HOW CAN SMART TRANSPORTATION SYSTEMS CONTRIBUTE TO THE REDUCTION OF CARBON EMISSIONS IN SINGAPORE? A SCOPING REVIEW

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Abstract

This paper examines the relationship between smart transportation and carbon emissions which has been identified to be the most significant driver behind increased climate change. It does so by conducting a scoping review of the available literature. In particular, it aims to answer the question: "How can smart transportation systems contribute to the reduction of carbon emissions in Singapore?". The Singaporean angle has been chosen as Singapore is currently the number one smart city in the world and for this reason it is expected to have an already developed smart transportation system. To ascertain the potential for reducing carbon emissions, several transportation initiatives are analysed in order to identify the strategies and technologies of each in terms of their impact on carbon emissions. Once examined, it showed that Singapore is implementing five initiatives including certain technologies and strategies which are effective in the reduction of carbon emissions. These include the use of autonomous vehicles, CERTAN, contactless fare payment, on-demand shuttle, and open data and analytics for urban transportation. Therefore, this paper allows for insight into the successful implementation of Singapore against carbon emissions which can provide to be helpful when applied on a broader scale.

Keywords: smart transportation, Singapore, carbon emissions, sustainability

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1 Introduction

1.1 Background

Greenhouse gases, including sulfur dioxide, nitrogen dioxide, carbon dioxide (CO_2) and many other compounds, were identified as the main cause of global climate change. This discovery attracted worldwide attention. Out of these gases, carbon dioxide is considered to be the most important, which is produced mainly by the burning of fossil fuels and deforestation. These emissions increase the concentration of greenhouse gases such as CO_2 in the atmosphere, trapping heat and leading to global warming. This discovery has encouraged many researchers to conduct further studies on this particular greenhouse gas and investigate potential methods to reduce it (Abeydeera et al., 2019).

The resulting climate change due to greenhouse gases include more frequent and severe weather events, rising sea levels, and disruptions to ecosystems and agriculture. Human activities have significantly increased CO_2 levels since the industrial revolution, with energy production, transportation and industry being the main contributors. Most efforts to reduce carbon emissions focus on transitioning to renewable energy sources, improving energy efficiency and protecting forests. Addressing global carbon emissions is critical to mitigating climate change and achieving a sustainable future (Cordero et al., 2020).

The importance of reducing carbon emissions in urban environments is crucial for mitigating climate change, improving air quality, and enhancing public health (Cordero et al., 2020). Cities are major sources of greenhouse gases due to high concentrations of transportation, industry, and energy consumption. Lowering emissions can decrease air pollution, reducing respiratory illnesses and thus healthcare costs. Additionally, sustainable urban practices, such as promoting public transit, energy-efficient buildings, and green spaces, contribute to a healthier living environment (Dong et al., 2021). Implementing these measures helps cities become more resilient to climate impacts, support economic growth through green jobs, and improves the overall quality of life for urban residents (Sun et al., 2022).

The transport sector represents the fastest growing source of greenhouse gas emissions globally. The main global objective is to reduce energy usage and associated greenhouse gas emissions from the transportation sector (Tarulescu et al., 2017). The implementation of Smart Transport Systems (STS) has the potential to address several challenges currently facing the sector, including congestion management, peak load reduction and the management of conventional or electric vehicles (EVs) in a cost-effective manner. This has major implications for public administration, as it requires the integration of different disparate elements, including tools, policies, and actors in both the public and private sector, to create coherent and sustainable solutions to urban mobility challenges. The use of data analytics, real-time monitoring and collaborative platforms can facilitate the improvement of policymaking and ensure the optimisation of resource allocation. It can also ensure that transport infrastructure evolves in response to urban dynamics. Furthermore, it enables the construction of an environmentally sustainable society through the optimisation of vehicle routing (Saharan et al., 2020). These factors collectively contribute to the reduction of carbon emissions and the creation of a more climate-friendly environment.

1.2 Significance of the Study

The study on the potential of STS to reduce carbon emissions is of significant relevance to Singapore's urban and environmental policies. Singapore has made a commitment to reducing carbon emission rates and aims to achieve net-zero by 2050 (Handayani et al., 2022). The country also faces several potential negative consequences of climate change, including higher temperatures and rising sea levels, which could result in flooding in certain areas if the (non-literal) tide does not change. These factors combine to position Singapore as an appropriate nation to examine the consequences and opportunities of STS.

Furthermore, the study is of great scientific and societal importance. The study provides a qualitative understanding of how government policies facilitate the integration of low-carbon transport solutions, offering invaluable insights for global urban planning efforts. By examining the specific technologies employed in Singapore's smart transport infrastructure, the study identifies practices that can be applied to a range of urban contexts. A qualitative analysis of the factors influencing the adoption and implementation of smart transport technologies offers policymakers and industry stakeholders, transitioning to sustainable transport solutions, a wealth of insights.

Lastly, the findings of this study have significant implications for urban planning and public health. The identification of effective smart systems, such as autonomous vehicles, intelligent traffic management, and electric public transport, enables city planners to design more sustainable and efficient cities. The reduction in carbon emissions resulting from the implementation of these technologies can lead to improvements in air quality, which in turn can reduce the incidence of respiratory illnesses and healthcare costs. The insights gained from this study can inform future infrastructure investments and policy decisions, thereby supporting Singapore's objectives of creating a healthier and greener urban environment. This research is in alignment with the city's sustainability goals and aims to enhance the overall public health and quality of life.

1.3 Research Question

This paper aims to examine the contribution of STS in reducing carbon emissions. It emphasizes the role that STS can play in the fight against climate change, through reduction of carbon emissions, and therefore promote sustainability. The reason for focusing on carbon emissions is that they represent the single greatest contributor towards climate change, which is the greatest factor influencing sustainability. Of the various factors contributing to carbon emissions, the transportation sector is one of the primary sources (United Nations, n.d.). This scoping review will focus on Singapore and its STS as a real-life case study. It will also utilize the Singaporean policies, strategies, and technologies as a unit of analysis when looking at how Singapore aims to achieve lower carbon emission rates.

The main research question formulated to investigate this topic is: " How can smart transportation systems contribute to the reduction of carbon emissions in Singapore?". To answer this explanatory research question, the following three sub-questions have been formulated:

- What types of smart transportation initiatives are currently implemented or planned to be implemented in Singapore?
- What technologies and strategies do these systems use to reduce carbon emissions?
- How effective are these technologies and strategies in reducing carbon emissions?

The dependent variable in this research is the reduction of carbon emissions and the independent variable is STS. The sub-questions will be answered through a scoping review and the answers to these questions will be used to formulate a conclusion to the main research question. The sub-questions will examine the concept of smart transportation initiatives in Singapore, specific technologies and strategies within STS, and the effectiveness of these technologies and strategies in reducing carbon emissions. The first sub-question is more general, the second is more specific and the last sub-question has a more technical aspect to it, to provide a framework for the main research question.

1.4 Structure of the Thesis

To fulfil the aim of answering the research question, this paper will first present the theory of this scoping review, which will include a discussion of the arguments and empirical findings of previous studies, as well as examine existing gaps in the literature. The second chapter is about the methodology in which the research design, data collection and data analysis will be explained. After this comes the analysis in chapter four. In this chapter, each sub-question will be individually analysed and answered. Finally, the discussion and conclusion will present a summary of the scoping review, discuss the limitations of the study, and provide some final remarks. However, most importantly, it will present an answer to the main research question of this research. After this, the references and appendix can be found.

2 Theory

This chapter of the thesis will delve into the theories used. The causal relationship examined in this scoping review is the impact of STS on carbon emission reduction. With the STS being the independent variable and carbon emission reduction being the dependent variable. The theories relevant to this topic and useful for its investigation are discussed and justified below. Firstly, the concept of STS will be explained. The definition and concepts are discussed and examples from other global cities are presented. Secondly, the carbon emissions from urban transport will be examined. Thirdly, STS within Singapore will be examined to provide more insight into the case used for this scoping review, Singapore. Then, the technical side of carbon reduction will be discussed in regard of the last sub question about the effectiveness of such systems. Finally, the gaps in the literature, that this scoping review addresses, will be presented. The goal of this chapter is to discuss theoretical arguments and empirical findings from previous studies and present theoretical expectations and insights which are derived from theory.

