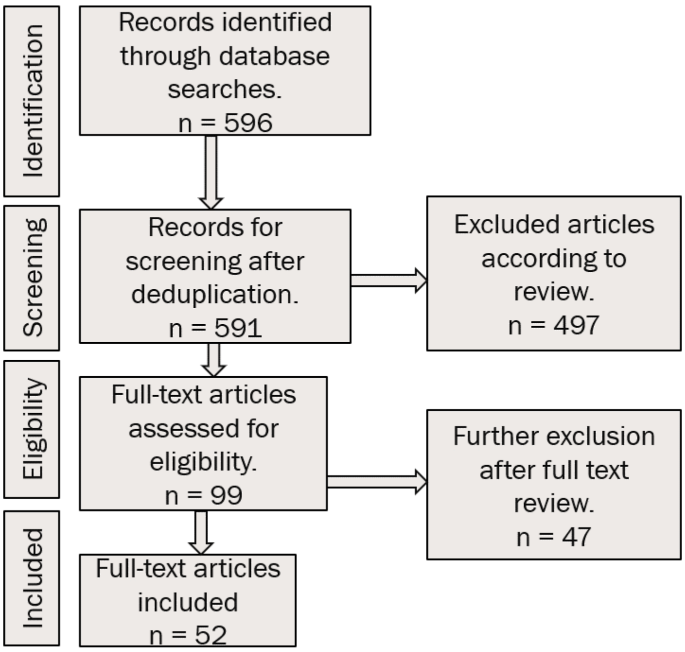

Figure 7: PRISMA 2009 flow diagram for this review

Source: Own illustration (2023), according to (PRISMA-P Group et al., 2015)

The next two steps in the SALSA process are synthesis and analysis, in which the articles included are examined and analysed for their interrelationships (Booth et al., 2016). In this study, the next steps were analysed using qualitative content analysis, according to Mayring and Fenzl (2022). This type of analysis was chosen because in a qualitative content analysis, according to Mayring and Fenzl (2022), categories are formed based on existing knowledge.

This article draws on the findings of sustainability research. In this context, sustainability is defined as a combination of ecological, social, and economic aspects (Figure 5) (Purvis et al., 2019). The three characteristics also represent the main categories of the present content analysis.

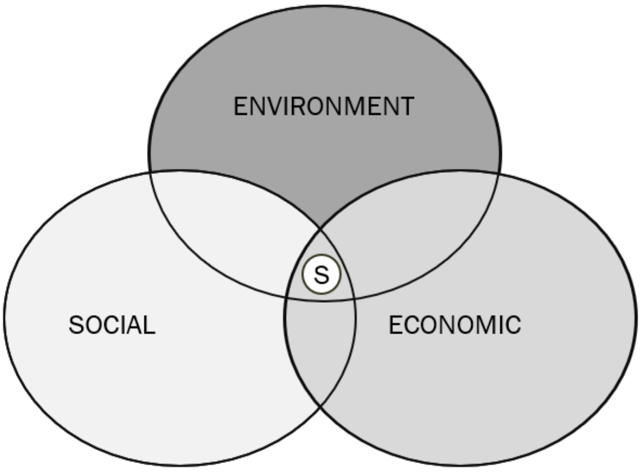

Figure 8: Three pillars of sustainability
Source: Own illustration (2023), according to Purvis et al. (2019)

This qualitative content analysis technique is characterised by the fact that it is summarising, explicit, and structured. As a result, the texts are paraphrased and refer to the respective literature (Mayring & Fenzl, 2022).

3. Results

The results of the work are presented in this chapter. First, a bibliometric analysis, followed by a qualitative content analysis, is carried out in the three categories.

3.1. Bibliometric analysis

The following data exploration provides an overview of the articles used in this work. A trend analysis shows that the total number of indexed articles was distributed over the period from 2014 to 2023. Figure 7 shows the development of publications over time since 2014. The trend analysis shows that the number of publications has increased significantly over the last 10 years. In particular, there was a great increase in publications between 2018 and 2019. The high level of publications in 2019 has been partially maintained over the last four years. The three years with the highest number of publications are 2019, 2020, and 2022 (Figure 6).

