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# Selected Aspects of Sustainable Mobility Reveals Implementable Approaches and Conceivable Actions

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**Abstract:** The transportation sector plays a prominent role in driving the economy of any given nation. However, with the recent tensions arising in and around the transportation sector, sustainable mobility concepts have evolved. However, it is quite unclear whether sustainable mobility is feasible and exhibits economic returns, environmental benefits, and societal advantages. Hence, taking into account the environmental, economic, and social impact, and technical possibilities, this study intends to analyse sustainable mobility in relation to economic returns, environmental benefits and societal advantages using bibliometric analysis. For this study, we considered two decades of research, from 2001 to 2021. An in-depth search was performed on articles generated in the last two decades to assess the state of the literature on sustainable mobility. The most reverent, frequently referenced papers and influential journals in the field of sustainable mobility were identified. The acquired findings highlight the most prominent publications, journals, and authors who have made significant contributions to sustainable mobility studies, as well as the sub-areas or themes linked to sustainable mobility. Overall, the analysis discovered current paradigms, significant research topics, and a relationship between the domains of sustainable mobility studies. Meanwhile, this study also demonstrates advancements in the primary themes and sub-areas during the previous 20 years and alterations in future research fields. In addition, this study identified the promotion of rapid-reliable-safe-convenient (RRSC) transportation services, reduction in urban car traffic, and support to low transportation demand as the critical steps that require immediate attention in order to build a sustainable mobility future. We also observed that hydrogen would be a promising fuel and potential technology for the future mobility sector in the post-COVID era.

**Keywords:** sustainable mobility; sustainable fuel vehicles; $CO_2$ emission from vehicles; transportation and climate change; alternative fuel vehicles; car sharing; shared mobility; public transport



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## 1. Introduction

Environmental degradation and global warming are being experienced worldwide due to the extensive use of fossil fuels. Several nations, as well as the European Union (EU), have agreed to lower their greenhouse gas (GHG) footprints under the Kyoto Protocol, which has set a target of decreasing GHGs by at least 18% below 1990 levels by 2020 in its second commitment period [1]. Despite such commitments, January 2020 was the warmest January on record throughout the world [2]. This statistic represents the global warming trend that is directly connected to anthropogenic GHG emissions. Climate change caused by the emission of GHGs is the most significant environmental problem in contemporary society [3]. GHGs are not actually pollutants, because $CO_2$ is a natural component of the atmospheric air. However, the high concentration of $CO_2$ emitted as a result of anthropogenic activity contributes to global warming and eventually leads to climate change. To stabilise the climate, it is increasingly necessary to significantly reduce the emissions by understanding their origins and exploring the mitigation steps [4]. $CO_2$ is the greatest GHG contributor, accounting for 76% of total GHG emissions. Methane, Nitrous Oxide and Fluorinated gases together contribute the remaining 24% [5]. The worldwide concentration of $CO_2$ is increasing exponentially, as shown in Figure 1.

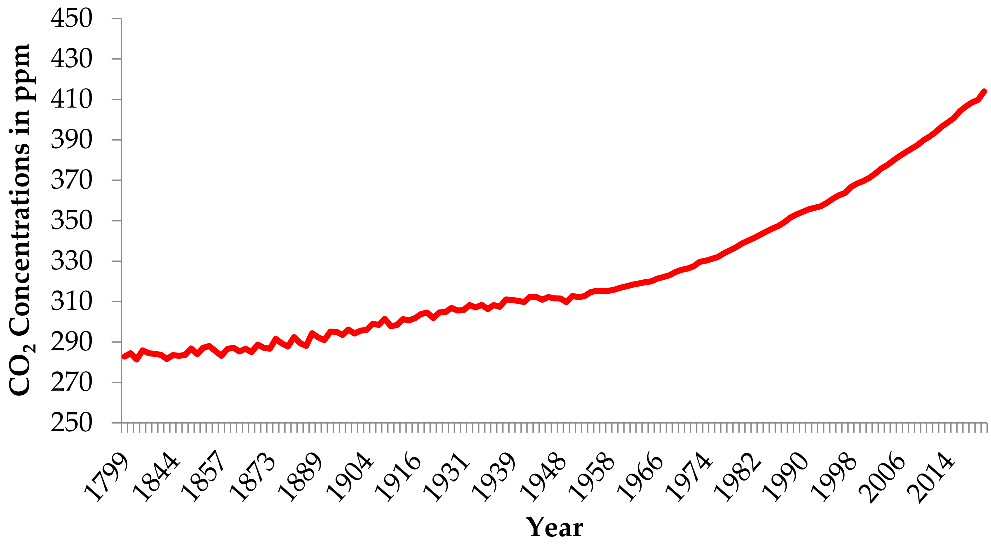


**Figure 1.** The concentration of $CO_2$ in the atmosphere in ppm. Data collected from Refs. [6,7].

Detailed investigation of Figure 1 shows that the stiffness of the graph started increasing drastically since 1900. A more detailed investigation shows that in the last 20 years, the concentration of $CO_2$ in the atmosphere increased by 44 ppm. See Figure 2.

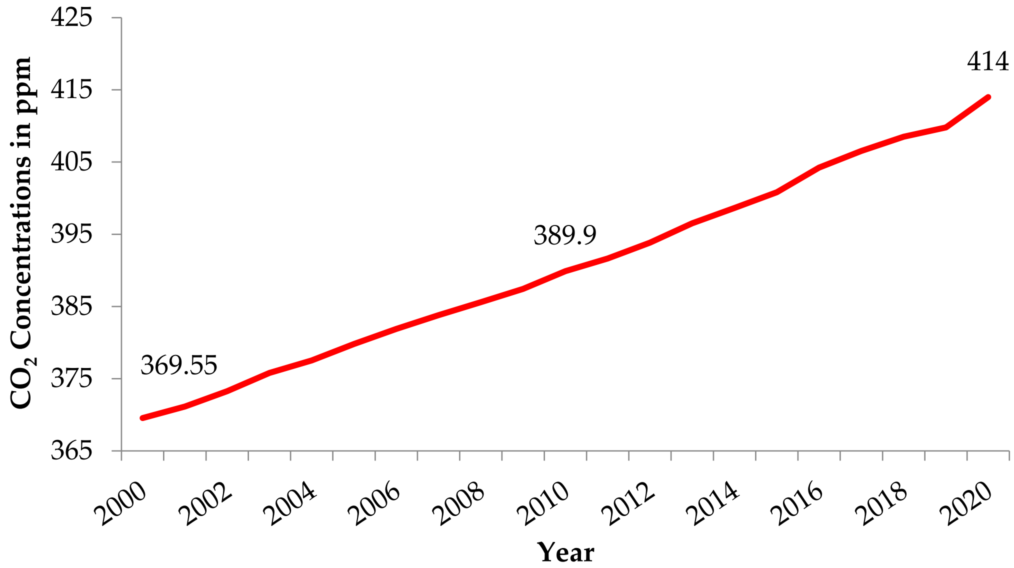


**Figure 2.** The concentration of $CO_2$ in the atmosphere in ppm for the period of 2000–2020. Data collected from Refs. [6,7].

Earlier, the same increment took 30 years, i.e., 1970 to 2000, as depicted in Figure 3. Prior to that, an increase in the same concentration of $CO_2$, i.e., 44 ppm, took 127 years (1843–1970), as presented in Figure 4. This continuous increase in the concentration of $CO_2$ is caused by anthropogenic activities, indicating that the appropriate measures were neglected, especially during industrial revolutions.

