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SUSTAINABLE AND SMART MOBILITY – RESEARCH DIRECTIONS. A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT: The article provides a classification of scientific research relating to the issue of sustainable and intelligent mobility, in order to identify emerging future research directions. A systematic literature review was based on bibliometric analysis and focused on articles in Scopus and Web of Science databases. The purpose of this article was to identify areas of research analysed in international literature in the area of sustainable and smart mobility. The systematic literature review aimed to identify, integrate and evaluate research on the selected topic based on clearly defined criteria. The analysis covered publications on sustainable and smart mobility published in Scopus and Web of Science databases from 2010 to 2022. Based on the bibliometric analysis, a bibliometric map was developed using mapping technique VOS – the visualisation of similarities. Clusters were created using the VOSviewer software.

KEYWORDS: sustainable mobility, smart mobility, literature review, bibliometric analysis, directions of research

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Introduction

Sustainable mobility focuses on how to move people and goods efficiently, safely, securely, affordably and in an environmentally friendly manner using inland transportation. The key aspects of Sustainable Mobility and Smart Connectivity examine how to improve connectivity between people, companies, governments, economies and even goods as well as how to make mobility more sustainable. It is a very wide subject area and one which has seen tremendous advances, but still has to be further developed, if it is to be fully aligned with the SDGs 9 (United Nations, 2021). The concept of sustainable mobility derives from the broader concept of "sustainable development", defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987).

Considering the growing importance of sustainable and smart mobility, supported each year by the increasing number of initiatives, the authors conducted a bibliographic analysis of the existing publications in this area, collected in Scopus and Web of Science databases. The article aims to identify areas of research analysed in the literature concerning sustainable and smart mobility. This measure represents the first stage of the research process, aiming to identify the research problems in the field of sustainable and smart mobility and solutions, which would constitute a theoretical and practical contribution to the development of sustainable and smart mobility.

In the introduction, a detailed analysis of the area of sustainable and intelligent mobility was carried out using literature to describe the importance of the topic being explored. Next, the methodology used for bibliometric analysis is described. The third chapter is devoted to the results of the conducted bibliometric analysis. The last part of the work analyses the obtained results and presents the conclusions. Sustainable mobility policies are focused on environmental protection. Sometimes, sustainable mobility is identified only as mobility that is able to reduce environmental impacts. Even if this concept is not correct, indeed most of the interventions aimed at the development of sustainable mobility have the reduction of pollutant emissions and greenhouse gases as their main objective. In the following sections of the paper, although dedicated to other topics, it will be noted that many of the socio-economic and technological aspects of the problem also have environmental objectives to achieve (Gallo & Marinelli, 2020). Intelligent mobility is the portmanteau used to refer to transportation in the context of smart cities. To have a good understanding of what smart mobility is, we need to take a closer look at what smart and mobility mean. Smart is an adjective that has gained increased use describing complex systems of the future. Broadly,

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a smart system is a technology-driven system that interacts with end-users and/or other smart systems. It uses a combination of hardware (e.g. sensors) and software (e.g. signal processing, machine learning) to accomplish its intelligent behaviour. How those interactions and their effects happen, changes with the availability of technology. But specifically, in the context of cities, what it means to be smart has changed over time. Earlier, smart cities were just communities that were using a "nifty gadget" in an existing ecosystem. However, more recently, the idea of a smart city is about developing and using technology with a specific outcome in mind. The key here is the development of technology. In earlier cycles, the technology was developed independently, and then applications for them were identified. Now, there is a push to identify end goals first, and then develop technologies to accomplish those goals. Better transportation is one of those goals that we hope to achieve through technology (Choudhry, 2022). Sustainable development has been a popular policy concept since the publication of the Brundtland Report in 1987. It has generated worldwide debate on the conditions and policy strategies for the achievement of environmentally benign development. However, it was soon recognized that the global nature of the sustainability concept did not contribute to a clear and operational policy focus. Hence, new complementary concepts have emerged that were more fine-tuned towards clearly demarcated economic sectors, such as sustainable land use or sustainable transport (Nijkamp et al., 2004). Due to its novelty, the field of research about MaaS (mobility as a service) is relatively young. Consequently, individual branches of research are emerging slowly, as publications on specific topics have only started to accumulate in measurable numbers since 2018. At first, publications focused on the question which features could be used to characterise MaaS and how the service could be differentiated from previous offerings (Maas, 2022). MaaS plays an essential role in discussions about the future of mobility. Due to the complexity of this field of research, MaaS can be expressed in terms of a currently emerging concept of future mobility, a vision for the future, a new technology, a new user behaviour, or a holistic new transport solution. Still, a universal definition of MaaS has not yet been established (Jittrapirom et al., 2017). Hensher (2017) summarised the demands on MaaS in the form of "three Bs" – bundle, budget, and broker. In contrast to the above-mentioned characteristics such as user-orientation and multi-modality, Hensher considered the innovation of MaaS to be the networking aspect and emphasised the innovations on the side of the provider (Hensher, 2017). A key element of MaaS is the combination of different means of transport with defined conditions of use, which are acquired as part of a package or bundle. The packages are linked to services such as the flexible selection of starting locations and starting times and are offered to the

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customer in a personalised way, e.g., depending on age, location, or passenger volume (Ho et al., 2018).

Nagy and Csiszár (2020) separated smart mobility into two segments: (1) innovative solutions and (2) development of current services. In Figure 1, the most relevant issues were illustrated in both segments, with light-grey oval boxes (Figure 1). White oval boxes present examples based on literature (Nagy & Csiszár, 2020).