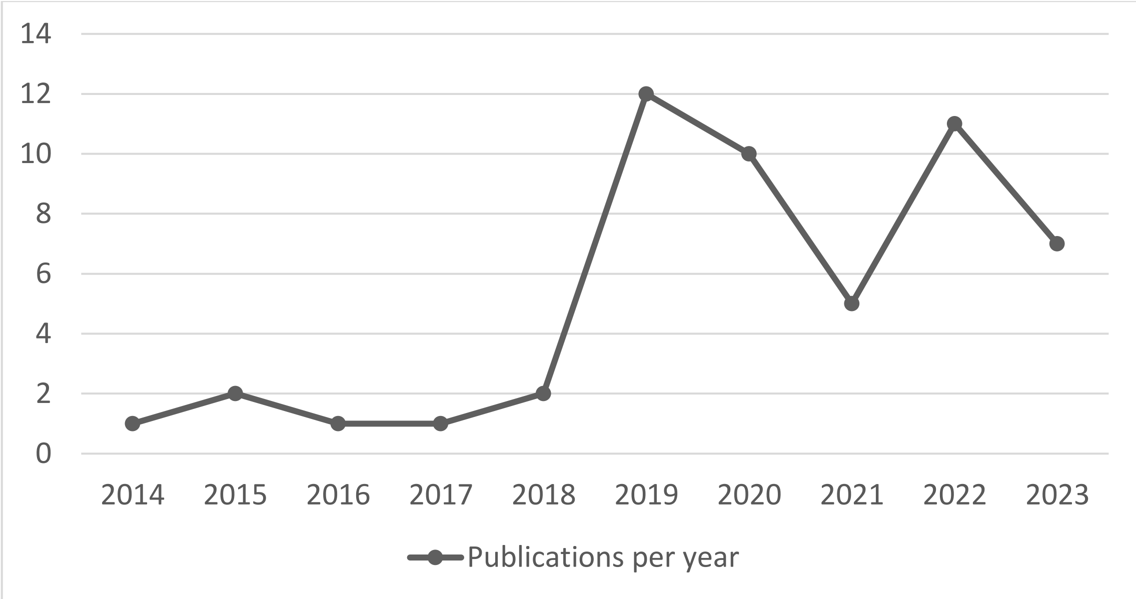

Figure 9: Publications per year
Source: Own illustration, according to Extract from 01.11.2023 by Scopus (2023)

This trend is also reflected in the percentage publication rate of the individual years. In 2014, the scientific output of publications on this topic was still at one paper. In 2023, there were seven scientific publications. Most of the publications (almost two-thirds) were articles in scientific journals, followed by books and conference papers (Figure 7).

Criteria	Category	Quantity	Percent
Date of publication	2014	1	1,2%
	2015	2	2,4%
	2016	1	1,2%
	2017	1	1,2%
	2018	2	2,4%
	2019	12	14,3%
	2020	10	11,9%
	2021	5	6,0%
	2022	11	13,1%
	2023	7	8,3%
Document type	Article	31	36,9%
	Book	10	11,9%
	Conference paper	6	7,1%
	Other	5	6,0%

Figure 10: General characteristics
Source: Own illustration, according to Extract from 01.11.2023 by Scopus (2023)

3.2. Qualitative content analysis

A total of 52 identified documents were included in the qualitative content analysis. The content of the 52 articles was analysed and the results were assigned to one of three categories: economic, social, or environmental. Of the remaining articles, 20 articles fall into the main category of the environment, the social category comprises 24 articles, and the economics category comprises 8 articles (Figure 8).

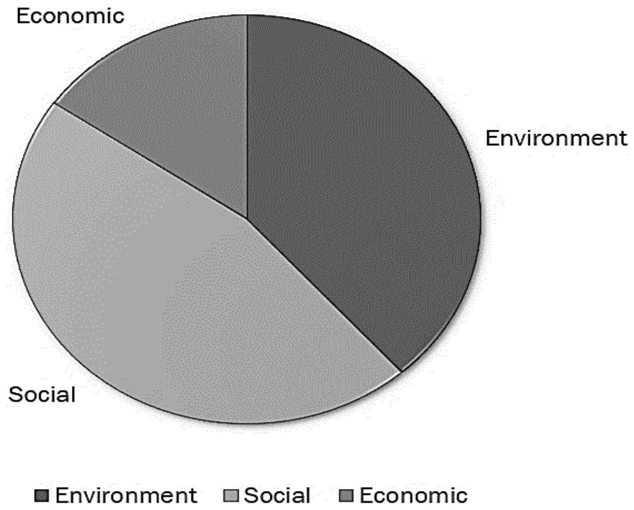

Figure 11: Distribution
Source: Own illustration based on the results (2023)

The following sections describe the levels and content of each of the main categories in detail. The focus is on providing a summary of the content.