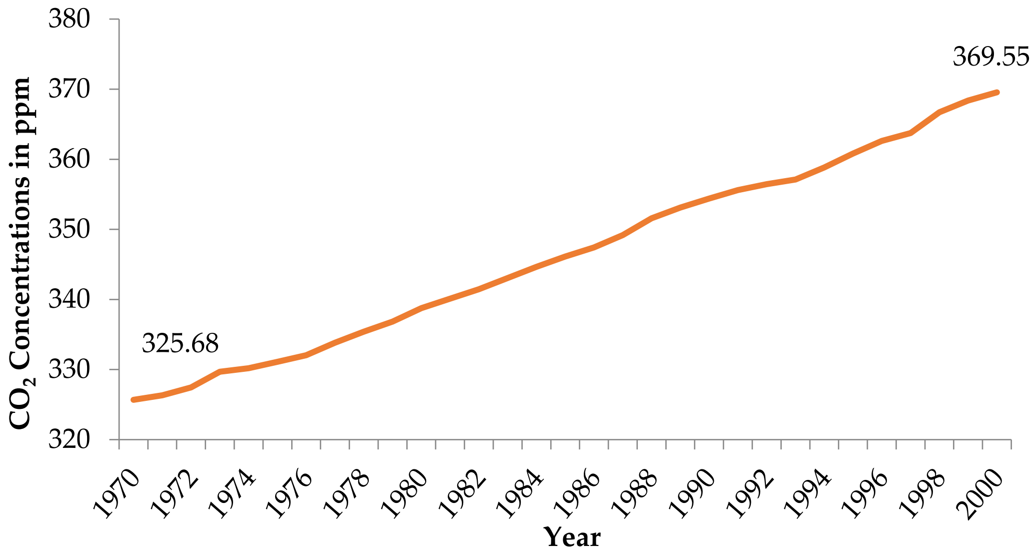


**Figure 3.** The concentration of $CO_2$ in the atmosphere in ppm for the period of 1970–2000. Data collected from Refs. [6,7].

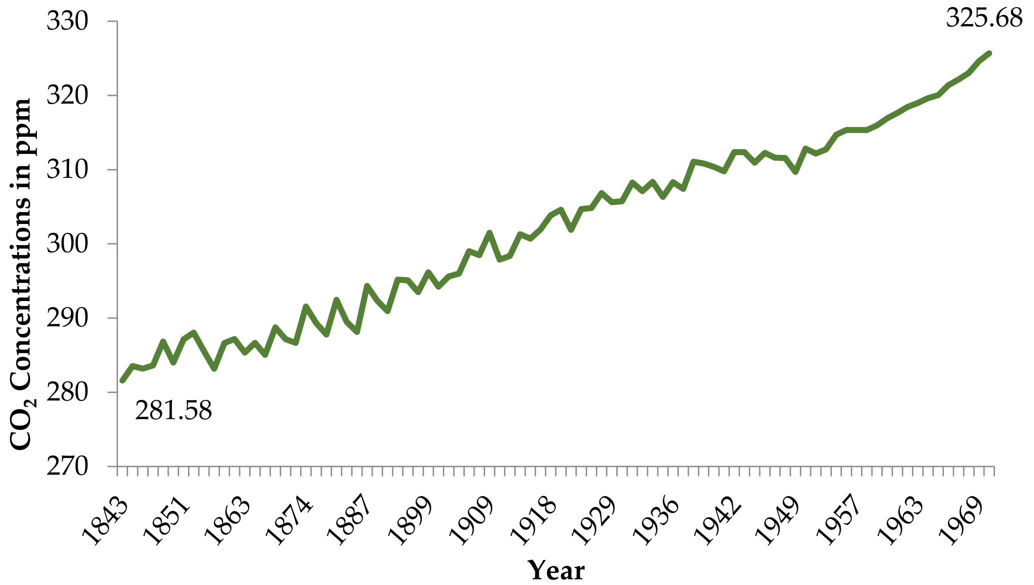


**Figure 4.** The concentration of $CO_2$ in the atmosphere in ppm for the period of 1843–1970. Data collected from Refs. [6,7].

Currently, the concentration of atmospheric $CO_2$ is more than 414 ppm, the highest ever in the last 800,000 years. This is correlated to the global temperature. The world has pledged to keep global warming well below 2 °C (3.6 °F), and the target is achievable through a low carbon budget [6]. Researchers claim that the human community may only release 565 Gt of $CO_2$ more and try to reach the 2 °C target—a limit that would be depleted in 15 years if emissions continue at the current trend of 36.6 Gt of $CO_2$ each year [4]. It is estimated that around 7 million people die worldwide every year due to air pollution-borne diseases [8].

Transportation is considered the second biggest contributor towards pollution in terms of greenhouse gas emissions, resulting in a hazardous effect on human health. Sector-wise $CO_2$ emissions in March 2021 are presented in Figure 5.

The transportation sector contributes 23% of total $CO_2$ emissions. As per the assessment, the transportation sector is expected to remain dependent on petroleum-based products for 90% of its fleet, while only 10% will operate on renewable energy sources. It is also expected that carbon emissions from the transportation sector may remain 33% higher than 1990 levels by 2050 [9].

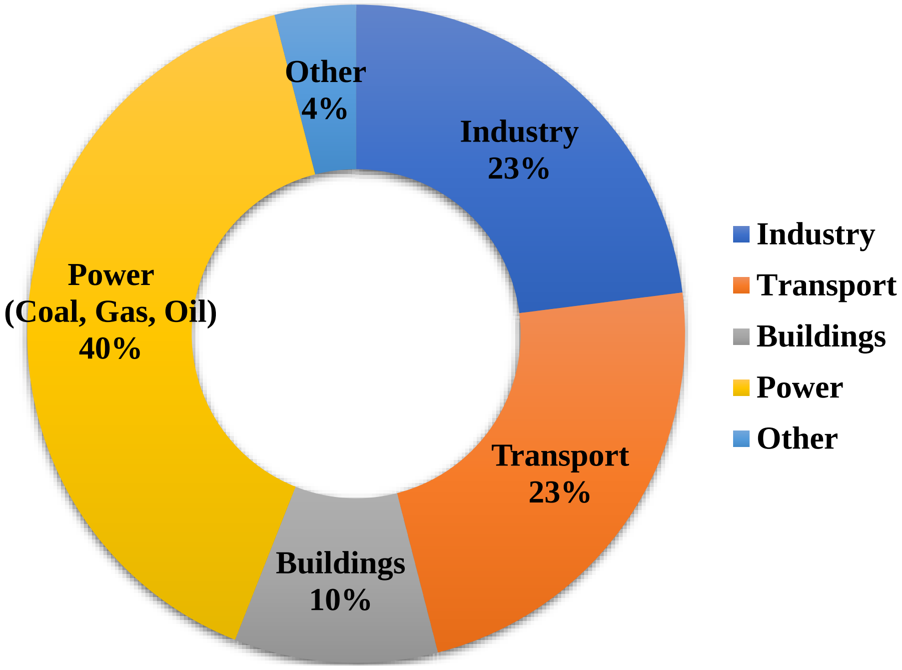


**Figure 5.** Sector-wise $CO_2$ emission. Data collected from Ref. [10].

Due to forced confinement, there is a brief drop in daily worldwide $CO_2$ emissions during COVID-19. Daily worldwide $CO_2$ emissions have dropped by 17% at the beginning of April 2020 with respect to the mean levels of 2019, and half of this reduction is from surface transportation [11]. However, the scenario will be different in the post-COVID 19 situation; thus, adopting the sustainable mobility approach is essential. While GHGs can come from various sources, those released by automobiles can be decreased by using alternative fuel vehicles (AFVs) or green automobiles. Advanced alternative fuel technologies have the potential to drastically cut fuel consumption in half, while subsequently lowering $CO_2$ emissions and their related environmental implications. While fuel-efficient technologies increase vehicle environmental performance, they cannot help reduce overall emissions. This is due to the reality that technology cannot modify consumption habits on its own. As a result, it is critical in developing a strategy that encourages consumers to choose energy-efficient vehicles over conventional ones and ensures that the use of AFVs complies with environmental pollution-reduction measures such as carpooling and using low $CO_2$-emitting vehicles, public transportation, or bicycles to save fuel [12–14].

Hydrogen is an emerging and potential candidate as a fuel source for cars [15–17]. Hydrogen cars have been determined to have a threefold lower impact on global warming than other alternative technologies [18–20]. The COVID-19 crisis is a game-changer in transitioning from the carbon age to the new hydrogen age [21].

The originality of this study refers to presenting an up-to-date and critical literature analysis on the effects and prospects of sustainable mobility. The present review research focuses on the socio-economic-environmental aspects of sustainable mobility as well as its approaches and technical aspects, by reviewing 207 relevant sources from scholarly journals and media reports. This study aims to assess the possibilities and approaches of sustainable mobility and discuss its implications in socio-economic, environmental and technological terms. To that objective, a variety of hypotheses are suggested on the components that may impact customers' readiness to adopt the sustainable mobility option. The paper provides an insight to help the policy makers and industries prioritise sustainable mobility as the potential future.