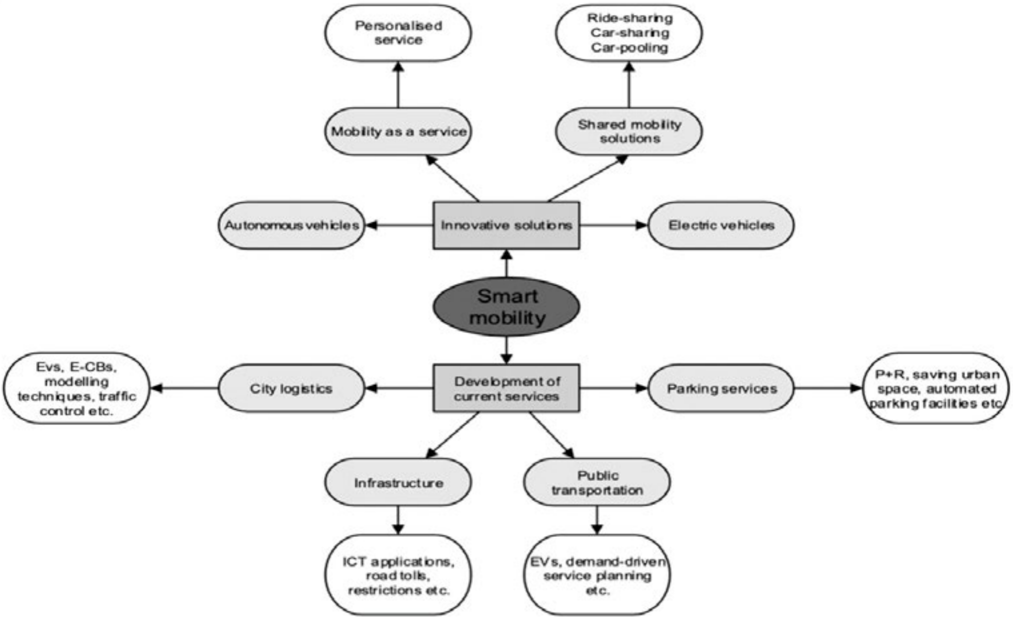

Figure 1. The main elements of smart mobility
Source: authors' work based on Nagy and Csiszár (2020).

Innovative solutions are not present in every urban transportation system, however, it plays a main role in smart mobility-oriented development. Autonomous vehicles (AV) and electric vehicles (EV) are tools on the vehicle side. Mobility as a Service (MaaS) is a new concept, with which demand-driven service planning and personalization of services are possible. Shared mobility solutions are effective tools to increase the efficiency of cars (Jittrapirom et al., 2017). Mobility makes up a part of the smart city agenda, which is supported by the adoption of sustainable transport practices. Sustainable mobility includes the objectives of smart mobility (Benevolo et al., 2016):

- reduce pollution,
- decrease traffic jams,

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- increase people safety,
- lessen noise,
- improve speed and decrease cost of movement.

Sustainable mobility also includes four smart perspectives which deal with design, system, infrastructure and usage (Lyons, 2018). The main characteristics of a sustainable mobility approach are (Holden et al., 2019):

- it focuses on people,
- it prioritises accessibility,
- it is proposed on a local scale, it recognizes the street as a useful space, and not only as a vehicular road,
- it finds relevant the inverted mobility pyramid where pedestrians and cyclists are privileged in the upper part and the automobile users are placed in the lower part,
- it is supplied with multi-criteria analysis to contemplate environmental and social concerns, it is focused on management,
- it has a tendency to integrate people and traffic and,
- it allows health benefits.

Mobility in the current context is based on the pillars of sustainability: the social, economic, and environmental features. In the scenario of receptive cities, it is necessary to articulate additional components: planning and governance that make it possible to achieve the goals of sustainable and intelligent mobility.

The economic component focuses on the productivity and economic local development, energetic efficiency, affordability, and operational efficiency. The social component includes equity, safety, and human health, as well as the community cohesion with the preservation of cultural heritage. The environmental component considers the reduction of emissions that contribute to climate change, the prevention of air, noise and water pollution, the reduction of hydric resource damage, the conservation of natural resources, the protection of biodiversity and open spaces. The governance and planning component addresses inclusive, comprehensive, and integrated planning (Litman, 2021).

Four main dimensions of sustainable development can be derived from the Brundtland Report (United Nations, 1987). Sustainable development, as explained in this report, is about safeguarding long-term ecological sustainability, about satisfying basic human needs, and about promoting intra-generational and intergenerational equity (United Nations, 1987; Holden et al., 2013).

Vallance et al. (2011) presented a broader perspective under the title "What is social sustainability?" Three different social sustainability orientations were presented. The first orientation is "development social sustainability". This form of sustainability relates directly to the Brundtland Report.

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The second orientation is "bridge social sustainability". In this form of social sustainability, the focus is on creating lifestyles and circumstances that make it possible for sustainability to flourish. The focus is on eco- friendly behaviour, on environmental ethics and on transforming the relations of modern households with the environment. There is a non- transformative part in this orientation, with a focus on technology and IT- solutions, as well as a more transformative part, focusing on low- energy lifestyles, without a car – lifestyles, or zero – emission neighbourhoods. The third orientation is "maintenance social sustainability". Here the focus is on practices that people would like to see maintained. It goes from indigenous rights for the aboriginals, to maintaining existing lifestyles that most households in the developed world would like to continue. Remaining and maintaining the existing experienced high quality of life is the orientation. A central concept in this orientation is "social acceptance". Lots of new visions and insights can be proposed, but acceptance is needed (United Nations, 1987; Holden et al., 2013).

The European Commission commissioned the SUMMA (Sustainable Mobility, policy Measures and Assessment) – project, as part of its Programme on Competitive and Sustainable Growth. One of the objectives of this project was to operationalize the concept of sustainable mobility. Walker et al. (2006) presented the results of this SUMMA project. Working from a three-pillar scheme for social outcomes, seven outcomes of interest are defined; accessibility and affordability (here seen as one outcome), safety and security, health, livability and amenity, equity, social cohesion and working conditions. From these core articles on structuring sustainable mobility, a greater convergence on relevant themes of social sustainability arises than from the generic perspective. Also, a convergence with the built environment sector can be noticed. To conclude, seven themes to operationalize social sustainability in mobility arise:

- affordability of mobility (share of household net income),
- accessibility of key services,
- social equity, meaning equal access to mobility,
- health conditions for households (air quality, noise, amenities),
- safety and security,
- social cohesion (related to the "sustainability of communities" – theme in the built environment sector),
- working conditions in the mobility sector.

When analysing sustainable mobility policies promoted by governance, it is possible to identify its focus merely on environmental protection and the reduction of environmental impacts. Nonetheless, other combined topics have to be considered, thus integrating the environmental aspects with the socio-economic and the technological level. These integrate the issues of air

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pollution, car-sharing, eco driving, intelligent transportation systems or taxes and incentives (Gallo & Marinelli, 2020).

The mobility of people and goods are amongst the major concerns for a more efficient and sustainable future. Current digital revolution allowed ushering in new and improved outlooks on the issues related to mobility of people and goods currently known as smart mobility (Ferreira et al., 2021) (Figure 2).