Social

The key point in this category is that the widespread introduction of autonomous vehicles could potentially significantly improve traffic flow in urban areas. The existing infrastructure does not need to be changed for this. This is mainly because the use of the latest technologies could reduce congestion and improve traffic management in the city as a whole (Barron, 2022; Bucchiarone et al., 2021; Kacperski et al., 2020; Kuru & Khan, 2021; Mora et al., 2020; Tennant et al., 2021; Zhu et al., 2023). This increase in productivity means that the time saved on travel could be used for other things, which in turn would improve quality of life (Mora et al., 2020; Ng & Kim, 2020). Another decisive advantage of autonomous vehicles is that they enable mobility for groups for whom current forms of transport only offer a limited range of mobility. Therefore, older people or people with disabilities, in particular, would benefit from the introduction of autonomous vehicles (Chen et al., 2023; Kacperski et al., 2020; Mora et al., 2020; Tennant et al., 2021; Underwood, 2014; Williams et al., 2020). In this way, autonomous vehicles contribute to the democratisation of mobility. They provide equal access to transport for all social groups (Chen et al., 2023; Martin, 2019b). However, it can be assumed that a certain proportion of people will continue to be dependent on human assistance for mobility in the future (Pakusch et al., 2020).

Another aspect of social justice is that the widespread introduction of autonomous vehicles is expected to result in significantly fewer road accidents (Martin, 2019b; Underwood, 2014). This point also plays a decisive role in people's intention to use this type of vehicle because perceived safety is a decisive factor in this matter (Montoro et al., 2019).

In addition, the introduction of autonomous vehicles may lead to a shift from private autonomous vehicles to autonomous ride-sharing services or autonomous shuttles (Coppola & Silvestri, 2019; Williams et al., 2020). In this context, attempts to break the trend towards the ownership of private vehicles and promote autonomous shuttle buses are also important. The aim is to gradually expand transport with such solutions to meet demand (Grush & Niles, 2017). The types of autonomous shuttles can facilitate connectivity in rural or hard-to-reach areas compared to traditional public transport (Bucchiarone et al., 2021). However, this is also associated with the risk of urban sprawl (May et al., 2020).

Particularly in the case of autonomous mobility solutions for public transport, it should be noted that feedback loops are required between the ecological, economic, and user perspectives. The problems of public transport can be solved only through multi-criteria decision-making (Hasan et al., 2019). This includes, above all, the involvement of the public in the process of developing future transport systems (Lampkin et al., 2023) as the use of existing public transport is currently expected to fall by 18% (May et al., 2020).

However, there are also concerns about the advantages of autonomous vehicles mentioned above. The main concern is the impact on other road users, such as cyclists or pedestrians, and the vehicles' interaction with them (Kacperski et al., 2020). This is of particular importance, as the introduction of autonomous vehicles will lead to an increase in journeys and therefore mileage (Mohammed & Horváth, 2023). In addition, political decision-makers' hesitancy with regard to clear regulations has also been criticised (Kacperski et al., 2020; Schreurs & Steuwer, 2016). It is therefore necessary to create a regulatory framework that enables the safe operation of autonomous vehicles (Merfeld et al., 2019). This should also be done primarily to prevent conflicts among road traffic (Martin, 2019b). In addition to this potential for conflict on the road, there is also the potential for ethical conflict. Connectivity and autonomous vehicles generate a large amount of personal data, which must be protected. The parties involved must also be aware of their responsibility for data protection. The willingness from the User´s to share their data also depends on perceived trust (Andorka & Rambow-Hoeschele, 2020).

Another concern is that autonomous vehicles and their comfort result in reduced active physical activity (Shatu & Kamruzzaman, 2022). A decrease in walking and cycling by 13% is expected (May et al., 2020). A clearer overview of the results in the social category is given in the following table (Table 1).