This paper is organized as follows; Section 2 deals with the methodology used to execute the critical review. Section 3 describes the broad view of sustainable mobility. Section 4 describes the environmental aspects of sustainable mobility. Section 5 discusses the socio-economic aspects of sustainable mobility. Section 6 describes the technical aspects of sustainable mobility in terms of sustainable fuel vehicles. Section 7 represents the different approaches to sustainable mobility. Section 8 concludes the complete analysis of the literature review.

## 2. Methodology

A comprehensive approach was followed to analyse and collect the most reputable and relevant publications for the study. This is due to the fact that a competent literature evaluation lays the groundwork for knowledge building. Consequently, thorough review research on content delivery was conducted. As seen in Figure 6, the procedure comprises five key searches on sustainable mobility, its environmental impact, social impact, economic impact, sustainable mobility approaches and technical aspects.

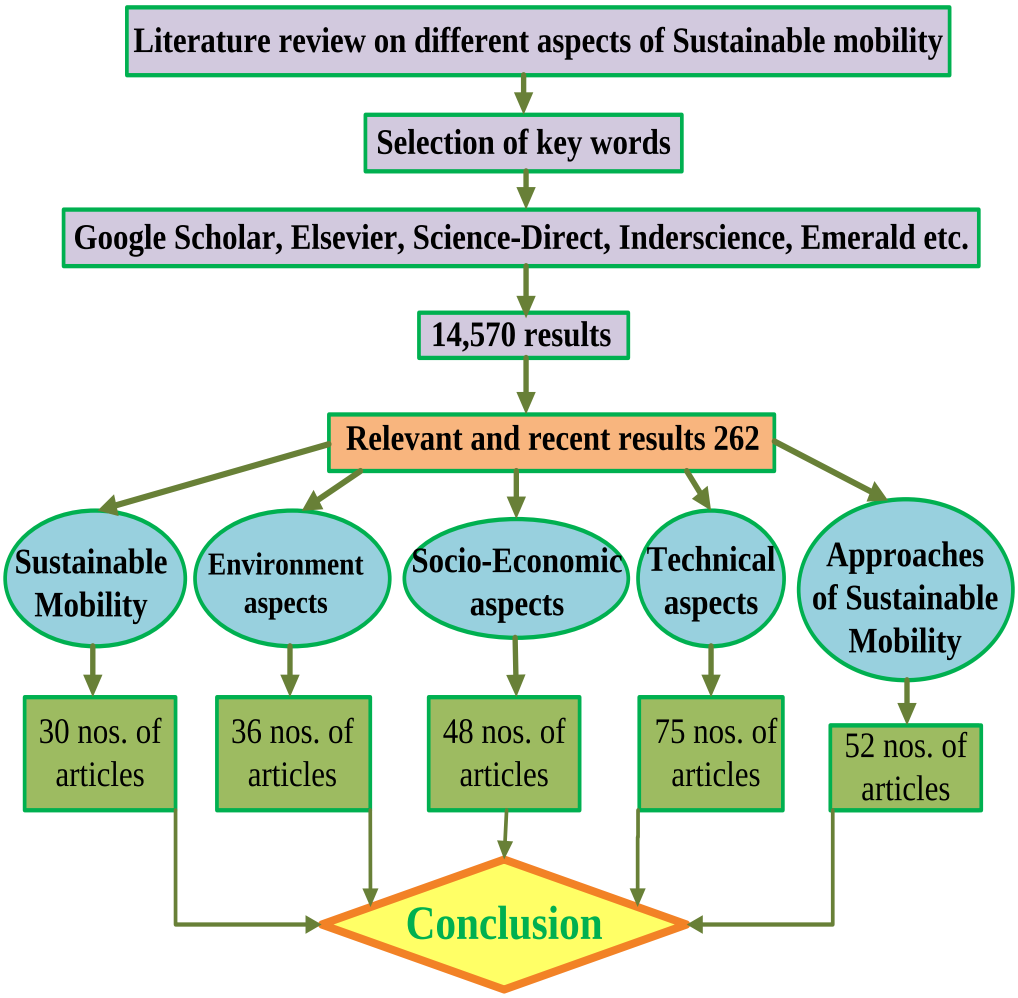


**Figure 6.** Flowchart for systematic research methodology.

The first step is a material acquisition, which entails getting research articles, abstracts, and unpublished material from Google Scholar, Elsevier, Science-Direct, IEEE, Springer, Taylor Francis, Wiley, Inderscience, and Emerald. Keywords such as 'sustainable mobility', 'environmental impact of sustainable mobility', 'societal impact of sustainable mobility', 'economic impact of sustainable mobility', 'sustainable mobility approaches' and 'technical aspects of sustainable mobility' were used to search the databases indicated above for appropriate materials. The search yielded a total of 14,570 results. Between 2001 and 2021, 14,464 resources were published, including 11,431 academic journals, 1694 conference materials, 502 magazines, 364 trade publications, and 183 books. The methodology of the paper is depicted in Figure 6.

A second step was created to find the most relevant information from popular publications. By the end of the second iteration round, the number of materials chosen had been whittled down to 329. Only articles and research papers that had been peer-reviewed were considered. Abstracts and unpublished theses were not considered. Of the 329 items, 262 were considered relevant. To reduce the number, the year of publication was utilised. The most recent publications were chosen for the study since they had the most up-to-date information. We have referred to the publications from the last 20 years, but focused mainly on the relevant articles published in the last 10 years, with the most attention given to the articles published in the last five years. Other selection factors were the substance, technique, and language utilised to choose the top papers for the study. Systematic reviews and meta-analyses were favoured since they ensured a comprehensive overview of the literature, while also offering extra information on the research issue. The contents were reviewed and classified in the third phase based on the kind of paper, year of publication and relevancy towards different sections of the current manuscript.

## 3. Sustainable Mobility

Sustainable mobility is a universal, effective, clean, and environmentally friendly transportation solution. The current global mobility structure is obviously unsustainable. While transportation does not have its own sustainable development goals (SDGs), it is crucial for achieving other SDGs to achieve targeted growth and development. Countries with the highest SDG scores have more resilient and sustainable mobility measures in place. In contrast, those with the lowest scores are condemned for insufficient transportation infrastructure [22]. The targeted SDGs, either directly or indirectly addressed by sustainable mobility, are presented in Figure 7.


**Figure 7.** Targeted SDGs addressed by sustainable mobility.

Sustainable mobility is originated from the wider definition of "sustainable development", which is described as "development that meets current needs without jeopardising the ability of future generations to meet their own needs" [23]. The broad benefits of sustainable mobility [24,25] are depicted in the infographic (Figure 8), which include energy security, economic growth, environmental sustainability, and improved quality of life.

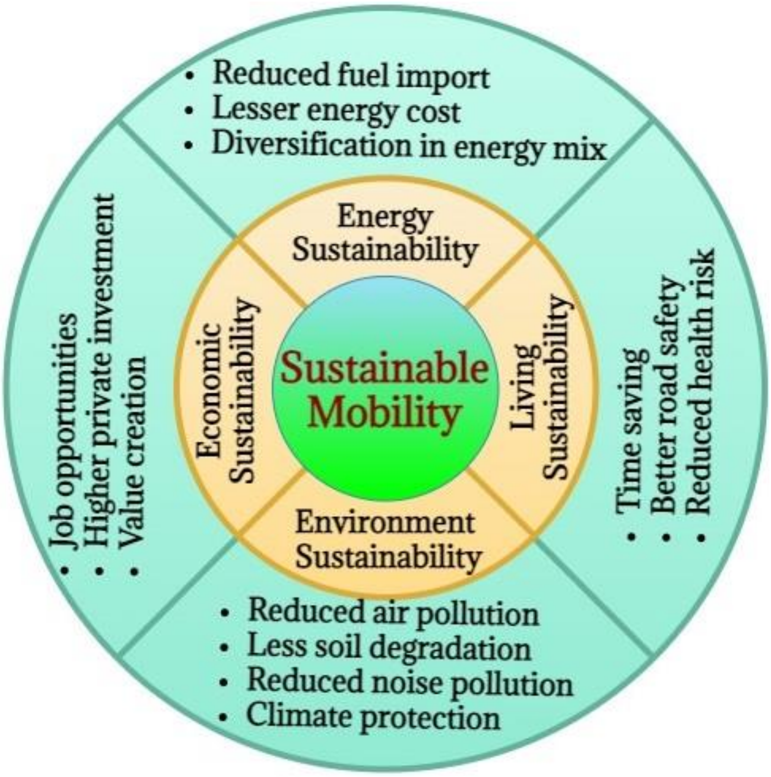


**Figure 8.** Benefits of sustainable mobility.

Several studies on sustainable mobility can be found in the literature; restricting ourselves to the most recent ones, we refer to [26–40]. Klecha and Gianni [26] investigated the role of technology in fostering a change in behaviour towards sustainable transportation. Some investigations on sustainable mobility are tabulated in Table 1.