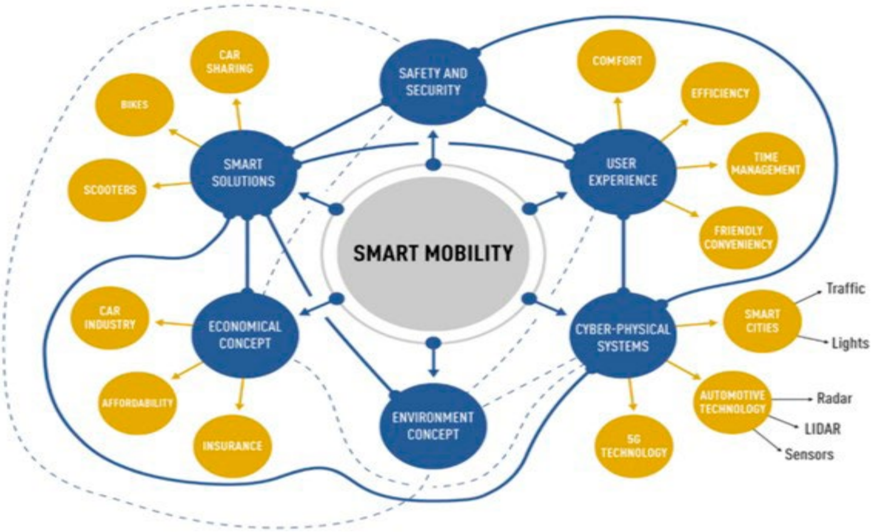

Figure 2. Conceptual framework comprising the main dimensions related to smart and sustainable mobility

Source: authors' work based on Ferreira et al. (2021).

To conclude, mobility efficiency directly affects the economic dimensions with a smarter use of resources and an effective reduction in energy consumption. These combined solutions translate into increased savings in both economic and environmental dimensions. These combined effects can be referred to as the greening effect of smart mobility. Finally, in a nutshell, considering all of the above, the greening effect of smart mobility allows foreseeing increased benefits from current electrification of transports, combined with the widespread use of smart solutions applied as a holistic approach to the mobility of people and goods.

Thus, one can conclude that the greening effect on mobility works both on reducing the need for people to move, combined with the more efficient mobility of people and goods whenever it is effectively necessary for them to move. These resource savings and decreased environmental impacts are related to several of the UN Sustainable Development Goals (United Nations, 2015; D'Alessandro & Besada, 2019).

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Research methods

A bibliometric analysis method was used to review the literature on sustainable and smart mobility. This method is often employed at the initial stage of interest in a research topic (Szpilko & Ejdys, 2022). Bibliometric analysis is commonly used in analyses of well-established research areas in the literature (Gudanowska, 2017; Halicka, 2017; Glińska & Siemieniako, 2018; Winkowska et al., 2019; Niñerola et al., 2019; Ejdys et al., 2019; Szum, 2021) as well as emerging ones (Siderska & Jadaan, 2018; Yarmak & Rollnik-Sadowska, 2022). Bibliometrics is a process in which a survey of scientific literature is performed using statistical and mathematical methods. It is a way of documenting, analysing and making conclusions referring to the scientific state (Klincewicz et al., 2012). Two types of bibliometrics can be distinguished: evaluative and descriptive. The former is based on the number of cited articles (Bornmann & Daniel, 2008), while the latter is based on the analysis of scientific research trends (Klincewicz et al., 2012). This article uses both types of bibliometrics by presenting the number of article citations along with an analysis of research trends and directions.

The operationalisation of the process used in this article with the bibliometric analysis method is presented in Figure 3.

The methodology according to which the research process was conducted consists of four stages, including the database selection (I), the selection of keywords (II) and criteria limiting the search for publications (III). The last stage (IV) was divided into sub-stages. The first involved identifying the most productive countries, organisations, journals and authors, while the second stage identified the most frequent keywords and then defined thematic clusters (Figure 1).

The first stage of the study selected Scopus and Web of Science bibliographic databases presenting a wide spectrum of scientific publications. The choice of databases was dictated by their availability and thematic breadth within all scientific disciplines. The first search included publications containing the indicated phrase in the entire range of documents, but the second search included phrases in titles, abstracts and keywords. Then, selected restriction criteria were applied. Materials published between 2010 and 2022 were searched. For further analysis proceedings papers, conference papers, articles, reviews, books, book chapters, editorials and early access were qualified. Other publication types (meeting abstract, new item, correction, retracted publication) were discarded. The results of the search are shown in Table 1.

A search for the phrases “mobility or transport*” and “sustainable or intelligent or smart” across a range of papers in the first sample generated

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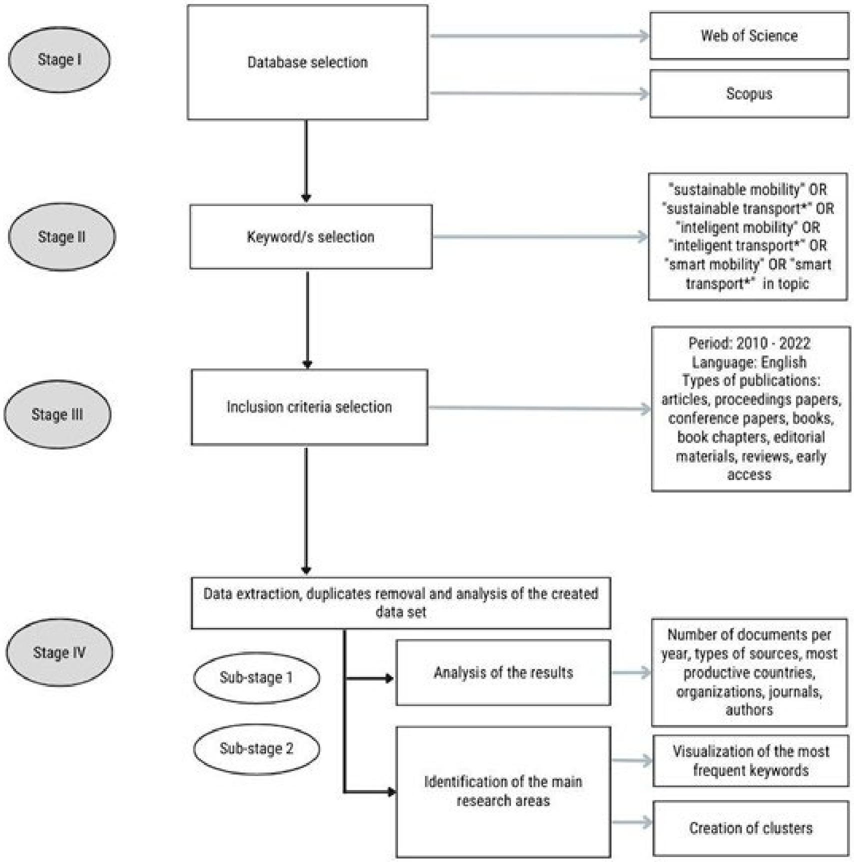

Figure 3. Methodology of bibliometric analysis

55 783 records in Scopus and 13 033 records in Web of Science. The first analysis of the results showed that many publications were not relevant to the study area. Therefore, in the second analysis, the search was limited only to publications containing the indicated phrase in the titles, abstracts and keywords. After searching for phrases in titles, abstracts and keywords, 10 980 records were obtained in Scopus and 7 953 in Web of Science. After adopting limiting criteria, 9 077 and 6 994 were obtained. The search results are presented in Table 1. Files containing the full description of the records in a *csv format were downloaded from each base. The file contained 16 071 records. After removing duplicates, a set of 8820 records was qualified for further analysis.