Table 4: Results of the category social

Author	Category	Findings
Barron (2022); Bucchiarone et al., (2021); Kacperski et al. (2020); Kuru & Khan (2021); Mora et al. (2020); Tennant et al. (2021); Zhu et al. (2023)	Social	Improved traffic flow.
Mora et al. (2020); Ng & Kim (2020)	Social	Improvement in quality of life.
Chen et al. (2023); Kacperski et al. (2020; Mora et al. (2020); Tennant et al. (2021); Underwood (2014); Williams et al. (2020)	Social	Mobility option for people with disabilities.
Chen et al. (2023); Martin (2019b)	Social	Equal access to mobility.
Martin (2019b); Montoro et al. (2019); Underwood (2014)	Social	Traffic accident reduction.
Bucchiarone et al. (2021); Coppola & Silvestri (2019); Grush & Niles (2017); Williams et al. (2020)	Social	Shift to autonomous shuttles.
Lampkin et al. (2023)	Social	Involvement and education of the public.
Kacperski et al. (2020)	Social	Difficult interaction with other road users.
Kacperski et al. (2020); Merfeld et al. (2019); Schreurs & Steuwer (2016)	Social	Regulatory Framework for Autonomous Vehicles
Andorka & Rambow-Hoeschele (2020)	Social	Challenges in the area of data protection and privacy.

May et al. (2020); Shatu & Kamruzzaman (2022)	Social	Reduced active physical activity.

Source: Own illustration and analysis (2023), based on the literature review

Economic

Autonomous vehicles can lead to a significant improvement in public transport services, especially in local public transport (Antoniou et al., 2020). Autonomous vehicles can also contribute to this as on-demand mobility. A key aspect of such models is their economic viability. This was demonstrated in a simulation using Rotterdam as an example. Here, the economic viability of autonomous on-demand models is given in this special case and can be further expanded by increasing efficiency (Stevens et al., 2022). In addition to fee-based financing models, autonomous vehicles can generate new sources of income in the area of mobility on demand, or robotaxis. For example, the user, who is exclusively available to the vehicle provider for the transport time in the vehicle, can be used for advertising during this time (Block & Herrmann, 2019). A study by Block & Herrmann (2019) assumed that 33 cents could be generated per mile. However, autonomous vehicles can be used not only for passenger transport but also for parcel delivery. The last mile, in particular, would benefit from the use of autonomous vehicles (Silva et al., 2023). Autonomous vehicles also offer great advantages for small and medium-sized companies in the logistics sector. They can reduce operating costs and increase logistical efficiency, leading to an increase in turnover and profitability (Mokonyama et al., 2022). In addition, autonomous driving technology offers further opportunities for mobility planning in cities. For example, major efficiency gains can be achieved on roads and motorways. It is assumed that the capacity of motorways can be increased by a factor of 3.2 if there is 100% market penetration of autonomous vehicles (Abdeen et al., 2022). However, it should be noted that every city has different needs when introducing autonomous vehicles, and there is no universal solution. Approaches can be tailored to the specific characteristics of a given city. The more densely populated a city is, the more worthwhile it is to use autonomous shuttles (Richter et al., 2022). It should be noted that the introduction of this technology also depends on the existence of a suitable infrastructure. This must be available for the introduction of such vehicles, which requires a high willingness to invest, especially in emerging markets. However, if it a suitable infrastructure is in place, it can overcome existing mobility restrictions and create an appropriate urban infrastructure (Andrade et al., 2023). A clearer overview of the results in the economic category is given in the following table (Table 2).

Table 5: Results of the category economic

Author	Category	Findings
Stevens et al. (2022)	Economic	Economic viability of on-demand models.
Block & Herrmann (2019)	Economic	Generating revenue through advertising.
Silva et al. (2023)	Economic	Use of autonomous vehicles for last mile delivery.
Mokonyama et al. (2022)	Economic	Increase efficiency in the logistics sector.
Abdeen et al. (2022)	Economic	Capacity increase of motorways.
Richter et al. (2022)	Economic	Autonomous shuttles are more efficient with high population density.
Andrade et al. (2023)	Economic	Need for suitable infrastructure for the use of autonomous driving.