**Table 1.** Investigations on sustainable mobility.

| Reference | Year | Research Work |
|---|---|---|
| Gonzales Aregall et al. [27] | 2018 | Green port techniques for mitigating negative externalities in the countryside were studied. |
| Ranieri et al. [28] | 2018 | Reviewed creative last-mile logistics solutions. |
| Taiebat et al. [29] | 2018 | Reviewed the effects of automated vehicles on long-term mobility. |
| Ferrero et al. [30] and Santos G [31] | 2018 | Reviewed shared mobility. |
| Biresselioglu et al. [32] | 2018 | Investigated electric mobility. |
| Letnik et al. [33] | 2018 | Discussed the policies and measures that need to be adopted for sustainable, energy-efficient urban transportation. |
| Pojani and Stead [34] | 2018 | Policy design for sustainable urban transport. |
| Martinez-Dìaz et al. [35] | 2019 | Future of autonomous driving. |
| Lopez et al. [36] | 2019 | Technological advancements in bus transportation and their effect on environmental and social sustainability. |
| Tirachini, A [37] | 2019 | Travel behaviour and sustainable mobility. |
| Holden et al. [38] | 2019 | Aspects of sustainable mobility at 2030. |
| Ren et al. [39] | 2020 | Review of Green and Sustainable Logistics. |
| Kumar, R.R. and Alok K [40] | 2020 | Prospects for sustainability. |

Scientists, transportation specialists, local government officials, and researchers from various organisations have developed a few techniques for evaluating the efficiency and cost-effectiveness of sustainable urban mobility initiatives, which are used to determine the most effective measures and their economic advantages [41,42]. In Portugal, the primary focus for building sustainable urban transportation strategies has changed to achieving social and economic advantages [43].

The diverse variety of particular goals of urban transportation should address the environmental, social and economic components of sustainability. The components mentioned above are closely interconnected to one another, and the most often discussed one is environmental aspects. Environmental aspects are achieved by minimising travel-trip replacement, distance (e.g., merging residential and retail functions), shifting modes (e.g., cutting private automobile usage, encouraging cycling and multimodality), and decarbonisation (e.g., zero or low-emission transportations) [44,45]. Policymakers are addressing these issues in order to meet the assumptions of better city decarbonisation [44]. One of them is the sharing economy, which entails both sustainable resource management and efficient asset management. Presently, more than 70% of Europeans live in cities, and the economy as a whole loses 1% of GDP each year due to traffic congestion; hence, urban mobility must be optimized [46]. According to Tilley and Houston [47], social and demographic changes may have a significant impact on mobility trends, particularly in urban and suburban regions. There may be a variety of reasons that drives such a tendency and the environmental views of urban dwellers, particularly young people [48]. Young adults were enthusiastic about the advent of recent mobility services, such as Uber and similar solutions, often known as Mobility-as-a-Service (MaaS) [49–52]. The increased popularity of MaaS in metropolitan cities may lead to changes in young people's mobility choices.

The following sections are focused on environmental, socio-economic and technological aspects of sustainable mobility. Some of the impacts of sustainable mobility overlap in socio-economic-environmental previews. Such impacts are discussed where they are more suitable, and discussions are limited to recent literature to cope with the recent trends.

## 4. Environmental Aspects

Environmental conservation is a major focus and concern of sustainable mobility policies; in some cases, it is described solely as mobility that reduces environmental consequences. Even if this definition is incorrect, eliminating pollutants and greenhouse gases is the primary goal of most interventions to create sustainable mobility. Korshunova et al. [53] explored sustainable mobility in the context of humanization in Belarus, Russia's urban environment. Their research took into account future generations' interests and found that "sustainable mobility" represents human freedom in spatial movement that does not impair the environment or the health of others. Papantoniou et al. [54] explored the sustainable mobility elements of university campuses. In this regard, policymakers must analyse students' mobility, particularly their travel habits, in order to identify priority measures for promoting sustainable mobility. Attard et al. [55] concentrated on the services in a university campus situated on the Island of Malta's metropolitan agglomeration. According to their findings, shared demand responsive transport (DRT) services can deliver mobility solutions that assist the adoption of green solutions for sustainable campuses.

This section is broadly divided into two subsections. Section 4.1 discusses the air pollution and global warming caused by transportation and the associated human health effects. It also discusses evident pieces of literature on the reduction in pollution from adopting sustainable transportation. In Section 4.2, the issue of noise pollution is investigated, and potential prevention and reduction approaches are discussed.

### *4.1. Air Pollution and Emission of GHG*

The most significant pollutants emitted by transportation are: $PM_{10}$ and $PM_{2.5}$ (particulate matter), $NO_2$ (nitrogen dioxide), $O_3$ (ozone), BaP (benzo [a] pyrene), $SO_2$ (sulphur dioxide), CO (carbon monoxide), and benzene [56]. The consequences for human well-being are enormous, as tabulated in Table 2.

**Table 2.** Premature deaths owing to exposure to $PM_{2.5}$, $NO_2$ and $O_3$ (2018).

| Pollutant Name | Premature Deaths in Europe | Premature Deaths in EU28 |
|---|---|---|
| $PM_{2.5}$ | 417k | 379k |
| $NO_2$ | 55k | 54k |
| $O_3$ | 20.6k | 19.4k |

$CO_2$, methane ($CH_4$) and nitrous oxide ($N_2O$) are the primary greenhouse gases released by transportation systems. In 2018, the transportation sector continued to contribute to the most $NO_X$ emissions (47% in the EU-28) [56]. Between 1990 and 2014, global $CO_2$ emissions from transportation increased by 63% [57]. Transportation-related $CO_2$ emissions have risen at a faster rate than any other sector over the last 50 years, accounting for 23% of global energy-related $CO_2$ emissions in 2014 [58]. In 2015, international and domestic aviation accounted for 10% of transportation $CO_2$ emissions, land freight (road and rail) accounted for 28%, and sea and air freight accounted for 12% [59].

Emissions are one of the most significant external factors of the transportation industry, wreaking havoc on the environment as well as the health of those exposed. The elimination of pollution is at the core of most policies supporting sustainable mobility. Because of improvements in productivity, electrification, and expanded use of bio-fuels, global transportation emissions increased by <0.5% in 2019, compared to 1.9% since 2000. Amidst this, transportation nevertheless accounts for 23% of direct $CO_2$ emissions from fuel combustion [60]. Nocera et al. [61] analysed oscillations in climate change induced by transportation pollution and analysed the economic efficiency of urban mobility interventions that reduce $CO_2$ emissions in their study. They discovered the following $CO_2$ reduction measures: reducing demand for transportation, enhancing the attractiveness of alternative transportation, making private vehicle travel less appealing, information distribution and marketing, reducing the number of municipal and private company fleet vehicles, and smart transportation. EVs minimise GHG emissions by 50–60% as associated with IC (internal combustion) engines in the EU's current electricity mix [62]. Additional pollution reductions would result from increasing the renewable energy component of the electricity mix. Sustainable mobility removes toxic emissions such as nitrogen oxide, carbon monoxide, sulphur dioxide, hydrocarbons, and particulate matter from vehicle exhaust [63]. Vehicle manufacturing companies play a key role in achieving sustainable mobility. Ford Motor Company's [64] proposal to reduce vehicle emissions is a recent example. Tesla is decreasing not only the overall volume of its emissions but also the amount of pollution produced by each of its vehicles [65]. According to studies, increased modal change from cars to collective transportation has been shown to result in a 20% reduction in $CO_2$ emissions [66,67].