Table 1. Preliminary search results

Stage	Web of Science	Scopus
First search		
Research query	ALL ="sustainable mobility" OR „sustainable transport*" OR „intel-ligent mobility" OR „intelligent transport*" OR „smart mobility" OR „smart transport*"	ALL („sustainable mobility" OR „sustainable transport*" OR „intel-ligent mobility" OR „intelligent trans-port*" OR „smart mobility" OR „smart transport*")
Number of articles before inclusion criteria	13 033	55 783
Number of articles after inclusion criteria	11 970	51 688
Second research		
Research query	TS="sustainable mobility" OR „sus-tainable transport*" OR „intelligent mobility" OR „intelligent transport*" OR „smart mobility" OR „smart transport*"	TITLE-ABS-KEY(„sustainable mobil-ity" OR „sustainable transport*" OR „intelligent mobility" OR „intelligent transport*" OR „smart mobility" OR „smart transport*")
Number of articles before inclusion criteria	7 953	10 980
Number of articles after inclusion criteria	6 994	9 077

Source: authors' work based on Web of Science (2022) and Scopus (2022) databases.

Based on the data obtained, analyses were carried out on the number of publications over a specific period of time, the most productive authors, organisations, countries and journals. The most recognisable (meaning the most cited) articles were also extracted. The most frequently occurring keywords were also presented. Next, a map reflecting the co-occurrence of keywords related to sustainable and smart mobility was presented. The map was prepared in VOSviewer (version 1.6.18) (van Eck & Waltman, 2019). Then, based on keyword analysis and an in-depth review of the collection of publications, thematic clusters depicting the main research directions were identified.

Results of the research

The first stage of the research included an analysis of interest in the issue over the years, identifying the dominant types of publications and their affiliation with major subject areas in the Scopus and Web of Science databases.

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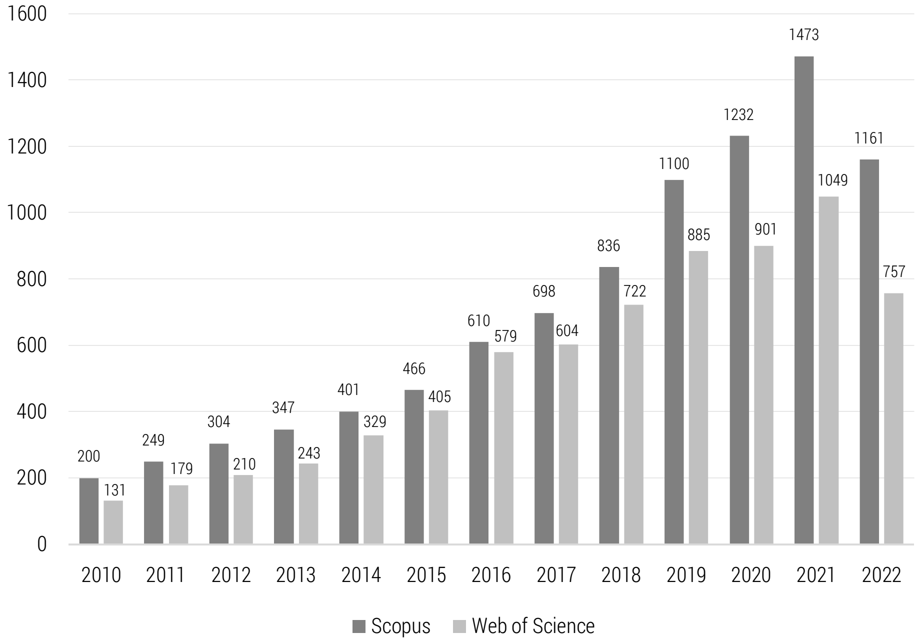

Figure 4. Number of publications in the field of Sustainable and Smart Mobility in Web of Science and Scopus databases (indexed from January 2010 to December 2022)

Source: authors' work based on the Scopus (2022) and Web of Science (2022) databases.

For both databases, numerous publications in the area of sustainable and smart mobility appeared between 2010 and 2022 (Figure 4). In previous years, a few publications on the topic appeared occasionally.

An analysis of the results shows that, in both the Web of Science database (89%) and the Scopus database (87%), the majority of publications were articles and conference papers. Book chapters, books or reviews represented a small fraction. The structure of publications by document type is presented in Figure 5.

Most of the publications in the Scopus and Web of Science databases are assigned to the Computer Science and Engineering areas, covering 15.7% and 25.3% in the former and 21.6% and 22.9% in the latter.

A noticeable number of publications in Scopus are assigned to the Environmental Science area (11.2%), while in the Web of Science database they are assigned to Transportation (20.6%), Green Sustainable Science Technology (19.3%) and Transportation Science Technology (17.3%). Nevertheless, the naming of areas differs in the Scopus and Web of Science databases.

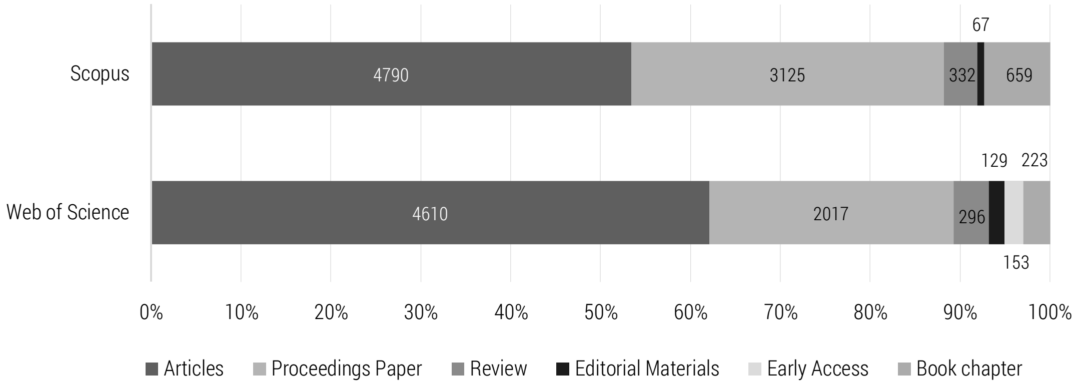

Figure 5. Type of documents among the publications in the field of Sustainable and Smart Mobility in Scopus and Web of Science databases (indexed from January 2010 to December 2022)

Source: authors' work based on the Scopus (2022) and Web of Science (2022) databases.