2.1 Concept of Smart Transportation Systems

Smart Transportation Systems (STS) is an advanced application designed to provide innovative services related to different modes of transport and traffic management. STS aims to improve the efficiency, safety, and coordination of transport networks by providing users with real-time information and smarter, more coordinated decision-making capabilities. Through the integration of technology, STS facilitates improved traffic flow, reduced congestion and increased overall road safety (*Intelligent Transport Systems*, n.d.).

STS gained popularity when the concept of smart cities came into the public eye and in recent decades. Smart cities aim to address sustainability challenges such as waste management, water management and energy policy (Barrionuevo et al., 2012). The concept of smart cities offers a tangible solution by reducing carbon emissions and addressing climate change-related issues such as flooding and rising temperatures (Lin et al., 2021). The goal of a smart city is to improve the quality of life by utilizing smart technologies and data analytics. (Yiğitcanlar & Kamruzzaman, 2018). Singapore claims to be number one in the world when it comes to being a smart city. It was named the Global Smart City of 2016 and has been at the top of smart city indices ever since (Chang & Das, 2020). One of the key contributions of smart cities to sustainability is their ability to significantly reduce carbon emissions. By implementing smart grids, STS and energy-efficient buildings, smart cities can reduce energy consumption and minimise greenhouse gas emissions. (Yiğitcanlar & Kamruzzaman, 2018).

STS, which include intelligent traffic management, public transport optimisation, and the promotion of electric and autonomous vehicles, can significantly reduce the carbon emissions associated with traditional vehicle transport. By prioritising sustainable transport modes and optimising traffic flow, smart cities reduce congestion-related emissions and promote cleaner air quality (Gopalakrishnan et al., 2015). STS are being developed to solve problems such as traffic congestion, road safety, accident detection, automatic fare collection and limited car parking facilities. The solutions STS bring to the table for these problems are all powered by the internet of things (*Smart Transportation System Using IoT*, 2017). Traditional land transport resources such as vehicles, roads, terminals, and other infrastructure are gradually becoming outdated. Many countries are struggling to modernise or install new transport systems within existing urban areas. However, recent technological advances and the connectivity provided by the internet are revolutionising transportation. This revolution includes the development of smarter, more autonomous, and safer vehicles that can communicate with each other and with urban infrastructure such as buildings and traffic signs. These advances have the chance to become the new standard. Cities that implement these STS are predicted to see improved mobility, increased economic productivity and reduced pollution (Jimenez, 2017).

In summary, STS provide an organized and integrated approach to minimising congestion and improving safety on city streets through networked technology (What Is A Smart Traffic Management System?, n.d.). Later in this scoping review, different types of smart transportation initiatives will be discussed further.

2.2 Carbon Emissions in Urban Transportation

Transportation-related emissions represent the most significant source of air pollutants in the present era. According to the European Environment Agency, transportation is responsible for approximately a quarter of the European Union's total greenhouse gas (GHG) emissions, which contribute to air pollution, noise pollution, and habitat fragmentation (*Transport And Mobility*, 2024b). Given the detrimental effects of transportation-related emissions on the social and economic environment, researchers and practitioners have devoted considerable efforts to identify solutions aimed at reducing these emissions (Yu et al., 2009).

The term "transportation" encompasses the movement of people and goods by a variety of vehicles, including cars, trucks, trains, ships, and airplanes. The largest sources of transportation-related greenhouse gas emissions are passenger cars, medium- and heavy-duty trucks, and light-duty trucks, including sport utility vehicles, pickup trucks, and minivans. Collectively, these sources account for over half of the emissions from the transportation sector. The remaining greenhouse gas emissions from the transportation sector originate from other modes of transportation, including commercial aircraft, ships, boats, and trains (*Sources Of Greenhouse Gas Emissions | US EPA*, 2024).

The government of Singapore has been proactive in addressing carbon emissions from the country's transport sector. As a densely populated urban city-state, Singapore faces unique challenges and opportunities in managing its transport emissions. Recent statistics show that Singapore's transport sector is currently responsible for around 15% of the country's total carbon emissions. With Singapore's Land Transport Authority (LTA) recently reporting that the country's vehicle population is approximately 950,000, including private cars, taxis, buses, and trucks, this is a good motivator for the government to invest and further explore the possibilities of an STS (Diao, 2019).

With recent initiatives, Singapore has shown a strong commitment to reducing carbon emissions, with a focus on implementing STS and promoting sustainable mobility. The Singapore Green Plan 2030 sets ambitious targets, including expanding the public transport network and phasing out internal combustion engine (ICE) vehicles (Chang, 2019). The Singaporean government aims to have all vehicles powered by clean energy by 2040 with electric vehicles playing a key role in this transition ("Assessing Singapore's Electric Vehicle Policies", n.d.).

Another area of focus is public transportation. Singapore boasts one of the most efficient and extensive public transport systems in the world with over seven million trips made daily on both buses and trains. The LTA is continuously expanding the rail network and enhancing bus services with the objective of reducing reliance on privately owned vehicles. Additionally, initiatives such as car-sharing programs, car-pooling, and the promotion of cycling and walking further support the reduction of carbon emissions (Mo et al., 2021).

2.3 Policies and Initiatives in Singapore

Singapore is a city-state and island nation in Southeast Asia with a population of almost 5.5 million. Even though, it is a rather small island, with a high GDP per capita of $82,808, it is the richest country in the entirety of the Asian continent. Due to Singapore's affluent position, it can continuously make investments in technology and propel innovation within the nation. (Lee & Qian, 2017). This proactive attitude allows Singapore to make a strong claim to the number one spot in the world when it comes to being a smart city (Chang & Das, 2020).

The reduction of carbon emissions is a key objective of Singapore's more sustainable STS, which the scoping review will examine in greater depth. In addition, it will present supporting research on the current smart transport initiatives in Singapore and the most effective technologies and strategies in reducing carbon emissions.

The Singaporean government has already implemented policies and regulations to reduce carbon emissions. Firstly, it is understood that the government has committed to reducing carbon emissions to net zero by 2050 (Deutch, 2020). To achieve this goal, they have already taken certain steps within policy and legislation to get closer to this goal. Examples of these, as outlined in Singapore's Green Plan for 2030, are: a) the carbon tax, which has been increased in 2024 to achieve the net-zero target (Carbon Tax, n.d.); b) the switch from fuel oil to natural gas for electricity generation, and further commitments to expand solar energy (Energy Reset, n.d.); c) the promotion and expansion of nature and green spaces (City in Nature, n.d.); d) the implementation of funds to support the development of green spaces (City in Nature, n.d.); e) the implementation of funds and grants to help industries and businesses become more carbon efficient (Green Economy, n.d.); f) the redesign of coastlines; g) the implementation of the vision to become a circular economy with the motto 'reduce, reuse and recycle'; h) the launch of GreenGov.SG, a platform that defines the role of government in achieving further sustainability.

Regarding the current transportation systems in Singapore, the STS incorporates a range of 'smart' transportation technologies, including one of the world's first Electronic Road Pricing Systems, real-time traffic information delivered through GPS-enabled taxis, and an integrated public transportation structure (The ASEAN Post, 2019). A more detailed examination of Singapore's current transport initiatives will be presented in the analysis chapter of this paper.