Target 11.2 of the SDGs calls for the provision of reliable, efficient, open, and sustainable transportation systems. By focusing on accessibility rather than mobility, there are significant opportunities for generating two-way convergence between climate change mitigation action and wider well-being and sustainable development goals in the transportation sector [68].

### *4.2. Noise Pollution*

Different transportation sectors such as road, rail, and air transport are the major sources of noise. Road traffic is the primary cause of noise in urban areas. At least one million healthy years of life are lost every year in Western Europe due to transportation-related environmental noise [69]. Some research works relevant to noise pollution and transportation have been tabulated in Table 3.

**Table 3.** Research works relevant to noise pollution and transportation.

| Area | Authors | Reference | Research Work |
| --- | --- | --- | --- |
| Mathematical models for measurement/predictions of road traffic noise | Garg and Maji, | [70] | The authors have given a comprehensive comparison of the most common traffic noise models used in industrialised countries. Technical features such as source modelling and sound propagation techniques were used to make the comparison. |
| | Khan et al. | [71] | The authors looked at the literature on air and noise pollution from urban road traffic, as well as other factors, including the dispersion models used, the GIS-based tool used, the geographic scale of exposure assessment, research location, sample size, traffic data type, and building geometry information. They discovered that deterministic modelling is the most often utilised evaluation approach for both short-term and long-term exposure to air and noise pollution. |
| | Agarwal and Swami | [72] | Under diverse traffic flow conditions, the authors developed an empirical noise prediction model for evaluating equivalent noise levels in terms of equivalent traffic density numbers. |
| | Bravo-Moncayo et al. | [73] | Using a discrete choice survey in Quito, Ecuador, the authors calculated the impact of noise pollution caused by traffic. |
| | Sirin | [74] | Addressed the benefits and drawbacks of different mathematical models for predicting pavement noise. |
| The effects of noise on human health | Recio et al. | [75] | Investigated the long- and short-term links between road traffic noise and health. |
| | Munzel et al. | [76] | The authors published a review that focused on the mechanisms and epidemiology of noise-induced cardiovascular diseases, and it revealed new information about the mechanisms underlying noise-induced vascular damage. |
| | Sakhvidi et al. | [77] | According to their study, noise exposure, primarily from air and road traffic, is linked to an increased risk of diabetes mellitus. |
| | Jafari et al. | [78] | Their research shows that future neuroimaging studies to quantify the possible contribution of noise in predisposing cognitive impairment and preclinical signs of dementia in humans are required. |
| | Khosravipour and Khanlari | [79] | The authors examined the connection between myocardial infarction and exposure to road traffic noise. |

**Table 3.** *Cont.*

| Area | Authors | Reference | Research Work |
| --- | --- | --- | --- |
| Infrastructures as well as mitigation techniques | Jiang and Kang | [80] | The authors studied the overall performance of noise barriers in minimising the environmental impact of motorways, taking into account their impacts on reducing noise and visual intrusions of moving traffic while also potentially causing visual impact. |
| | Ohiduzzaman et al. | [81] | Investigated noise generation and amplification mechanisms, as well as various traffic noise measurement methods and their correlations, as well as pavement noise abatement, approaches used by various agencies. |
| | Thomas et al. | [82] | Based on the direction-dependent attenuation of prior recordings made with a dedicated 32-channel spherical microphone array, the authors proposed an auralization technique that allows an auditive preview of noise abatement steps for road traffic noise. |
| | Van Renterghem and Botteldooren | [83] | Investigated and carried out long-term continuous sound pressure level measurements along a busy lane. |
| | Horne et al. | [84] | Authors have compared rounded and sinusoidal milled rumble strips to reduce roadside noise emissions. |
| | Kleiziene et al. | [85] | The authors proposed a model for the acoustic performance of asphalt pavements. |
| The reduction of engine noise | Ferrari et al. | [86] | The authors suggested a closed-loop strategy for regulating the fuel-injected mass in a Common Rail diesel engine's combustion chamber. They demonstrated that the new technology would significantly reduce $CO_2$ engine emissions (3%) and combustion noise (up to 0.5 dBA). Substantial fraction reductions in NOx (3%) and soot (6%) emissions have also been discovered. |
| | Qin et al. | [87] | The authors presented noise, vibration, and harshness reduction strategies for various forms of hybrid electric vehicles (HEVs), as well as their benefits. |

The aim of transportation policy should be to reduce the population's exposure to noise that is harmful to their health and that causes other forms of trouble. Possible intervention techniques necessitate multidisciplinary expertise, as they must operate on many fronts, from infrastructure and pavement design to mitigation structure design, vehicle noise reduction, and decontamination.

## 5. Socio-Economic Aspects

The importance of transportation in terms of economic growth and human resources cannot be overstated. The way people move to work or enjoy recreation, how companies send workers to reach clients, and how businesses ship goods to distribution centres—transport shapes lives and underpins everything.

The goal of the transportation system should be to advance the excellence of life in the city and suburbs by providing a safe, dependable, integrated, multi-modal, effective, and environmentally friendly transportation system (particularly by employing low/zero-emission cars, park and ride solutions, and so on) [88]. There are various socioeconomic facets of sustainable mobility. In addition, some of them also overlap with the environmental or technical categories. Rackwitz et al. [89] investigated income from sustainable transportation systems, job opportunities, and economic growth. Offer et al. [90] studied the relationship between sustainable transportation infrastructure, job development, and economic growth. The progress and commercial research into the potential viability of hydrogen-fuelled vehicles, battery-electric, and hybrid-fuel gas cell plug-ins in the UK's road transportation network are presented in this article. Majumdar et al. [91] evaluated electric vehicle infrastructure's potential economic and environmental consequences in Kolkata public transportation. They discovered that substituting 2% of the current passenger road transportation mode reduces the amount of fuel and LPG usage each day, demonstrating the viability of constructing parallel electric vehicle infrastructure.

In this section, some socio-economic aspects are addressed in terms of accessibility, pricing, taxes, and incentives.

### *5.1. Accessibility*

Accessibility is seen as a helpful notion that may be utilised to create insights into difficulties connected to social exclusion caused by a lack of transportation alternatives. Affordability should be a part of sustainable mobility [92,93]. Several studies have emphasised the importance of transportation equity: An equal distribution of transportation services (infrastructures and transit systems) aids in attaining social justice, with significant implications for health and quality of life [94]. Martens [95] suggested a thorough investigation of equity in transportation development. Beyazit [96] suggested a study of the literature on social impartiality in transportation. Delbosc and Currie [97] suggested using Lorenz curves and the Gini coefficient to measure public transportation equity, which has since been used in many other studies [98–103]. Camporeale et al. [104] considered the importance of fairness and proposed a solution for achieving an equal allocation of transportation impacts (benefits and costs) among consumers. Camporeale et al. [105–107] proposed a methodology for planning and designing public transportation routes that address the demands of cities while promoting equitable access. Gallo [108] suggested a method for improving the price equity of transportation systems. Caggiani et al. [109] concentrated on implementing a cordon-based congestion pricing system on a multimodal network where private vehicles and public transit coexist and included a sensitivity study for a monocentric metropolitan reality by adjusting the scale of the charging area and the volume of the toll.

Attaining equity goals should be one of the transportation policy's guiding standards. Any deal in this field that uses public funds and equity must be included in transportation planning. Sustainable mobility is inherently rational, provided that the poorer social classes often writhe the most from pollution and climate change.

### *5.2. Pricing and Taxation*

Pricing may normally be applied to the use of road facilities or car parking. A toll is levied on car drivers for the use of a single piece of arrangement or for accessing a certain part of a city, and the driver is responsible for paying for parking. In terms of sustainable mobility, the policies seek to raise the relative costs of private vehicle usage in order to encourage a modal break in favour of other means of transportation, such as mass transportation, cycling, and walking. Often, road pricing has a straight environmental implication, discriminating prices based on the vehicle's environmental compatibility [110–112]. In order to achieve competitive mobility, road pricing should be closely related to the principle of external costs [113]; in fact, the best road pricing should be that which is capable of charging the car user with all of the external costs it generates [114,115]. Indeed, optimal pricing is not feasible from this perspective, and parking pricing and road pricing strategies are still regarded as second-best approaches [116].