The author with the highest number (thirty two) of publications was Banister, and the most cited articles were "Cities, mobility and climate change" from 2011 (233 citations in WoS) and "Te trilogy of distance, speed and time" from 2011 (118 citations in WoS). This was followed by Ignaccolo (29 publications), Basbas (27 publications), Longo (26 publications), and Inturri and Alba with 25 each. Banister and Kucukvar had the highest average number of citations per publication in each database (48.2 and 46.2 citations in WoS). Kucukvar's most cited publication was "Application of the TOPSIS and intuitionistic fuzzy set approaches for ranking the life cycle sustainability performance of alternative vehicle technologies," published in Sustainable Production and Consumption in 2016. A detailed list of the most productive authors is shown in Table 2.

The largest number of publications were from the United States (1019 publications), Italy (901) and China (788). Considering the author's affiliation, the highest number of publications were from the University of London (73), Universidad Politecnica De Madrid (64) and Sapiena University Rome (60). Publications from the University of California were the highest cited (40.5 in Scopus and 41.3 in WoS). In comparison with other organisations in the ranking, it had by far the highest average number of citations in Scopus and Web of Science databases.

In the ranking of the most productive journals, Sustainability (Switzerland) took first place (624 publications). It was followed by Journal Of Cleaner Production (128) and International Journal Of Sustainable Transportation (116). However, the journal Transportation Research Part A-Policy and Practice achieved the highest average number of citations in the Scopus database (32.7), while in WoS the Journal of Transport Geography achieved the highest average number of citations (28.7).

Table 2. Most productive authors, organisations, countries and journals

No.	Item	NP	[%]	Average Citation count	
				Scopus	Web of Science
Authors					
1	Banister D.	32	0.4	42.9	48.2
2	Ignaccolo M.	29	0.3	15.6	12.5
3	Basbas S.	27	0.3	13.2	9.9
4	Longo M.	26	0.3	10.7	7.4
5	Inturri G.	25	0.3	16.5	6.0
6	Alba E.	25	0.3	14.1	9.5
7	Onat N.C.	24	0.3	24.2	30.0
8	Campisi T.	18	0.2	14.5	12.3
9	Sierpiński G.	18	0.2	N/A	7.9
10	Kucukvar M.	16	0.2	36.1	46.2
Countries					
11	United States	1019	11.6	22.5	22.5
12	Italy	901	10.2	10.7	9.5
13	China	788	8.9	17.9	16.4
14	United Kingdom	674	7.6	19.1	21.1
15	India	671	7.6	7.5	8.9
16	Germany	600	6.8	12.7	10.4
17	Spain	495	5.6	10.2	8.9
18	Australia	368	4.2	20.4	20.9
19	Poland	320	3.6	7.5	5.7
20	Sweden	312	3.5	15.4	16.5
21	Canada	311	3.5	20.3	22.7
Organisations					
22	University of London	73	0.8	19.1	16.5
23	Universidad Politecnica De Madrid	64	0.7	12.8	10.6
24	Sapienza University Rome	60	0.7	9.6	7.5
25	University of Naples Federico II	59	0.6	8.9	5.9
26	University of California	58	0.6	40.5	41.3

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No.	Item	NP	[%]	Average Citation count	
				Scopus	Web of Science
Journals					
27	Sustainability	624	7.1	9.9	8.1
28	Journal of Cleaner Production	128	1.5	31.3	25.9
29	International Journal of Sustainable Transportation	116	1.3	17.4	15.5
30	Journal of Transport Geography	115	1.3	32.5	28.7
31	Transportation Research Record	114	1.3	17.1	13.1
32	Transport Policy	108	1.2	29.2	26.9
33	Transportation Research Part D-Transport and Environment	105	1.2	19.9	17.5
34	Energies	100	1.1	9.7	8.7
35	Transportation Research Part A-Policy and Practice	94	1.0	32.7	28.0
36	Transportation Research Procedia	88	0.9	6.8	8.1

Note: NP – number of publications, [%] – the percentage of the total number of publications (8820), N/A – not applicable

Source: authors' work based on the Scopus (2022) and Web of Science (2022) databases.

The total number of citations of publications on sustainable and smart mobility was 84975 for WoS and 90380 for Scopus. The top ten publications included two articles published in IEEE Access and one each in IEEE Internet of Things Journal, Transportation Research Record, Biomass and Bioenergy, Transportation Research Part B: Methodological, Future Generation Computer Systems, Transport Reviews and IEEE Communications Surveys and Tutorials. The four most cited publications were from 2013.

The most cited publication (1521 in Scopus, 1102 in Web of Science) was the article by Lin et al. (2019), "A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy and Applications". This was followed by such articles as: "Bikesharing in Europe, the Americas, and Asia" by Shaheen et al. (2010) and "A Survey on the Edge Computing for the Internet of Things" by Yu et al. (2017). The total number of citations was slightly lower than for the first publication (766 and 694 in Scopus; 666 and 555 in Web of Science) (Table 3).

Table 3. The most cited articles on the Sustainable and Smart Mobility

Authors	Article title	Journal	Number of citations	
			Scopus	Web of Science
Lin et al. (2017)	A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy and Applications	IEEE Internet of Things Journal	1521	1102
Shaheen et al. (2010)	Bikesharing in Europe, the Americas, and Asia	Transportation Research Record	766	666
Yu et al. (2017)	A Survey on the Edge Computing for the Internet of Things	IEEE Access	694	555
Slade and Bauen (2013)	Micro-algae cultivation for biofuels: Cost, energy balance, environmental impacts and future prospects	Biomass and Bioen-ergy	642	546
Choen and Kietzmann (2014)	Ride On! Mobility Business Models for the Sharing Economy	Organization and Environment	572	491
Furuhata et al. (2013)	Ridesharing: The state-of-the-art and future directions	Transportation Research Part B: Methodological	570	480
Farahni et al. (2018)	Towards fog-driven IoT eHealth: Promises and challenges of IoT in medicine and healthcare	Future Generation Computer Systems	517	367
Fishan et al. (2013)	Bike Share: A Synthesis of the Literature	Transport Reviews	436	373
Khan et al. (2013)	Mobile phone sensing systems: A survey	IEEE Communica-tions Surveys and Tutorials	434	353
Kaiwartya et al. (2016)	Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects	IEEE Access	411	335

Source: authors' work based on the Scopus (2022) and Web of Science (2022) databases.