2.4 Mechanisms of Emission Reduction

Emission reduction is the process of reducing the release of greenhouse gases (GHGs) by individuals, organisations, or countries. These gases include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and hydrofluorocarbons (HFCs) (*What Is Emission Reduction? | Trace*, n.d.). The consequences of these emissions are numerous and complex. From an environmental perspective, these emissions contribute to the greenhouse effect, which in turn leads to global warming and climate change. In more detail, the increased levels of CO2 and other greenhouse gases in the atmosphere act to trap heat, thereby causing global temperatures to rise. This phenomenon results in the melting of ice caps, the rise in sea levels, and the occurrence of extreme weather events. From a public health perspective, pollutants such as particulate matter and nitrogen oxides (NOx) can lead to respiratory and cardiovascular diseases among the population, which in turn reduces life expectancy and increases healthcare costs (Environmental and Energy Study Institute (EESI), n.d.). Therefore, reducing these emissions is crucial in combating both the climate crisis and the public health crisis (World Health Organization: WHO, 2023).

The application of technological innovation has been shown to be an effective strategy for reducing energy consumption and carbon emissions in a number of countries. For example, in

China, technological advancement has led to a notable reduction in energy consumption and greenhouse gas (GHG) emissions (Zhang et al., 2020b). This trend is also evident in South-Korea, where innovation activities such as patenting and increased R&D investments have been directly linked to reduced carbon emissions in the manufacturing sector (J. Y. Mo, 2021). Similarly, Finland's systematic investments in technological development have demonstrated substantial long-term benefits in mitigating GHG emissions (Lehtilä et al., 2005).

However, the relationship between technological innovation and CO2 emissions is intricate and varies across different national contexts. The complexity of this relationship arises from several factors, including the stage of economic development, the industrial structure, and the specific types of technologies being implemented. Furthermore, international cooperation can be considered essential to maximize the positive effects of technological advancements, as innovations in one country can have spillover effects that benefit other nations (Chen & Lee, 2020). Consequently, while technology plays a pivotal role in reducing emissions, a collaborative global approach is imperative to effectively address the climate crisis.

A few measures can be implemented at the individual, organisational and governmental levels to reduce emissions. For instance, individuals may choose to install solar lighting, utilise renewable energy sources, adjust their thermostat settings or purchase solar panels (Nielsen et al., 2021). Regarding the pollution caused by vehicles and engines, individuals can reduce their driving or drive more efficiently, choose fuel-efficient vehicles, use efficient lawn and gardening equipment, and optimise home deliveries (Kazancoglu et al., 2021). This thesis will further analyse the potential for public adoption of STS regarding carbon emission reduction.

2.5 Gaps in the Literature

STS are a topic of great interest to researchers currently. However, despite numerous research being done on the topic, there are still areas yet to be investigated further. The objective of this paper is to conduct a scoping review of the existing literature on STS and its role in reducing carbon emissions. This review will identify any gaps in the existing literature and provide recommendations for future research to bridge these gaps.

One of the most significant research gaps is the limited number of studies investigating the impact of different transportation technologies on carbon emissions. Most current studies examine a single technology in isolation, such as traffic management systems or electric vehicles. However, in the present, there is a need to combine these individual technologies in a single study in order to gain a more detailed and useful STS framework. The potential for further studies, such as those that examine the interactions between different technologies, offers the opportunity to gain deeper insights into the ways in which these technologies can be optimised for the greatest environmental benefit (Zhang & Batterman, 2013).

The current body of research lacks geographical scope, with most of the literature focusing on case studies from Western countries. This study addresses this gap by focusing on Singapore and providing insights into STS in an Asian context. This is essential for a variety of geographical contexts to develop strategies that are applicable more globally and to address the unique challenges that arise in different locations (Benevolo, Dameri, & D'Auria, 2016; Kang, Yoo, & Kim, 2020).

The next research gap concerns the cost-benefit analyses of STS. A significant number of studies have been conducted on the environmental benefits of these STS, yet only a few have provided a detailed economic analysis, including the costs of implementation and maintenance, in comparison to the long-term savings from reduced emissions and improved public health. It is therefore evident that these analyses are of crucial importance to policymakers in order to enable them to make the most appropriate and well-informed decisions regarding investments in STS (Schulz & Geis, 2015). The consciousness of the costs can help in the push for investments in this perhaps ground-breaking technology.

Lastly, the current literature falls short in combining the environmental, economic, social and engineering aspects of STS. The challenge of reducing carbon emissions through the implementation of STS necessitates a comprehensive approach that encompasses a multiplicity of perspectives and methodologies (Geels et al., 2017; Sovacool, 2016).

This scoping review addresses the identified research gaps, which will not all be explicitly stated, but will be revealed through the sub-questions. The aim is to provide a more comprehensive understanding of how STS can effectively contribute to the reduction of carbon emissions, with the goal of promoting sustainable urban mobility.

3 Methods

The methodology section of this paper outlines the approach taken in designing the research. It will explain the scoping review methodology while first providing a definition of what a scoping review is. Then, it will delve into why the choice was made to do a scoping review and how scoping reviews are useful. Lastly, it will answer why Singapore is chosen for this scoping review. After this, the data collection is discussed with eligibility criteria, data sources and search strategy, study selection process and data extraction. Finally, the data analysis part explains the data charting and synthesis.

3.1 Research Design

This paper employs a scoping review methodology to explore the impact of STS on reducing carbon emissions in Singapore. According to the Canadian Institutes of Health Research (2010), scoping reviews are exploratory projects that systematically map the literature on a topic, identifying key concepts, theories, sources of evidence, and research gaps.

Arksey and O'Malley (2005) outlined four primary reasons for conducting a scoping review. Firstly, it examines the extent, range, and nature of available research on a specific topic, assisting to map existing literature and classify studies based on their characteristics. This approach provides a comprehensive overview of the field, informing future research agendas and understanding the current state of knowledge. Secondly, scoping reviews determine the value of undertaking a full systematic review. By surveying existing research, they assess whether there is sufficient and relevant literature to justify a more detailed review, thus avoiding unnecessary efforts if the literature is sparse. Thirdly, scoping reviews summarize and disseminate research findings across a broad body of evidence. They synthesize and present key findings, making the collective knowledge accessible and understandable to various stakeholders, including policymakers, practitioners, and researchers. This enhances the practical application and wider use of research. Lastly, scoping reviews identify research gaps in the literature, aiding in the planning and commissioning of future research. By mapping the current body of knowledge, researchers can pinpoint areas that are underexplored or lack sufficient evidence, guiding future research efforts to address these gaps.

Scoping reviews are particularly useful for clarifying working definitions and conceptual boundaries of a topic. They are essential when the literature has not been comprehensively reviewed or is large, complex, or heterogeneous. By systematically mapping existing research, scoping reviews provide a comprehensive overview, enabling the identification of key concepts, gaps, and the extent of available evidence. This approach facilitates understanding the scope of a field and directs future research efforts to address unresolved questions and advance knowledge meaningfully (Peters et al., 2015; Tricco et al., 2016).

Singapore was selected for this scoping review because of its exemplary role in the adoption and implementation of STS. As a highly populated urban city-state, Singapore faces unique transport challenges. This makes it an ideal case study for evaluating the effectiveness of smart transport initiatives. The government's proactive stance on carbon emission reduction, through policies such as the Singapore Green Plan 2030 and initiatives to phase out internal combustion engine vehicles by 2040, is a testament to its commitment to sustainability (*Our Vision*, n.d.). In addition, Singapore provides a rich context for studying the impact of these systems on carbon emissions, with its advanced infrastructure, robust public transport network and significant investment in smart transport technologies. These factors provide valuable insights and lessons that can be applied globally, thereby establishing Singapore as a leading model for other cities seeking to implement similar strategies. The external validity of this study is reinforced by the potential for the findings to be generalised to other contexts. By analysing the ways in which Singapore's STS address issues such as congestion and peak load reduction, cities around the globe can adopt and adapt these strategies to suit their specific urban environments, thus enhancing the global applicability and relevance of the findings.

3.2 Data Collection

3.2.1 Eligibility Criteria

The eligibility criteria for selecting studies have been established to ensure that the included research is both relevant and of an appropriate quality. The inclusion criteria for this study encompass articles, reports, and other forms of literature that focus on the impact of STS on carbon emissions, with a specific focus on Singapore. Only articles that have been peer-reviewed, government reports and files, and other forms of scholarly literature that have been published in English from 2020 onwards will be considered.