Taxation policies on fuels or car ownership are commonly used in Western countries, distinguished from environmental effects and greenhouse gas emissions. Santos [117] calculated and compared petrol and diesel taxes for 22 European countries, taking into account the impact of fuel taxation on fuel efficiency. Steinsland et al. [118] investigated the climate, financial, and equity implications of a fuel tax, a road toll, and a commuter tax credit. According to the research by Montag [119], fuel taxes are the primary tool for reducing automotive emissions. Using data from the US airline industry, Fukui & Miyoshi [120] investigated the impact of an increase in aviation fuel tax on cuts in fuel usage and carbon emissions.

### *5.3. Incentives*

The use of various sorts of incentives in transportation systems to develop sophisticated transportation congestion management solutions has recently received a lot of attention. Rather than employing assumed or fixed-amount rewards, Xiong et al. [121] examined integrated and individualised passenger information and suggested an incentive strategy to encourage more energy-efficient travel and mobility decisions. Herradoe et al. [122] proposed the idea of "incentivized sustainable mobility" that encompasses four stakeholders: residents, municipalities, commerce, and mobility services. According to the investigations of Ricci et al. [123], incentive-based strategies might promote the adoption of sustainable transport. Their research lays the groundwork for creating sophisticated algorithms capable of tracking mobility and incentivizing people's habits concerning sustainable mobility. Some literature on the incentive approaches in transportation systems is tabulated in Table 4.

**Table 4.** Literature on the incentive approaches in transportation systems.

| Authors | Reference | Research Work |
|---|---|---|
| Semanjski et al. | [124] | The authors have explored the role of smartphones as mobility behaviour sensors, as well as the responsiveness of various attitudinal profiles to customised route recommendation incentives supplied via mobile phones. Their findings demonstrate which user profiles are most likely to accept such incentives. |
| Xie et al. | [125] | The authors have investigated different demographic segments' perceptions of incentives and timetable delays to investigate sustainable mobility. |
| Kacperski and Kutzner | [126] | The authors have discovered that financial and symbolic incentives encourage 'green' charging decisions. |
| Pianese et al. | [127] | The authors have developed a unique external incentive system based on a verifiable third party with the purpose of encouraging long-term sustainability by changing the profit margins for proof-of-work contributors without choking the transaction rate. |
| Storch et al. | [128] | According to their findings, even a minor increase in financial incentives may significantly influence specific user groups' ride-sharing acceptance. |
| Tian et al. | [129] | The authors have defined preferred users of an incentive-based traffic demand management method. They proposed incentive-based traffic demand management (IBTDM), which gives monetary incentives to commuters to change their departures geographically or temporarily in order to alleviate congestion. |
| Fisher et al. | [130] | The authors have investigated how place making and positive incentives may improve urban walkability and revolutionise citizens' perceptions of streets as public spaces. They discussed the operations of the EMPOWER project, which began in May 2015 to gather evidence on the power of positive incentives and social innovation to promote sustainable transportation. |

**Table 4.** *Cont.*

| Authors | Reference | Research Work |
| --- | --- | --- |
| Eshtiaghi et al. | [131] | The authors worked on analytic network methodology, and identified and prioritised the elements that influence the adoption of electric cars. In comparison to other criteria, their findings revealed that economic variables had the most significant influence. The most important factors in each criterion were depreciation time, production firm, fuel subsidy, availability of repair shop, automobile, and relevance to the environment. |
| Yongling and Mingming | [132] | The authors used duopoly analysis to look into the impact of incentives on the uptake of electric vehicles under subsidy programmes. They discovered that extended driving range might inhibit EV adoption and suggested that the government raise its subsidies for a longer-range EV. |

Government subsidies play a vital role in the adoption of sustainable transportation [133–136]. Zhang and Huang investigated the vehicle product-line strategy in the context of government subsidy schemes for electric/hybrid automobiles [133]. Ouyang et al. [134] examined the entire cost of owning an electric car in China in the post-subsidy period. They discovered that the elimination of the buying subsidies, as well as the proliferation of COVID-19, had a substantial impact on Chinese customers' purchasing intentions for EVs. Their findings indicate that tiny BEVs will attain parity before 2025, but medium and large BEVs will do so by 2030. They discovered that incentive programmes have a large influence and that oil prices are expected to considerably influence the time it takes for EVs to achieve parity. As a result, policymakers should implement incentive programmes to ensure a seamless transition to China's vehicle fleet electrification. Li et al. [135] investigated the influence of the Chinese government's subsidy plan for hydrogen filling stations on the market dissemination of hydrogen fuel cell cars (HFCVs). Their model suggests that the dynamic subsidy mode, which is based on an experience weighted attraction method, outperforms the static subsidy mode. They discovered that selecting an effective first subsidy scheme can improve HFCV sales by about 40%. Their findings reveal that early government intervention in establishing first HRSs can boost market diffusion efficiency by more than 76.7%.

## 6. Technical Aspects

This section focuses on the key subjects linked to technical solutions created to improve sustainable transportation. The following section focuses on the primary sustainable fuel vehicles (SFVs) currently employed in the automobile industry. Enormous effort has been put into developing new fuels and engines that can cut air pollution. In recent years, the automobile industry has boosted the manufacture of alternative fuel vehicles (AFVs) fuelled by electricity, natural gas, and hydrogen, because they create less of a carbon footprint and have the potential to boost vehicle fuel efficiency. All AFVs are not sustainable fuel vehicles, but all SFVs are AFVs in the present era. In this section, AFVs are discussed, which are SFVs. Alternative fuelling stations in the U.S.A by 2019 are presented in Figure 9.

Technology advancements and government assistance programmes have already raised the demand for alternative fuel vehicles (AFVs) [137]. According to Kamila and Masaru, a government subsidy for AFVs might enhance the public image and may support an increase in AFV market penetration rates [138]. The following major forms of sustainable fuel vehicles, as depicted in Figure 10, are currently the most promising and employed in road transportation [139].

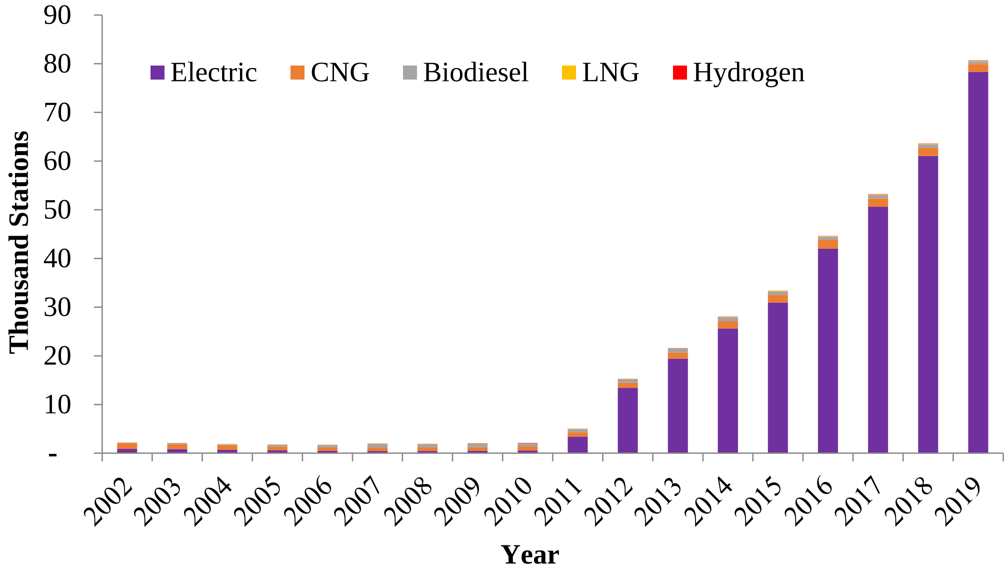


**Figure 9.** Alternative fuelling stations in the USA. Data collected from Ref. [136].

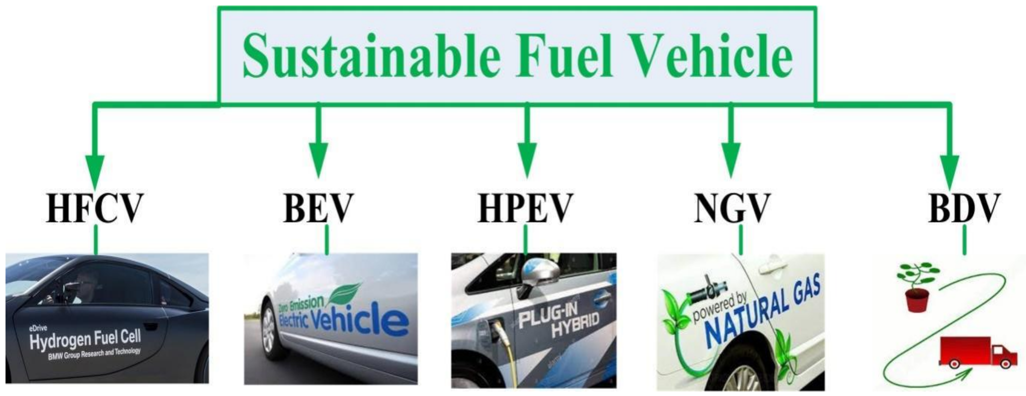


**Figure 10.** Different types of commercialized SFV.

The strength and shortcomings of different types of commercialized SFV are presented in Table 5.