Source: Own illustration and analysis (2023), based on the literature review

Environment

An important aspect of the environmental impact of autonomous driving is the potential for CO_2 reduction (Chester, 2015; Hardy & Fenner, 2015). Vehicle emissions can be reduced through optimised driving patterns and reduced congestion. An important aspect of optimised driving patterns is so-called platooning. This involves the networked driving of several vehicles (Martin, 2019a, 2019c; Neufville et al., 2022). The greatest possible CO_2 savings are achieved if not only route guidance is optimised by autonomous vehicles but also no pollutants are emitted locally by electric cars (Biloria, 2022; Prideaux & Yin, 2019). This is also evident in the case of heavy-duty vehicles. The greenhouse gas savings potential of automated electric trucks over their life cycle is 4.7 thousand tonnes of CO_2 equivalents lower than that of automated diesel trucks (Sen et al., 2020). A general increase in vehicle kilometres is assumed (Tajaddini & Vu, 2023), but the expected additional kilometres driven would be compensated for in the same way (Martin, 2019b). Not only for cars and lorries but also for buses, a microsimulation has shown that autonomous buses are expected to save 27.2% in CO_2 emissions compared to today's buses used in local public transport (Hasan et al., 2022). A study in Singapore even demonstrated a 47% reduction in greenhouse gas emissions over the entire life cycle of autonomous electric minibuses compared to diesel buses (Pathak et al., 2021). The emissions reductions are also reflected in the logistics networks of the food industry. Here, CO_2 emissions can be reduced by 22% through the use of autonomous vehicles (Gružauskas et al., 2018). The reduction in air pollution would also improves the general air quality in cities (Paiva et al., 2021).

In addition, the need to own a vehicle would be reduced, as this new form of transport would enable a new form of shared mobility (Dlugosch et al., 2022; Hillenbrand, 2022). To this end, companies that offer shared autonomous vehicles should also be promoted (Riggs, Ruhl, et al., 2019).

Autonomous vehicles are expected to change road use so that less space is needed for roads and more space is available for other activities (Riggs, Larco, et al., 2019; Shen et al., 2018). The need for car parking spaces in cities would also be reduced (Yigitcanlar et al., 2019). In addition, sustainability concerns have been shown to have a significant impact on citizens' attitudes towards autonomous vehicles (Dirsehan & Can, 2020). A clearer overview of the results in the environment category is given in the following table (Table 3).

Table 6: Results of the category environment

Author	Category	Findings
Chester (2015); Hardy & Fenner (2015)	Environment	Potential for reduction of CO_2 emissions.
Martin (2019a), Martin (2019c); Neufville et al., (2022)	Environment	Optimization of driving behavior.
Biloria (2022; Prideaux & Yin (2019)	Environment	Electric drive for maximum CO_2 savings.
Sen et al. (2020)	Environment	Significant CO_2 advantages for electric heavy trucks.
Tajaddini & Vu (2023)	Environment	Increase in annual mileage.
Hasan et al. (2022) Pathak et al. (2021)	Environment	Significant CO_2 savings in buses compared to conventional buses.
Gružauskas et al. (2018)	Environment	CO_2 reduction in logistics networks.
Paiva et al. (2021)	Environment	Improvement of air quality.

Dlugosch et al. (2022); Hillenbrand (2022)	Environment	Shared mobility.
Riggs, Larco et al. (2019); Shen et al. (2018)	Environment	Reduce the amount of land needed for roads.
Yigitcanlar et al. (2019)	Environment	Reduce the number of parking spaces.
Dirsehan & Can (2020)	Environment	Sustainability promotes autonomous driving.

Source: Own illustration and analysis (2023), based on the literature review

4. Conclusion

This systematic literature review has shown that the topic of autonomous vehicles and sustainability is attracting increasing attention. The focus of this work was primarily on the three areas of sustainability. The aim of this work was to provide an initial general overview of existing studies and literature. This goal was achieved by highlighting the most important effects on sustainability known today and the potential for sustainable development.

Well-founded research has been carried out in this field, particularly in the definition of social aspects. Autonomous driving can have a major impact on users' quality of life by shortening journey times, allowing the time gained to be used differently (Mora et al., 2020). Another important point is that this technology can further democratise mobility by opening up new opportunities for people who are currently rather restricted in their mobility (Martin, 2019b). In economic terms, autonomous vehicles will make an important contribution to the economic viability of on-demand models (Stevens et al., 2022). In addition, new sources of revenue are expected in the area of usage-based advertising opportunities (Block & Herrmann, 2019). The biggest effect in terms of environmental impact is the expected CO_2 savings (Prideaux & Yin, 2019). However, depending on the model and the object under consideration, the range of assumed reductions is very wide.

This study also had limitations that must be considered. One limitation lies in the selection of databases, as only one scientific database was used in this review. Furthermore, the three sustainability categories may overlap in some aspects. This is because the studies in this field are generally broad in scope and do not investigate one dimension of sustainability exclusively. Another important point is that no distinction was made between qualitative and quantitative research methods in this work, and therefore, no evaluation of the studies' methodologies was carried out.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that appeared to influence the work reported in this paper.

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