The criteria for exclusion of studies from the review were based on the following considerations: those that do not directly address the research question, lack empirical data, or are not available in full text. Furthermore, studies that are solely theoretical in nature, lacking practical applications, or conducted outside of Singapore are also excluded. This methodical approach guarantees that the review encompasses the most pertinent and of the highest caliber of research currently available.

3.2.2 Data Sources and Search Strategy

The data sources for this scoping review include major academic databases such as Google Scholar, ScienceDirect and SpringerLink. These databases provide comprehensive coverage of the scientific literature across different disciplines. The search strategy uses a combination of keywords and search terms tailored to capture relevant studies on STS and carbon emission reduction in Singapore. Key search terms include 'smart transport', 'carbon emissions', 'Singapore', ‘smart transport systems' and 'sustainability'. This comprehensive approach ensures that a wide range of relevant studies are included in the review.

3.2.3 Study Selection Process

To identify studies that meet the inclusion criteria, the study selection process involves two key screening stages: title/abstract screening and full-text screening. At the first stage, the titles, and abstracts of identified studies are initially reviewed in order to exclude those that fail to meet the inclusion criteria. Studies that pass this stage are subjected to a more detailed evaluation during full-text screening. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram is utilised in order to document each step of the screening process, ensuring transparency and reproducibility. The diagram facilitates the monitoring and documentation of the numbers of records identified, included, and excluded, along with the reasons for exclusions.

3.2.4 Data Extraction

The data extraction process involves the use of a standardised form to facilitate the systematic collection of key information from selected studies (see Appendix A). This form is designed to facilitate the collection of essential details relevant to the study, including aspects such as study objectives, methods used, sample sizes, interventions used and outcomes observed, and key findings. It also identifies the setting, characteristics, and limitations of the study. The structured approach will ensure consistency and precision in data collection, setting the basis for subsequent exploration and aggregation. The extracted data will provide a comprehensive overview of the evidence to be compiled, allowing the identification of patterns, gaps in the evidence and findings relevant to the research questions.

3.3 Data Analysis

3.3.1 Data Charting and Synthesis

The objective of this scoping review is to organise and synthesise the extracted information in a systematic manner, to ensure replicability. The fundamental concepts and operational definitions of the study are clearly outlined in this section, providing a structured approach to analysing the data. This subsection outlines the method of information organisation and analysis for each sub-question. It, thus, ensures the replicability of the methodology for other researchers.

The development of the standardised data extraction form mentioned above is the first step in the data charting process. This structured approach ensures consistency and makes it easier to compare and synthesise the data from several different studies. To organise the information, each sub-question is addressed separately.

In order to identify common themes and patterns, the qualitative data from the studies will be coded according to emerging themes related to the effectiveness, the challenges and the benefits of STS. To identify recurring themes and significant findings across the studies, thematic analysis is used. A deeper understanding of key concepts and findings is provided through this qualitative synthesis.

Quantitative data is presented in a descriptive manner with the objective of providing a numerical overview of the studies. This includes information such as the number of studies conducted per year, the geographical distribution of the studies, the types of interventions employed, and the study designs employed. This approach allows for the identification of trends and the identification of gaps in the research landscape.

The evolution of STS and their impact on carbon emissions are analysed to identify trends and changes over time. This involves a mapping of the chronology of technological advancements and policy implementations against the reported outcomes. The aim is to provide insights into the progress and future direction of smart transportation initiatives.

The systematic methods employed for data charting and synthesis in the scoping review enable a thorough and insightful analysis of the available literature. This approach ensures the reliability and comprehensiveness of the findings. Therefore, contributing to a more profound comprehension of the role of STS in reducing carbon emissions and providing a foundation for future research.

4 Analysis

In this chapter of the scoping review, the sub-research questions will be answered by analysing the collected data and documents. First, the search results will be discussed briefly, after which the characteristics of included studies will be presented. Then the three sub-questions will each be analysed individually based on the collected data, and an answer will be formulated to each question. Finally, a thematic analysis will be conducted, during which common themes will be identified and discussed after which this chapter will be concluded.

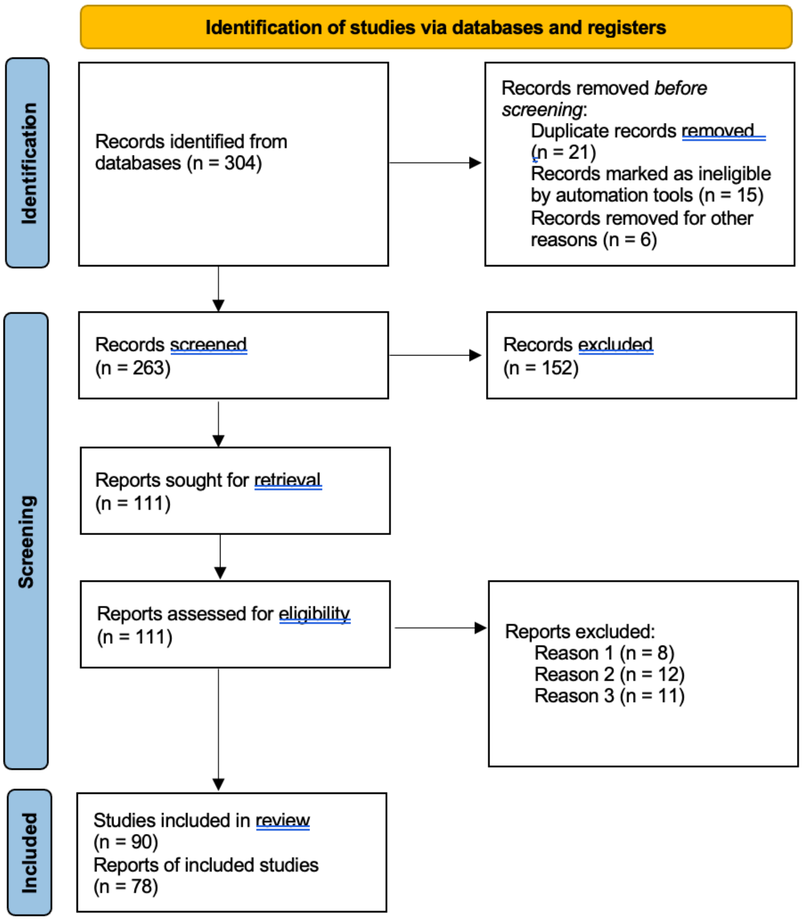
The ensuring of transparency and reproducibility in the scoping review process is achieved through the following steps, which help to establish a clear methodological link between the selected articles and the overarching goals of the scoping review. In order to identify the relevant articles, several articles have been identified to link towards each sub-question through a systematic search of relevant databases and sources. This search was conducted to gather a comprehensive set of relevant articles relating to each sub-question of the scoping review. The inclusion and exclusion criteria were employed to filter the articles, after which they were categorised according to each sub-question. Through this process, the objective to guarantee transparency and reproducibility in the scoping review is achieved. These steps facilitate the establishment of a clear methodological link between the selected articles and the overarching goals of the scoping review.

4.1 Search Results

This section presents a summary of the search process and the results obtained during the scoping review. A comprehensive literature search was conducted across multiple databases, using keywords related to STS and carbon emissions reduction in Singapore. The search strategy included terms such as "smart transportation," "smart transport systems," "carbon emissions," and "Singapore."

For the search for useful articles and the PRISMA flowchart below, no distinction was made between the three sub-questions. The sub-questions arise from each other, and all have the same aim, which is to answer the main research question. Therefore, the diagram below applies to all data and analysis. This diagram outlines the steps of identification, screening, eligibility, and inclusion, providing a clear overview of the search process and the resulting articles included in the review.