Grid load management control may become increasingly important as the number of EVs on the road rises, resulting in higher energy consumption [206]. This problem has been addressed using the vehicle-to-grid (V2G) technology [207], which is based on returning battery collected energy to be dispersed in the grid in order to minimise total energy requirements from the primary source. However, in order to offer effective energy service to the grid, management techniques are necessary to improve the energy distribution process during the day [208]. Finally, a developing charging method on electrified highways is the inductive charging system, which permits battery charging while driving [209]. In 2018, Sweden's first electrified road, dubbed eRoadArlanda, opened to recharge electric cars by transmitting electricity from a road-rail [210]. Hydrogen is a promising technology for the future mobility sector, and the post-COVID 19 era is a transition to the hydrogen era [21].

**Table 5.** Comparison of the strengths and shortcomings of each SFV model.

| | |
|---|---|
| | **Hydrogen Fuel Cell Vehicle (HFCV) [140–147]** |
| → | The First Hydrogen Fuel Cell Vehicle Was Created in 1966 |
| ↑ | • Emission is water only.<br>• Rapid refuelling<br>• Quicker battery charging.<br>• Reduced reliance on oil.<br>• Lower greenhouse gas emissions<br>• Reduced noise pollution<br>• High reliability<br>• Installation and operation flexibility |
| ↓ | • Vehicle cost<br>• Hydrogen obtained from renewable energy sources is expensive<br>• Costly transportation of hydrogen/Hydrogen infrastructure<br>• On-board hydrogen is held at either high pressures or extremely low temperatures.<br>• Scarcity of refuelling stations |
| | **Plug-in hybrid Vehicle (PHEV) [148–154]** |
| → | 1st time invented: 2008 |
| ↑ | • Household charging arrangement is adequate<br>• ICE can outspread the range for longer journeys<br>• The electric model has a lower cost/km<br>• No GHG emissions during operation. |
| ↓ | • The full-electric range can only solve short commutes<br>• Batteries, in addition to an ICE, raise the cost of the vehicle.<br>• Daytime charging may overload the power infrastructure.<br>• Installation of the plug-in facility is needed.<br>• Driving behaviours have an impact on the advantages. |
| | **Battery Electric Vehicle (BEV) [155–168]** |
| → | 1st time invented: 1884 |
| ↑ | • Noise-free operation<br>• No GHG emissions while operation<br>• Electric infrastructure is extensive<br>• Electricity is partly derived from renewable sources depending on the energy mix of the country |
| ↓ | • Charging times<br>• Limited range<br>• Scarcity of charging infrastructure<br>• Multifaceted load administration for the electricity grid<br>• Excess grid burden |

**Table 5.** *Cont.*

| | |
|---|---|
| **Natural Gas Vehicle (NGV) [169–175]** | |
| | 1st time invented: 1930 |
| | • Less expensive than gasoline<br>• Cleaner than gasoline at equivalent power levels |
| | • Due to the presence of gas tanks, trunk space has been reduced.<br>• Limited range<br>• Limited refuelling stations. |
| **Biodiesel Vehicle (BDV) [176–205]** | |
| | Rudolph Diesel himself developed biodiesel in 1890 |
| | • Produced using renewable resources.<br>• Synthesized on purpose.<br>• With little or, no modification can be utilised in current diesel engines.<br>• Improves engine lubrication and enhances engine life.<br>• Reduction in emissions of greenhouse gases (e.g., B20 reduces $CO_2$ by 15%).<br>• Biofuel refineries discharge less hazardous substances.<br>• Risk-free handling, storing, and transportation.<br>• Positive economic consequences.<br>• Less reliance on imported oil. |
| | • Quality variation<br>• Unsuitable for use at low temperatures<br>• Some engines' rubber houses may be damaged by biodiesel<br>• Food Shortage<br>• More expensive than petroleum<br>• Increased fertilizer consumption.<br>• Engine clogging<br>• Water shortage<br>• Monoculture<br>• Nitrogen Oxide emissions |

## 7. Approaches

Different approaches to implementing sustainable mobility are discussed in this section. New solutions for people's mobility have mostly been observed in cities. Among these options are free-floating and station-based car-sharing systems [211], an integrated passenger transportation system and shipping tariff [212], bus rapid transit, fare management integration, payment system integration, smart cards systems, bike-sharing systems [213], bus priority (dedicated lanes), cycling, the expansion of pedestrian infrastructure [214,215], free-fare public transportation [216], and many more alternatives. Different approaches to sustainable mobility proposed by researchers are tabulated in Table 6.

Different sustainable mobility approaches, such as shared mobility services, the promotion of cycling, walking, public transport, green transports and eco-driving are presented in Figure 11.

**Table 6.** Different approaches to sustainable mobility.

| Reference | Proposed Approach | Location |
|---|---|---|
| [211] | • Car-sharing systems that are free-floating and station-based | Romania |
| [212] | • Car-sharing and an integrated passenger transit system | Switzerland |
| [213] | • Rapid bus transit<br>• Integration of fare management and payment systems<br>• Smart card systems<br>• Bike-sharing schemes | Zagreb and its Surrounding Area |
| [214,215] | • Dedicated lanes for different mobility approaches<br>• Cycling<br>• Expansion of pedestrian infrastructure | Paris, Mediterranean Partner Countries (MPCs) |
| [216] | • Free-fare public transportation | Greek cities |


**Figure 11.** Different sustainable mobility approaches.

### 7.1. *Shared Mobility Services, Public Transportation and Eco-Driving*

Over the last few decades, the idea of shared mobility services has evolved in terms of how to incorporate them into urban transportation networks and make them more efficient from a social, economic, and environmental standpoint [217,218]. Shared mobility will result in substantial changes in a short period and at a low cost of technology [219]. Furthermore, shared mobility services are transforming the conventional transportation business. They have the disruptive possibilities to craft a transition toward social, environmental, and economic efficiency by applying technologies [217]. New shared mobility networks, on the other hand, may have both advantages and disadvantages. In terms of optimistic externalities, new ways of taxation could raise new tax revenue from new services. The usage of statistical data by emerging mobility providers, on the other hand, is at the heart of market control [218,220]. Shared mobility's negative externalities vary depending on the service model, local characteristics, and time of day. The influence of vehicle sharing, the portrayal of user characteristics, and the knowledge of adoption barriers in various situations have all been studied extensively, with the bulk of studies focusing on personal motives and the system's consumer-demand feasibility [221–223]. With growing pressure on car-sharing productivity, there is a greater need for new and innovative solutions.

Inturri et al. [224] describe the instance of Catania, a medium-sized city (300,000 people) in southern Italy, where university students enjoy fare-free public transportation (FFPT). They discovered that FFPT for students goes beyond mobility difficulties and may be viewed as a University of Catania social policy aiming at increasing the welfare and wellbeing of its students. They found a significant influence of this policy on student behaviour, paving the way for future stages in which continuous monitoring of PT level of service, along with student experience, will be critical to improving PT and promoting a paradigm shift in transportation. Inturri et al. [225] used a spatial and statistical method to establish meaningful and easy indicators for sustainable mobility planning by investigating the association between PT usage, user satisfaction, and PT accessibility. Eco-driving is another modern approach that tries to reduce GHG emissions in the existing vehicle infrastructure through efficient fuel use.