The most frequently occurring keywords related to the topic of the Sustainable and Intelligent Mobility were also extracted through bibliometric analysis. VOSviewer software was used during the analysis. The generated set contained a total of 18325 words or phrases that appeared at least fifteen times in the keywords included in the 8820 articles analysed. The set included words with the same meaning as abbreviations or repetitions (e.g., air pollution, pollution) and words directly unrelated to the topic of analysis (e.g., article, analysis). These words were excluded from the set. Key words used in the search (e.g., sustainable mobility, sustainable transport, smart mobility) were excluded from the collection. The notation of terms and abbreviations with the same meaning was also standardised, and terms irrelevant to the analyses conducted were removed. The final collection contained 36 keywords. The most frequent terms and the links between them are shown in Figure 6.

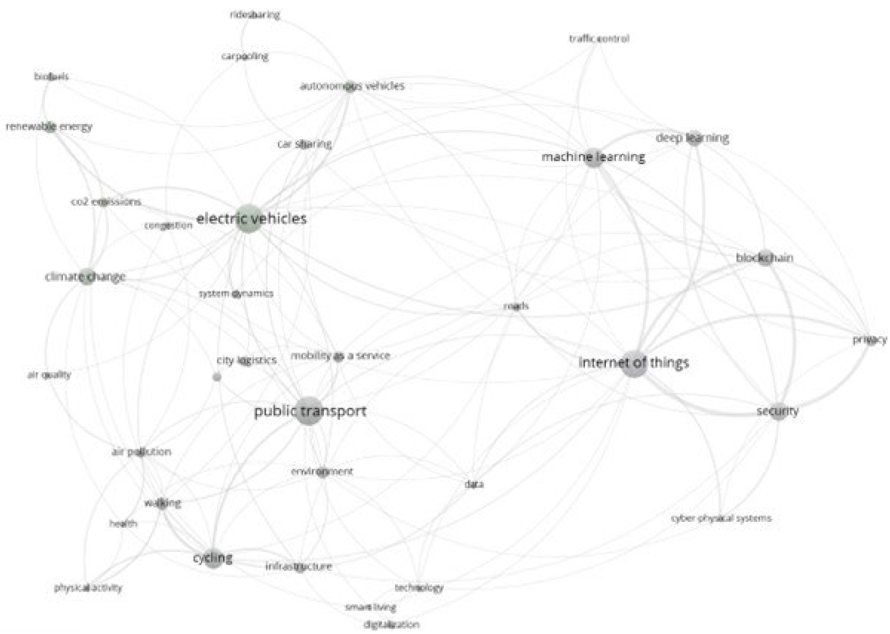

Figure 6. Keyword co-occurrence map on the Sustainable and Smart Mobility area

Source: authors' work based on VOSviewer software.

Among the most frequent keywords related to sustainable and smart mobility were terms related to city logistics (public transport had 251 occurrences of the word in the set), air pollution (CO_2 emissions 42), health (cycling 130, walking 55), infrastructure (infrastructure 46), Internet of Things (machine learning 131, deep learning 87), urban solutions (carsharing 42), energy (renewable energy 57), technology (digitalization 18). The larger the circle in Figure 5, the higher the number of occurrences for a given keyword. It should be noted that these terms also show the most links to other terms.

An in-depth analysis of the most frequently occurring keywords made it possible to identify eight thematic clusters (Figure 7, Table 4).

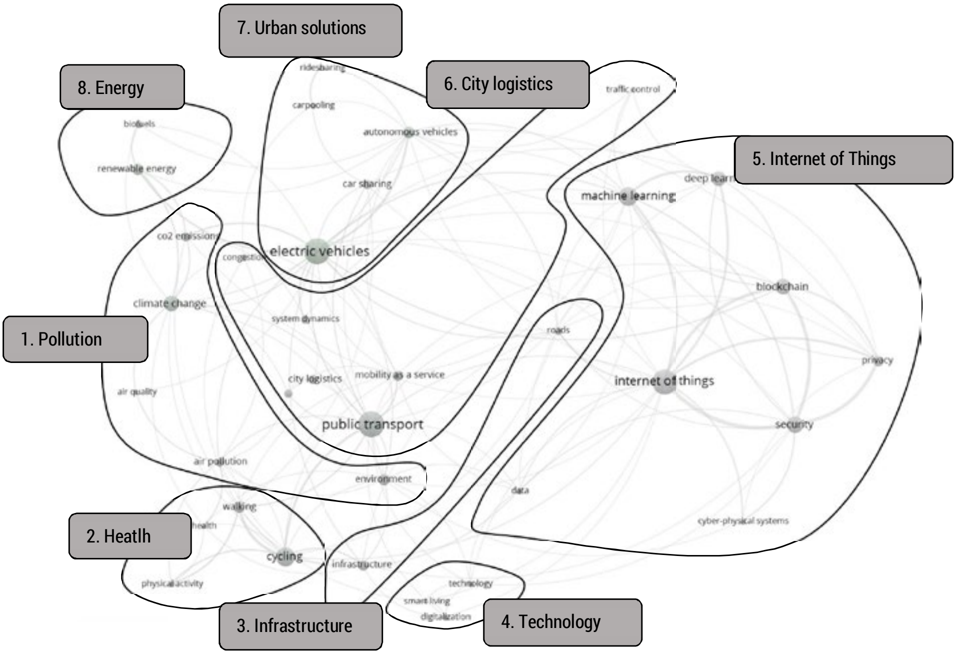

Figure 7. Thematic clusters on Sustainable and Smart Mobility

Source: authors' work based on VOSviewer software.