Figure 1



PRISMA flow diagram of scoping review

A brief description of the figure above is as follows: initially, 304 articles were identified as potentially useful for this study on scientific databases. During the screening process, the titles and abstracts of these studies were reviewed, leading to the exclusion of several articles due to various reasons. These reasons included: 1) an excessive focus on other cities or cities in general, 2) an excessive focus on side topics not directly related to the study in question, and 3) the absence of any useful data. This left 90 papers deemed useful for the review.

The systematic organisation and synthesis of data from the 90 articles included in the review will provide comprehensive insights into the effectiveness of STS in reducing carbon emissions in Singapore. The analysis of these studies will assist in the identification of key trends, technologies, and strategies, as well as in the highlighting of gaps in the current research landscape.

4.2 Characteristics of Included Studies

This section will present an overview of the study designs, publication years, and sources included in the review. It will begin with an examination of the study designs employed in the studies included in the review. The data analysis for this scoping review encompasses a diverse range of study designs, including case studies, policy analyses, empirical research, comparisons, descriptive studies, and technical evaluations. The variety of these designs provides a comprehensive overview of each topic.

Secondly, the publication years of the included studies is discussed. The objective was to include as many relevant studies as possible, published between 2020 and 2024. This approach did not yield results for all the collected data, but for most of it, it did. Finally, the sources of the included studies are presented. As already mentioned in section 3.2.2, the main academic databases Google Scholar, ScienceDirect and SpringerLink are used in this scoping review to collect its data.

In summary, the included studies represent an extensive and representative cross-section of recent research, encompassing a variety of methodologies and sources, thus providing a robust basis for analysing the impact of STS on carbon emissions in Singapore. The inclusion of a wide range of studies allows for a comprehensive analysis that encompasses both the successes and the obstacles encountered in the implementation of these systems.

4.3 Types of Smart Transportation Initiatives

The initial sub-question to be addressed is as follows: “What types of smart transportation initiatives are currently implemented or planned to be implemented in Singapore?”. The objective of this section is to provide an answer to this question. This objective will be achieved through a critical analysis of nine scientific articles that have conducted studies on STS. The literature search allows for the identification of the various types of smart transportation initiatives, which are discussed in further detail below. The aforementioned categories were the most prevalent and therefore warrant further examination in this scoping review. A brief introduction to these initiatives will be provided at the outset. Subsequently, the geographical distribution of these initiatives will be considered and different types, combined with a discussion of the initiatives currently implemented or planned in Singapore. Lastly, a short summary which will provide an answer to the sub-question.

Transport has existed for as long as the human world has. The development of transportation is one of the greatest inventions in the whole world. From the first tracks across continents, to horse and carriage, to a bullet train with a top speed of over 320km/h. Transport has become indispensable and with the rise of technology and the current era we live in nowadays STS are everywhere (Lei et al., 2022). In the theory chapter of this paper was already a definition of STS provided along with some background information.

The Singaporean government has set aside 12% of the country's land for roads and infrastructure. Given that Singapore is a relatively small island, this 12% represents a significant percentage of the country's total land area. However, with over one million vehicles in operation, it is a significant challenge to design a more safe, efficient, and reliable transportation system (Haque et al., 2013). There are many different types of STS. Given the current prevalence of this topic, it is evident that new technologies in this field are constantly emerging. The current discussion will focus on different types of STS, and how these systems are being implemented or planned in Singapore itself. The following initiatives have been identified through a scoping review of several articles relating to the topic of this sub-question and have been subjected to a systematic analysis.

4.3.1 Autonomous Vehicles

The first smart transportation initiative that Singapore plans to implement and further develop is the autonomous vehicle, also known as the self-driving car. Autonomous vehicles (AVs) use a combination of cameras, radar, sensors, and artificial intelligence to sense their environment and operate without any human involvement needed. They are equipped with advanced control systems allowing them to independently operate and adapt to changing environments. With a wide range of technologies being used, they ensure safe and efficient transport (Faisal et al., 2019).

The implementation of AVs in Singapore has been made possible using a range of cutting-edge technologies, including advanced sensors, machine learning algorithms and real-time data processing. These technologies are designed to enable safe navigation in complex urban environments. The vehicles are equipped with LIDAR - cameras and radar systems that enable them to detect and react to surrounding objects and traffic conditions. This ensures safe and efficient driving (Tan & Taeihagh, 2021).

4.3.2 CERTAN

The Central Expressway Real-Time Adaptive Network (CERTAN) in Singapore is an advanced traffic management system implemented with the aim of reducing carbon emissions. This objective has been achieved through the implementation of several innovative technologies and strategies. The CERTAN system uses a combination of intelligent traffic signal control, real-time traffic monitoring and data analysis to optimise traffic flow along the Central Expressway and surrounding arterial roads. This optimisation reduces stop-and-go traffic, which in turn reduces fuel consumption and vehicle emissions (Wan, 2022).

One of the key technologies used in the CERTAN system is Adaptive Traffic Signal Control (ATSC), which modifies signal timing according to real-time traffic conditions. This technology ensures that traffic lights operate as efficiently as possible, minimising idle time at intersections and reducing congestion. In addition, the CERTAN system incorporates video surveillance and traffic sensors to continuously monitor traffic patterns. The data collected from these sensors is analysed to predict traffic conditions and dynamically adjust signal timing (Wan, 2022).

The CERTAN system also supports the integration of electric and hybrid vehicles into traffic systems. By providing real-time traffic information, the system helps drivers of these vehicles to develop more efficient route plans, thereby reducing overall emissions. The system also encourages the use of public transport by improving the efficiency and reliability of bus services along expressways (Bock, Kreutz, & Lienkamp, 2019).

4.3.3 Contactless Fare Payment

One of the principal elements of STS is the implementation of intelligent public transportation systems. These systems are designed to enhance the efficiency and safety of public transportation. Such systems employ technology to enhance the quality of services, including the implementation of electronic ticketing, the provision of crowd-aware route recommendations, and the real-time tracking of vehicles. The deployment of these technologies, in the form of smart public transportation systems, ensures the safety of both the public and individuals, and addresses challenges such as irregularities in public transportation scheduling by providing real-time information and alerts to users (Rajput et al., 2022; Jalaney & Ganesh, 2019).

In Singapore, they implemented such a system officially in 2019 called: SimplyGo. The contactless fare payment started already in 2017 with the launch of contactless credit and debit cards. Contactless fare payment in Singapore refers to the use of electronic payment technologies that allow commuters to pay for their public transport journeys without the need for physical contact with payment devices. The system uses technologies such as Near Field Communication (NFC) and Radio Frequency Identification (RFID) to speed up and simplify transactions. Commuters can use their credit or debit cards, mobile phones or wearable devices to contact fare readers installed in MRT stations and buses. The fare is automatically deducted from linked accounts, eliminating the need for physical cash or tickets. The use of this contactless system provides greater convenience and efficiency, while reducing the risk of infection through physical proximity (Prakasam, 2008).

4.3.4 On-Demand Shuttle

The on-demand shuttle service in Singapore represents a forward-thinking public transport initiative that utilises technology to offer flexible and efficient transportation options for passengers. This service, which incorporates providers such as GrabShuttle and Beeline, enables users to book rides in real-time via mobile apps, thereby facilitating the optimisation of travel time and reducing the necessity for personal vehicle usage. The shuttles operate on dynamic routes based on the users' locations and destinations, thereby further optimising travel time and reducing the need for individual vehicle usage (Oh et al., 2020).

These on-demand shuttle services utilise data analytics and algorithms to plan optimal routes and schedules, ensuring that passengers experience minimal wait times and direct journeys. The system minimises traffic congestion and carbon emissions by maximising the occupancy of each shuttle and encouraging shared transportation. By integrating with existing public transport networks, these on-demand shuttles provide an alternative to private car travel, thereby supporting Singapore's stated goals for a smart and green city (Oh et al., 2020).