### *7.2. Promotion of Cycling and Walking*

The encouragement of walking and cycling, known as "soft mobility", is one of the most frequent forms of sustainable mobility in urban environments [226–228]. This approach has a huge societal advantage in terms of healthy living [229–232]. Physical activity was found to be favourably linked with total walkability and residential density by Van Dyck et al. [233,234]. Other research [235,236] has discovered favourable links between the built environment and emotional wellbeing, as well as life satisfaction. In a Swedish study, Sundquist et al. [237] looked at moderate to vigorous physical activity and discovered a link between frequency of physical activity and community walkability. Blečić et al. [238] conducted an assessment of operational approaches for analysing walkability. Their study provides decision-making aids for environmentally conscious planning and urban design. Urban planning and design that is focused on pedestrians—paying attention to their requirements, habits, and perceptions—is gaining popularity among academics, practitioners, and public policymakers interested in sustainability [239–246]. The literature on this entire topic is vast; we have reffered to a few generic publications that help us better understand the individual themes [247–254].

Following these steps and policies can promote pedestrian mobility:

- Maintenance and repair of sidewalks,
- Construction of underpasses and overpasses or marked and lit pedestrian crossings, and
- Construction of movable infrastructure to aid pedestrian movements.

The following are the primary policies that encourage cycling:

- Construction of bike lanes,
- Preparation of bicycle parking places,
- Incentives for bicycle purchases, and
- Bike-sharing.

Increased non-motorized mode usage, especially when replacing motorised trips, has a number of advantages. The environmental consequences are, of course, only if the trip taken by bike or on foot is a replacement for a trip that would otherwise be taken by car.

Freudendal-Pedersen et al. [255] explored how the mobility transformation is intertwined with contemporary society's cultural values, which are profoundly ingrained in the mobile-risk society. They proposed that robust, socially cohesive, and inclusive mobility systems that are more than just transportation systems and links are needed to establish viable mobility activities.

### *7.3. Policies*

European transportation policy has traditionally prioritised transportation's long-term sustainability. The Transport White Paper [256] lays out the transportation policies for the year 2050. By 2050, the European transport policy seeks to reduce greenhouse gas emissions by 60%. A more recent publication [257] looks at Europe's long-term sustainability, including mobility challenges, until 2030. This document quotes the Action Plan for Low-Emission Mobility [258], which notes, "*Low-emission mobility is an integral component of the larger move to the low-carbon, circular economy that is required for Europe to remain competitive and meet the mobility demands of people and goods*." The European Commission suggested 20 initiatives for urban areas in the Action Plan on Urban Mobility [259], eight of which are directly related to sustainable mobility on the following topics: plans for sustainable urban mobility; sustainable urban mobility and regional policy; urban transportation and health; sustainable mobility campaigns; energy-efficient driving; lower and zero-emission automobiles; clean and energy-efficient vehicles; internalization of external expenses.

The SUMP (Sustainable Urban Mobility Plan) is given special attention since it is defined as follows: "A Sustainable Urban Mobility Plan is a strategic plan developed to meet the mobility demands of people and companies in cities and their environs for a higher quality of life." It draws on existing planning processes while also taking into account ideas of integration, involvement, and assessment [260]. This planning tool is becoming increasingly popular; over 1100 cities in Europe have developed a SUMP today [261]. In the United States, where there is an overlap of responsibilities and competencies between the federal state and the member states of the union, sustainable mobility is fostered, but in a less organized fashion, as highlighted by [262], which advocated a policy review between 2000 and 2011.

This research shows that European transport policy is geared toward sustainable mobility, with a specific focus on emissions reduction. Furthermore, there is a significant tendency toward eliminating or drastically reducing the use of conventional fuels for passenger and freight transportation, choosing electric mobility for land transport: rail travel in cities and suburbs, and electric or zero-emission automobiles in cities. This trend is predicted to encourage the automotive industry to spend more and more on alternative fuel cars, with a special focus on electric vehicles, in addition to having a significant influence on future mobility patterns. This industrial revolution can already be witnessed today, with an increase in the number of electric and hybrid automobile models on the road, as well as a corresponding increase in market share.

## 8. Conclusions, Limitations and Future Research

This review investigated the selected aspects of sustainable mobility using two decades of research available in the literature from 2001 to 2021. The selected aspects include environmental, economic, and social impacts and technical possibilities. The bibliometric analysis revealed numerous implementable approaches and policy driven-conceivable actions.

The environmental and socio-economic elements demonstrate that sustainable mobility is the potential option for future mobility. The analysis reveals a possibility for using different mobility options that broadly fall under sustainable mobility to fight against the most stressing environmental and socio-economic constraints in transportation. Encouraging walking (given the lower distances within the neighbourhoods/community), cycling (within neighbourhoods and surrounding areas), shared mobility (car-sharing, mass transit, and others), green transportation, eco-driving, and other electric mobility options could help achieve sustainability in the transportation sector. It was also observed that some of the above-highlighted mobility options are already well recognised in climate-concerned countries, and it is time for others to adopt such options. Emerging countries, including the developing and the underdeveloped ones, are also gradually adopting the same options.

However, it was observed that attaining sustainable mobility is likely the most challenging task among the innumerable challenges associated with the larger picture of achieving sustainable development.

Technology element-based analysis carried out in this review positions the present state of developments in the transport sector as still unsustainable when a thought is given from a lifecycle point of view. Moreover, they are on a sustainable course. Though numerous technology options are available, most of the world's population has been culturally bound to the existing technology options that are unsustainable. Though many current mobility options are unsustainable, the users are quite satisfied with the performance, i.e., fuel use efficiency, mileage, and affordability. The transition to new mobility options would take time and is only possible with the intense policy initiation that benefits the users in all the investigated aspects.

Overall, this research review reveals a clear understanding of what has to be done; it has opened up a question of how to do it. Given the interdisciplinary nature of the stakeholders, each of their opinions about sustainable mobility will be different and more or less confined to their functions and operations. Hence, it may take considerable work to develop acceptable ways to convey it to stakeholders ( i.e., raw material providers, manufacturing or production companies and the general public), since the suggested mobility systems and actions must be appreciated even if the outcomes do not match with the expectations of others. Every stakeholder should understand that their fundamental aim is to support a future sustainable mobility system, and that this has to be accomplished. Furthermore, the promotion of efficient, safe, and convenient transportation services, as well as the lowering of urban car traffic and support of low transportation demand, are other vital issues observed from this bibliometric analysis. These observations are quite similar to the existing literature. However, the missing element is the promising technological development toward a future of sustainable mobility. Though we did not deal with this element in detail in this review, our preliminary assessment suggested that hydrogen could be a promising fuel for sustainable mobility, given the limited availability of resources for battery manufacturing.

The authors do acknowledge the limitations of this review. For instance, though there exists a vast literature on this entire topic, we limited our analysis to two decades, mainly referring to a few academic publications, technical reports, and white papers related to environmental, socio-economic and technical aspects of sustainable mobility, along with the different approaches that help us in better understanding the individual themes. Though there are different modes of transport, for instance, on-road and off-road, this review's primary focus was only on sustainable on-road mobility. Additionally, there are a few limitations with the methodological approach we adopted. For example, the data sample can be more extensive due to the broader range of journals and indexing tools, but only limited data are considered in this review; data filtration considering the metrics of relevant and non-relevant citations, is another issue this review did not account for. Based on the limitations and the observations made in this review, the following points can be considered as future research works.

- The selected aspects (environmental, economic, social impact, and technical possibilities) in this review article could be leveraged for other sustainable mobility modes, for instance, water and air transport.
- There is a possibility for cascading impacts on the power sector due to the massive deployment of sustainable mobility systems, especially the electrically operated ones. So, it would be better to discuss the impact on the power grid due to the increased charging demand.
- The impact of sustainable transportation in societal life could be taken up purely from an environmental point of view to understand air quality.
- A key focus could be on policies to promote sustainable mobility considering technological progress.

We believe the review results may serve as a foundation for assessing the future development of sustainable transportation and would provide a potential lead for sustainable mobility methods. The insight into current paradigms, key areas of research, and the interrelationships amongst the involved fields along with future research options could initiate new research among the practitioners.

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