Table 4. Subareas of the Sustainable and Smart Mobility research

Cluster number	Cluster name	Words
1	Pollution	CO_2 emissions, climate change, air quality, air pollution, environment, raising environmental awareness,
2	Health	walking, cycling, physical activity, health
3	Infrastructure	infrastructure, roads
4	Technology	smart living, digitization, technology, mobility applications, photovoltaics, biofuel advancement, alternative fuels
5	Internet of Things	data, cyber-physical systems, Internet of Things, security, privacy, blockchain, deep learning, machine learning, VANet, Industry 4.0
6	City logistics	public transport, mobility as a service, system dynamics, traffic control, urban logistics, developing countries, congestion, Low Emission Zone, congestion charging
7	Urban solutions	ridesharing, carpooling, car sharing, free-floating carsharing, electric vehicles, autonomous vehicles, electric car sharing, peer-to-peer carsharing, eco-driving, Plug-In Hybrid vehicles, e-scooters, electric busses, Smart Parking
8	Energy	biofuels, renewable energy, hydrogen economy, electricity management system

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The first cluster, "Pollution" primarily refers to climate change and the state of air quality (e.g., CO_2 emissions, climate change, air quality, air pollution, environment). The second cluster, "Health" focuses on health aspects related to daily movement. It includes keywords such as walking, cycling, physical activity, health. The third cluster, "Infrastructure" is represented by such words as, infrastructure, roads, etc. It focuses on infrastructure in transportation. The fourth cluster, "Technology" covers issues related to modern technology to help people in their daily lives. It includes such keywords as smart living, digitalization, technology. The fifth cluster, "Internet of Things" is related to Industry 4.0, which is mainly based on artificial intelligence and the Internet of Things, which is an emerging trend in the digital industrial revolution. It is related to keywords such as data, cyber-physical systems, Internet of Things, security, privacy, blockchain, deep learning and machine learning. The sixth cluster, "City logistics" focuses on logistics, including, but not limited to, problems occurring in cities, urban management and urban development. It is represented by keywords like public transportation, mobility as a service, system dynamics, traffic control, city logistics, developing countries, congestion. The penultimate cluster was named "Urban solutions," as the topics in it referred to urban logistics solutions to improve individual and public transportation (ridesharing, carpooling, car sharing, electric vehicles, autonomous vehicles). The last cluster, "Energy" contains keywords on the use of renewable energy sources (biofuels, renewable energy, hydrogen economy). This topic is related to the use of natural resources to reduce greenhouse gas emissions. Like the "Internet of Things" cluster, this research area can also be considered an emerging one. It should be mentioned that the mentioned clusters are directly or indirectly related to the implementation of the Strategy for sustainable and intelligent mobility.

Discussion of the results

Transportation is a major contributor to local, regional and global air, soil and water pollution. It is the source of 24% of global CO_2 emissions (European Commission, 2020). The origins of the concept of sustainable mobility date back to the late 20th century. Despite the advances in civilisation and urbanisation made during this time, transport still does not contribute sufficiently to the achievement of international greenhouse gas reduction targets (Holden et al., 2020), as well as the goals of the Sustainable and Smart Mobility Strategy, which is closely linked to the European Green Deal (Kunytska et al., 2023).

The increasing number of vehicles in cities is seen as a key driver of climate change and negatively affecting urban sustainability (Vajjarapu et al.,

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2023; Toh et al., 2020; Henke et al., 2020; Evtiukov et al., 2020; Zhao et al., 2020). Innovative technologies are of great importance to mitigate environmental problems (Awan et al., 2022). Mobility as a service, traffic flow optimisation and autonomous vehicles are some of the services and applications that are also important topics in the context of sustainable urban mobility development (Paiva et al., 2021).

Every year, 1.35 million people worldwide are killed and 60 million are seriously injured as a result of vehicle collisions. An object of interest for researchers in this context is to determine how vehicle telematics can contribute to safer, cleaner and more sustainable urban transport (Ghaffarpasand et al., 2022). Intelligent transport uses the latest communication technologies for efficient movement, location monitoring, interaction between vehicles and other traffic elements and overall improvement of traffic safety resulting in reduced accidents (Evtiukov et al., 2020). Solving congestion and traffic safety problems using information technology and UAVs (Unmanned Aerial Vehicle) results in the rapid collection of information, including from hard-to-reach zones (Evtiukov et al., 2020; Guzman et al., 2020). Unmanned aerial vehicles and drone technology has great potential to support solutions for intelligent transport (Syed et al., 2021).

With the development of Internet of Things (IoT) devices, datasets are available that can be used to provide smart, sustainable transport solutions in cities (Majumdar et al., 2021). The dominant role of sensors and the Internet provides solutions to a wide range of real-world problems in smart transport, among others (Krishnamurthi et al., 2020; Porru et al., 2020). With the increasing industrialisation in IoT, a large amount of sensor data is provided from various device sensors in Industrial IoT. The object of research in this area is to design and develop IoT architecture with blockchain and artificial intelligence (AI) to support efficient big data analytics (Singh et al., 2020; Abbas et al., 2021). Blockchain technologies can be integrated into various smart city domains, including smart transportation (Makani et al., 2022).

The Internet of Things has developed a new theme in the field of vehicle networking, known as the Internet of Vehicles (IoV) (Qureshi et al., 2021; Chen et al., 2020). The Internet of Vehicles is of interest to the automotive industry and academia. There are rapid advances in vehicle technologies, in terms of many components such as on-board units (OBUs) and sensors. Sensors generate large amounts of data that can be used to inform and facilitate decision-making (e.g. traffic navigation and obstacles) (Zrar et al., 2020).

In order to reduce traffic congestion and improve the efficiency of public transport, many intelligent transport systems (ITS) should be developed (Lee & Chiu, 2020). The development of solar car parks using an intelligent management system is also an important topic. This includes optimal solu-

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tions for Internet of Things (IoT-Based) parking spaces and locating electric vehicle charging stations (Bokhari, 2022).

There is a growing demand worldwide for smart mobility solutions to reduce the negative externalities of private car travel. Mobility-as-a-Service (MaaS) is an integrated system that, through a web-based interface, allows trips to be planned, booked and paid for using multiple mobility service providers. MaaS also enables the integration of new service options with traditional modes of transport (Butler et al., 2021; Polydoropoulou et al., 2020; Alyavina et al., 2020).