4.3.5 Open Data and Analytics for Urban Transportation

The Singaporean Land Transport Authority (LTA) has implemented sensors in public buses to gather real-time location data and arrival times, thereby significantly enhancing transport planning. Furthermore, the LTA collects anonymized data from commuters' fare cards with the objective of identifying hotspots and managing bus fleets and commuter demand in an efficient manner. The data-driven approach has resulted in a 92% reduction in crowded bus services and a 3- to 7-minute reduction in waiting times for popular routes. This innovation supports the encouragement of sharing open data in order that developers can provide creative solutions to improve the transport system (*Open Data & Analytics For Urban Transportation*, n.d.).

4.3.6 Summary

To summarize, Singapore is currently engaged in the implementation of five smart transportation initiatives with the objective of reducing its country's carbon emissions and improving its transport system. All of these implementations show the care and effort which the Singaporean nation puts into developing itself as a smart and green city.

4.4 Technologies and Strategies for Carbon Emission Reduction

Having identified and examined the various types of STS, it is now necessary to assess their contribution to reducing carbon emissions. This section will analyse and answer the second sub-question, namely, “What technologies and strategies do these systems use to reduce carbon emissions?”. A brief introduction to this sub-research question will be provided, after which different themes will be presented in regard of carbon emission reduction. These have been selected through a data extraction of thirteen scientific articles and the most occurring and themes in regard with the previous mentioned initiatives have been chosen to be discussed. Finally, a summary and response to the sub-question will be provided in this section.

The Land Transport Authority (LTA) of Singapore has set a target of reducing emissions from land transportation by 80% by 2050. The LTA has devised a roadmap to achieve this goal, with targets including 90% of peak hour journeys on walk-cycle-ride modes and 100% of cleaner energy vehicles to be achieved by 2040. Furthermore, the LTA plans to expand charging infrastructure for EVs, particularly in public car parks (Devihosur et al., 2024). Considering the aforementioned objectives, it is of paramount importance that the STS outlined above make a significant contribution towards carbon reduction. Several themes have been identified in this regard and will now be discussed. The four technologies and strategies below have been identified through a systematic scoping review as the most common themes in reducing carbon emissions.

4.4.1 Electric Vehicles and Charging Infrastructure

The initial promising technology that Singapore plans to implement is the adoption of electrical vehicles (EVs) and the construction of associated charging infrastructure. This contributes towards the reduction of carbon emissions as EVs are powered by electric motors that are recharged by batteries. A widespread adoption of these vehicles would necessitate the development of accessible and efficient charging infrastructure. Consequently, the advent of EVs calls for the implementation of smart charging infrastructure (Omase et al., 2023). Currently, Norway is the global leader in EVs adoption, with a comprehensive network of charging stations (Yang et al., 2023).

The electrification of vehicles represents a significant step towards reducing carbon emissions. It entails replacing internal combustion engine vehicles, which emit greenhouse gases, with EVs that produce zero tailpipe emissions. This transition results in a notable reduction in the quantity of carbon dioxide and other pollutants released into the atmosphere, particularly when the electricity utilised to charge EVs is generated from renewable energy sources. Consequently, it contributes to improved air quality and overall mitigates the impacts of climate change (Wolfram et al., 2016).

With the five initiatives mentioned in the previous section, Singapore will deploy these EVs and charging infrastructure across multiple sectors. For example, the autonomous vehicles will all be electric, as will the on-demand shuttle buses be. The actors involved in this are the Land Transport Authority (LTA) of Singapore. The LTA is responsible for Singapore's planning, coordination, and implementation of policies and infrastructure. They are responsible for the adoption and implementation of EVs and the associated charging infrastructure.

4.4.2 Intelligent Traffic Management

Intelligent Traffic Management Systems (ITMS) are sophisticated, integrated networks designed to optimise traffic flow and enhance the user experience (Vijayaraghavan & Leevinson, 2020). These systems employ technologies such as artificial intelligence and real-time communication to prioritise emergency vehicles at intersections (Ghawate et al., 2023). ITMS comprise a number of subsystems, including traffic signal control, video monitoring, and traffic guidance, which work in conjunction to manage traffic facilities and devices in a comprehensive manner. Moreover, ITMS employ big data analysis to optimise traffic organisation and decision-making, thereby enhancing the efficiency, safety, and comfort of the transportation system (Wan & Li, 2020).

The use of Intelligent Traffic Management Systems (ITMS) has the potential to reduce emissions of carbon dioxide and other greenhouse gases. These systems allow traffic flow to be optimised and stop-and-go driving to be minimised. This, in turn, reduces fuel consumption and in the long run, emissions. The systems use real-time data and adaptive signal control to reduce congestion. They also prioritise public transport and emergency vehicles. They also use big data analytics for informed traffic management. These systems reduce idling time, improve public transport efficiency, and reduce emissions in urban areas (Barth et al., 2015).

Singapore is planning to utilise intelligent traffic management systems in the implementation of the on-demand shuttle and the open data and analytics for urban transportation. The following actors will be involved in this process: the traffic police, the Urban Redevelopment Authority (URA), public transport operators, and the LTA.

4.4.3 Public Transportation Enhancement

One of the principal elements of STS is the implementation of intelligent public transportation systems. These systems are designed to enhance the efficiency and safety of public transportation. Such systems employ technology to enhance the quality of services, including the implementation of electronic ticketing, the provision of crowd-aware route recommendations, and the real-time tracking of vehicles. The deployment of these technologies in the form of smart public transportation systems ensures the safety of both the public and individuals, and addresses challenges such as irregularities in public transportation scheduling by providing real-time information and alerts to users (Rajput et al., 2022; Jalaney & Ganesh, 2019).

Singapore's goal is to expand its public transport network and integrate autonomous vehicles into this network. From a carbon reduction perspective, AVs contribute to this goal by reducing idle time and optimising routes to avoid congested areas. This reduces fuel consumption and emissions. In addition, a significant proportion of these AVs will be electric, eliminating tailpipe emissions and directly supporting Singapore's Green Plan 2030 goals (Ng & Kim, 2021).

A review of the preceding section reveals that this type of technology will be integrated into each initiative that Singapore is currently engaged in. For instance, the CERTAN initiative will make use of autonomous vehicles, while contactless fare payment will be a significant contributor to the enhancement of the public transport network. The Singapore Ministry of Transport (MoT) is responsible for the oversight of the country's public transportation system. In order to ensure the continued improvement of service quality and responsiveness to community needs, the MoT engages in regular consultations with stakeholders, including commuters, through a variety of channels, such as public surveys and feedback forms.

4.4.4 Micro-Mobility Solutions

The last technology Singapore uses to reach its goals for carbon emission reducing is a combination of smaller things. It combines strategies as bike-sharing, e-scooters, and mobility-as-a-service; all in all, micro-mobility solutions.

Bike-sharing and e-scooters represent an innovative micro-mobility solution that is reshaping urban transportation. The two systems in question facilitate sustainable urban mobility by offering shared bicycles and electric scooters which can be utilized for short-term journeys. Both systems contribute to the development of smart urban transportation by providing flexible and sustainable alternatives to traditional modes of transport (Bieliński & Ważna, 2020).

The goal of Mobility-as-a-Service (MaaS) is to combine various transportation services and mobility services such as trains, buses, e-scooters, and bike sharing into a single application. Within this application users can plan, book, and pay for a sustainable route from A to B (Dyczkowska et al., 2023).

Both strategies make use of technics to reach a lower carbon emission reduction. The objective is accomplished by the provision of low-energy, zero-emission alternatives to traditional automotive transportation. These transportation modes result in a reduction in fuel consumption, which in turn reduces the incidence of traffic congestion, thus limiting the release of greenhouse gases and reducing carbon footprints in urban settings (Abduljabbar et al., 2021). Singapore's approach to urban mobility is characterised by a collaborative effort among government agencies, private operators, advocacy groups, and the public. This approach is designed to ensure the provision of safe, convenient, and sustainable urban mobility options. Once more, the LTA, MoT, URA and Public Transport Operators (PTOs) are involved.

4.4.5 Summary

In conclusion, the answer to the sub-question "What technologies and strategies do these systems use to reduce carbon emissions?" is as follows; Singapore employs EVs and charging infrastructure, intelligent traffic management, public transportation enhancement, and micro-mobility services to reduce carbon emissions. The subsequent section will assess the efficacy of these strategies and technologies.

4.5 Effectiveness of Smart Transportation Systems

The objective of this final sub-question is to assess the efficacy of the technologies and strategies. Having identified the initiatives that Singapore is pursuing to implement and the technologies and strategies that these systems will employ to reduce carbon emissions, it is crucial to ascertain whether these systems will succeed in this reduction, and if so, to what extent. Therefore, the objective of this section is to respond to the third and final sub-question: "How effective are these technologies and strategies in reducing carbon emissions?". The question will be addressed using an inductive approach. This entails the collection of data from a variety of case studies, nine scientific articles in the case of this sub-question, and real-world implementations with the objective of reaching general conclusions regarding the efficacy of these technologies and strategies. The discussion of these real-world implementations demonstrates the efficacy of the strategies and technologies in question. This approach could be applied to the smart transportation initiatives currently being implemented in Singapore. In the preceding section, the specific strategies and technologies that are pertinent to each initiative have been identified.

The analysis, based on the systematic collection of data, allows for a comprehensive understanding of the scope and nature of existing research. This provides valuable insights and guidance for future research directions. This linkage guarantees that the review's conclusions are well-founded and pertinent to the research objectives. For instance, the analysis of data from cities that have implemented smart transportation initiatives can reveal patterns and outcomes that demonstrate the success of these technologies and strategies in reducing carbon emissions. By employing this approach, it is possible to identify effective practices and potential areas for improvement. This allows to gain a comprehensive understanding of how STS can contribute to sustainability goals. Firstly, an introduction to the concept of effectiveness will be provided. This will be followed by a detailed analysis of each technology and/or strategy, and finally, a conclusion will be drawn, which will provide an answer to the research question of this section. The results of the scoping review have enabled the identification of the key themes that emerged from the data, and each will be analysed individually in relation to their respective articles.

The term 'effectiveness' is used in this section to refer to the capacity of STS to achieve the desired outcome of reduced carbon emissions. It encompasses a multitude of factors, including the extent of emissions reductions, enhancements in air quality, and the overall environmental impact. The effectiveness of such systems can be quantified by measuring changes in carbon dioxide levels, fuel consumption and the rate of adoption of sustainable transportation modes.

4.5.1 Electric Vehicles and Charging Infrastructure

The first technology to be examined is the change of conventional cars to electric cars. According to a report from the UK's Royal Society electric cars can emit between 17% to 30% less carbon dioxide than petrol cars over their lifetime (Hinchly, 2024). Nevertheless, the transition from conventional to EVs is not the sole determining factor in their effectiveness. Rather, the efficacy of EVs is contingent upon the implementation of intelligent charging strategies. The optimisation of regional charging infrastructure and schedules has the potential to reduce greenhouse gas emissions from power generation by up to 97% (Tu et al., 2020). Meaning that the combination of EVs and charging infrastructure represents an effective strategy for reducing carbon emissions.

Oslo, the capital of Norway, is also the capital of EVs. In 2021, Oslo succeeded in having a greater number of EVs than petrol cars. In 2022, 79% of all cars sold in Norway were EVs. By the end of 2023, Oslo had replaced its last diesel-fueled buses with electric models, thus establishing a zero-emission public transport system five years ahead of schedule (Infra Journal, n.d.). This city serves as a compelling exemplar and catalyst for Singapore to pursue further implementation and investment in its EVs and charging infrastructure.

4.5.2 Intelligent Traffic Management

The effectiveness of intelligent traffic management systems (ITMS) in reducing carbon emissions is significant. Studies have shown that by only improving the overall traffic efficiency due to minimizing stop-and-go traffic it can already reduce 20% (Wan, 2020). Another study has shown that such smart traffic management systems could potentially reduce 41% of carbon emissions by 2027 (Carey, 2022). In the study of Wan (2020), it is also shown that in Los Angeles, United States of America, the implementation of ITMS, such as real-time traffic monitoring, synchronized traffic signals and adaptive traffic control, has led to a 10% decrease in carbon emissions.

4.5.3 Public Transportation Enhancement

The transition from private vehicle use to public transportation can result in a reduction of up to 2.2 tons of carbon emissions per individual on an annual basis. A single bus can already replace 40 cars on the road. The enhancement of public transportation can thus be directly linked to a reduction in carbon dioxide emissions. The replacement of car journeys by bus can result in a reduction of carbon emissions of between 42% and 73%, depending on the mode of transport used. In the United States, the use of public transportation has been found to result in a 45% reduction in carbon emissions compared to driving alone. This equates to a saving of 37 million metric tons of carbon annually within the country (Team & Team, 2024).

4.5.4 Micro-Mobility Solutions

The deployment of micro-mobility solutions, such as e-scooters and bike-sharing programs, has been demonstrated to be an effective means of reducing carbon emissions, particularly in urban areas. The principal areas in which they achieve their reduction are short trips; micro-mobility solutions are designed for short trips of up to five kilometres. Secondly, energy efficiency; e-scooters and electric bikes are significantly more carbon neutral than cars. Finally, there is the issue of congestion. The greater the number of e-scooters or shared bikes in use, the fewer cars will be on the roads, and the overall traffic congestion will be reduced. Furthermore, smoother traffic will result in a reduction in carbon emissions (Abduljabbar et al., 2021).

To demonstrate the efficacy of micro-mobility solutions in practice, the case of Paris will be examined. In Paris, the capital of France, a bicycle-sharing program called *Vélib* was implemented, which has been demonstrated to reduce carbon emissions by between 10% and 15% for each individual trip that is replaced by a bicycle instead of a car (Paris La Défense, 2023). A further case study, based on data from the 50 largest American cities, demonstrated that the introduction of shared mobility services could result in the reduction of 100 million metric tons of greenhouse gas emissions on an annual basis. This equates to 40% of all emissions generated by the transportation sector in the United States (GreenBiz, 2023).

4.5.5 Summary

In conclusion, the efficacy of each of the technologies and strategies presented in section 4.4 has been evaluated through the lens of separate case studies from the real world. Each of the technologies and strategies has been demonstrated to be effective in its own way. The initial technology, that of EVs and charging infrastructure, demonstrated that EVs can reduce emissions by 17-30%, while charging infrastructure can reduce emissions by up to 97%. Therefore, the average reduction in emissions resulting from the combination of these two technologies is 60.25% (calculated as follows: (((17+30)/2) +97)/2=60.25). The second technology, ITMS, is projected to result in a 41% reduction in CO_2 emissions by 2027. Thirdly, public transportation in the United States demonstrated a reduction of 45% in emissions, while micro-mobility solutions also in the United States showed a reduction of 40%. These four percentages collectively indicate that the implementation of these technologies and strategies could result in the reduction of approximately half of global carbon emissions. This represents a significant and noteworthy impact.

4.6 Thematic Analysis

The thematic analysis of the scoping review on STS in Singapore aims to identify and discuss common themes that emerge from the literature. In the subsequent section of this synthesis, the findings are summarised and presented in a way that allows the key trends, technologies, policies, and their implications for carbon emission reduction to be clearly identified and understood.

4.6.1 Identification of Common Themes

The first common theme is the electrification of transport. Singapore's dedication to the transition of its vehicle fleet to EVs is evident in the implementation of policies that facilitate the installation of extensive charging infrastructure and incentives for EV adoption. This transition not only reduces direct emissions from vehicles but also aligns with the broader objective of achieving a low-carbon economy and society.

The second theme that emerges from the analysis is the integration of advanced technologies. Several articles reviewed from the LTA reports and the scientific article by Lei et al. (2022) showed that technologies such as the Internet of Things (IoT), artificial intelligence (AI) and big data analytics play a significant role in Singapore's journey towards achieving its net-zero goal by 2050. The theme of advanced technologies emerged repeatedly in this study, as well as in Singapore’s own smart initiatives, such as CERTAN. Additionally, the study identified smart technologies and strategies, including ITMS and public transportation enhancement.