Sustainable mobility requires not only environmentally friendly transport systems, but also a fundamental change in human travel behaviour (Liu et al., 2022; Liu et al., 2023). One way to bring about change is to design technologies that incorporate sustainability goals (Sadeghian et al., 2022). More and more cities are innovating with shared mobility systems (Benedict, 2022). The literature contains articles on different aspects of shared mobility: bike-sharing, e-scooter sharing (Laa & Leth, 2020; Huang et al., 2022), carpooling, car-sharing, ride hailing (Mouratidis, 2022; Luna et al., 2020; Guyader et al., 2021; Li et al., 2022), e-cargo bikes (Carracedo & Mostofi, 2022), peer-to-peer carsharing (Aden et al., 2022), and methods for popularising public transportation like Park & Ride, Bike & Ride (Curtale et al., 2021). In recent years, such systems have been established in many cities around the world to encourage their inhabitants to use them as part of increasing sustainable mobility or to complement journeys made by other modes of transport (Macioszek et al., 2020).

The increased use of electric vehicles (EVs) is considered a positive development. Electric vehicles effectively and efficiently reduce the negative impact of transport on the environment and improve quality of life (Zagorskas & Burinskiene, 2020). Also, the transition of the transport industry from internal combustion engines to electric vehicles is considered a solution to these problems and a progression towards more sustainable transport (Bokhari, 2022). The use of electric vehicles has been positively received by the market, consumers and governments, making them increasingly popular in European societies (Zagorskas & Burinskiene, 2020). The literature also contains articles on the design of energy-efficient powertrains involving optimisation of components, systems and controls (Ehsani et al., 2021; Neidhardt et al., 2022).

A new class of vehicle has also emerged – smart electric vehicles. These can reduce carbon emissions by up to 43% compared to diesel vehicles. However, a supporting architecture is needed to introduce such vehicles. Accordingly, research and industry research are working on, among other things, the implementation of the Digital Twin in various aspects of smart vehicles (Bhatti et al., 2021).

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Encouraging users to buy and use electric vehicles to help improve the environment also hold a key place in the research (Omahne et al., 2021). Electric car sharing is also gaining popularity as a new area of research to address environmental challenges (Aden et al., 2022). Research on the social acceptance of electric cars will also be one important area of research (Omahne et al., 2021).

Implemented autonomous driving technologies offer new opportunities for smart and sustainable urban mobility initiatives. The literature indicates that shared autonomous vehicles (SAVs) are a key component of on-demand mobility services (Golbabaei et al., 2021). However, there is great uncertainty about how autonomous vehicles may shape urban mobility (Acheampong et al., 2021). They may threaten people's quality of life and safety, which is why researchers are looking into attack and defence issues for autonomous vehicles (Kim et al., 2021).

The electrification of urban transport and the use of renewable energy sources (RES) in transport systems are the leading issues in sustainable transport. The literature points to the environmental benefits of electric vehicles (EVs) when including RES in the production of the electricity needed to charge EV batteries (Bartolucci et al., 2023). Research is also being conducted into which energy mix options will yield the greatest environmental benefits, as well as which technologies and fuel types have the greatest environmental impact (Petrauskienė et al., 2020).

Researchers emphasise the need to shift from conventional fuel-based transport to low-carbon alternative fuels (Logan et al., 2023). Alternative fuels produced from biomass or CO_2 and hydrogen can help reduce greenhouse gas (GHG) emissions by replacing fossil petrol or diesel in internal combustion engines (Linzenich et al., 2022; Pamucar et al., 2021). The literature indicates that biofuels will contribute to the European Union's goals (Gracia et al., 2020). Biofuels will make a significant contribution to EU targets, with a gradual transition to advanced feedstocks (Chiaramonti et al., 2021; Chiaramonti & Maniatis, 2020; Panoutsou et al., 2021). The hydrogen economy represents the next step in the technological evolution toward an emission-free and sustainable energy system (Trattner et al., 2022).

Although the impact of transport on physical health is relatively well known, the relationship between transport and subjective well-being (SWB) is a focus of research interest (Singleton, 2019). Walking and cycling trips are found to be rated more positively than car trips (Gatersleben & Uzzell, 2007; Giannico et al., 2022). These results have implications for sustainable transport policy initiatives aimed at convincing people to abandon the car (Gatersleben & Uzzell, 2007; Oviedo et al., 2022). It is also emphasised that cycling is a climate-friendly and cost-effective mode of transport that induces a positive impact on public health (Scorza & Fortunato, 2021).

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Conclusions

The study mostly focused on the identification of current and future directions for research relating to the issues of sustainable and intelligent mobility. The Strategy for Sustainable and Smart Mobility – European Transport on the Road to the Future was adopted by the European Commission in 2020. It requires the introduction of many measures, including research and the application of modern technological solutions by society.

Achieving the ambitious goal of transitioning to sustainable and intelligent mobility will depend on the level of achievement of the sub-goals, which have been set for 2030, 2035 and 2050. By 2030, at least 30 million zero-emission vehicles are to be on Europe's roads, 100 European cities are to be climate-neutral, high-speed rail traffic is to double, and public transportation should be carbon-neutral. By 2035, zero-emission ships should be prepared for market introduction, and by 2050 the main goal is to switch to zero-emission vehicles such as cars, vans, buses.

An emerging area of research is energy, including the application of the hydrogen economy, which is becoming a focus of research due to the benefits of using this element in transportation. Research in this area is particularly focused toward a low-carbon and sustainable energy system.

Another research area related to the Strategy for Sustainable and Smart Mobility is digital transformation i.e. the Internet of Things, which can improve the level of integration. IoT has implications for the transportation industry in the form of forward-looking and modern services, where information management is a key variable. A challenge from both a scientific and practical point of view is research related to the use of innovative technologies among people and their confidence and willingness to change.

The research made it possible to reach scientific and practical conclusions and identify horizontal research directions, including energy and digital transformation, i.e. the Internet of Things. From a practical point of view, the analysis and research carried out in connection with sustainable and smart mobility (including that presented in this article) provide insights into important problems that require broader consideration and development of solutions in this area.

The research results obtained have identified key and emerging areas where further research and in-depth analysis should be conducted. These are essential, if the goals of the Strategy for Sustainable and Smart Mobility, by individual years, are to be achieved. This will only be possible by combining knowledge from research with its practical application.

After a period of planning and implementation of the Sustainable and Smart Mobility Strategy, and the subsequent implementation of specific

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measures, it will be necessary to measure the effectiveness and efficiency of the actions taken.

It will continue to be important to research the development of new forms and methods of public participation and the involvement of various stakeholder groups for common and important goals to gain acceptance for the implemented solutions.

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The contribution of the authors

Conceptualisation, D.S. and K.P.; literature review, D.S., K.P. and H.D.; methodology, D.S. and K.P.; formal analysis, K.P.; data collection, K.P. and A.R.; writing, D.S., K.P., H.D. and A.R.; conclusions and discussion, D.S., K.P., H.D. and A.R.

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