A third theme that come forward multiple times is the integration of shared vehicles. Not only by micro-mobility solutions or shared e-scooters or bikes, also autonomous vehicles or even small buses could be shared in regard of lower carbon emissions. Several studies, such as Bieliński & Ważna (2020), have indicated that micro-mobility solutions are becoming more prevalent, with bike-sharing and e-scooters being particularly popular and influential.

However, all these common themes regard smart initiatives, strategies, or technologies, but one of the most important themes is the supportive policy and regulatory frameworks. The successful implementation of STS necessitates the formulation of robust policies that facilitate innovation while guaranteeing environmental sustainability. The Singaporean Green Plan 2030 provides a comprehensive framework for the transition to smart, sustainable transportation solutions.

All the issues discussed in this chapter involved the same set of actors, stakeholders and policies. For example, the studies conducted by Wan (2020) and Haque et al. (2013) were of significant value in demonstrating the impact of intelligent traffic management systems on congestion and emissions. A major role is played by the LTA of Singapore as an actor responsible for the entire transport network of the country. One of the biggest stakeholders is the commuters themselves who are involved through public engagement. Smaller technology companies are also involved, as well as the other Singapore authorities mentioned above.

The overarching question is whether the technologies and strategies proposed in sub-question two, and further examined in sub-question three, would be effective in Singapore. Given that Singapore is already engaged in the implementation of smart transportation technologies, several of the strategies and technologies identified in sub-question two are already being utilised in Singapore. However, the scoping review indicates a positive correlation between these strategies, technologies, and initiatives, suggesting that Singapore is already making progress but has the potential to further enhance its transport network through continued development in this area.

In conclusion, the thematic analysis of STS in Singapore reveals a multifaceted approach to reducing carbon emissions. The identified themes not only highlight the current advancements in sustainable urban transportation but also provide a roadmap for future developments in this field. The findings demonstrate the potential of STS to significantly contribute to Singapore's sustainability goals and serve as a model for other cities worldwide.

5 Discussion and Conclusion

The final answer to the research question will be presented in the concluding chapter, following after a discussion of the findings. The discussion will commence with a summary of the key findings which will be followed by an interpretation of those findings. Subsequently, the limitations of the study and potential avenues for future research will be outlined. This will be followed by the conclusion of the scoping review, which will provide an overview of the study and include some final remarks. Subsequently, the references and appendix will be provided to conclude this scoping review.

5.1 Discussion

5.1.1 Summary of Key Findings

The principal findings of this preliminary investigation indicate the existence of several initiatives that have already been implemented or are scheduled for implementation in Singapore. The mentioned initiatives make use of strategies and technologies that have been empirically demonstrated to be carbon emission reduction effective. A significant contributor to these developments is the Land Transport Authority of Singapore, which has taken the opinions of its commuters into account. In section 4.5 of the discussion of the third sub-question, it is evident that EVs and the requisite charging infrastructure are the most effective means of reducing carbon emissions.

5.1.2 Interpretation of Findings

These findings indicate that Singapore is already performing well in reducing its carbon emissions in relation to its transport system. Regarding its public administration, Singapore has established policies in accordance with its Green Plan 2030. In addition to focusing on its own initiatives, the country is setting a benchmark for other cities aiming to implement similar strategies. Additionally, Singapore implements promotional initiatives to encourage the utilisation of more environmentally friendly modes of transportation. Nevertheless, they can still improve on this. The planned initiatives will integrate numerous EVs, which will in turn facilitate the development of an adequate charging infrastructure. This represents a significant step towards the country's net-zero goal of 2050. This indicates that Singapore is already on the right trajectory and that continued development and implementation of these strategies will enable it to make significant progress towards achieving a CO2-neutral environment.

5.1.3 Limitations of the Study

A scoping review of the literature revealed that a significant number of articles were identified as potentially relevant to the study yet were ultimately excluded due to various reasons. This implies that not all pertinent articles on the subject have been considered. A further limitation of the articles examined is the language barrier. Singapore has four official languages, one of which is English while the others are Malay, Tamil, and Singaporean Mandarin. However, articles published in the other official languages, beyond English, have been excluded from this scoping review due to insufficient knowledge of said languages to utilize them. Finally, the rapidly evolving nature of the field ensures that the findings of this scoping review remain relevant for the time being, given that many studies included were published in 2020 or later. Nevertheless, the field of STS is a rapidly evolving technology, with the potential for significant change in a relatively short period of time. Therefore, the research landscape is predicted to continue to keep rapidly adapting and changing.

5.1.4 Areas for Future Research

For future research, it is recommended that the following additional gaps are identified. As previously stated, the study's limitations include the rapid evolution of the technology in question. Given that Singapore is currently engaged in the development of new technologies, such as the whole CERTAN initiative, it is recommended that future research examine new findings in relation to these new initiatives, which are currently still being developed. A further suggestion for future research is to examine the effectiveness of the systems in greater depth. This is a scoping review, rather than a comprehensive examination of the technical aspects of carbon emission reduction. Finally, it is recommended that further studies be included in this scoping review to integrate additional data, which was not possible due to the current limitations of words and time.

5.2 Conclusion

5.2.1 Overview of the Study

In conclusion, the answer to the primary research question will now be presented. The question posed was as follows: "How can smart transportation systems contribute to the reduction of carbon emissions in Singapore?" By addressing the three sub-questions in the analysis chapter, all aspects of STS have been examined. The first sub-question was to get an indication of what Singapore is currently implementing and planning to implement in terms of intelligent transport. The second question looked at what makes these systems work and how, and how this relates to Singapore's initiatives. The final question was to see how effective the systems are in reducing carbon emissions, to fulfil the last part of the main research question, i.e. to see if it makes a significant difference.

It can be concluded that STS can play a significant role in reducing carbon emissions in Singapore. The Land Transport Authority (LTA) is a statutory board under the Singaporean government. It is responsible for regulating the transport system and has made significant progress in making the country's transport network more sustainable. However, there is still a long way to go. Singapore has the potential to further develop its STS initiatives through the incorporation of new carbon-free technologies and strategies. It has been demonstrated that these technologies and strategies result in a reduction of over 50% of carbon emissions. Consequently, it can be concluded that Singapore can make a significant contribution to the reduction of carbon emissions via STS.

5.2.2 Final Remarks

In conclusion, the most effective method to reduce carbon emissions in transportation is by decreasing the number of miles driven. This scoping review identifies strategies and technologies that aim to achieve this goal through regulatory measures, actor collaboration, financial investments, and technological advancements. The implementation of effective policies, exemplified by Singapore's Green Plan 2030, provides a regulatory framework for the reduction of emissions. The collaboration between government agencies, private sector stakeholders, and the public, ensures the seamless integration of intelligent transport systems. Financial resources support the construction of infrastructure, such as EV charging stations and intelligent traffic management systems, which facilitate congestion reduction and idle time minimisation. Technological advancements, such as big data analytics and machine learning (AI), further enhance traffic management and emissions reduction, thus setting global sustainability benchmarks. The tide might change in a positive way, regarding climate change, if this development continues. It, then, may not be floodings that will face parts of the world, but the introduction of a healthier and more sustainable living.

6 References

Abduljabbar, R. L., Liyanage, S., & Dia, H. (2021). The role of micro-mobility in shaping sustainable cities: A systematic literature review. *Transportation Research. Part D, Transport And Environment*, *92*, 102734. https://doi.org/10.1016/j.trd.2021.102734

Abeydeera, L. H. U. W., Mesthrige, J. W., & Samarasinghalage, T. I. (2019). Global Research on Carbon Emissions: A Scientometric Review. *Sustainability*, *11*(14), 3972. https://doi.org/10.3390/su11143972

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal Of Social Research Methodology*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Assessing Singapore's electric vehicle policies. (n.d.). In *IAEE Energy Forum: Vol. Fourth Quarter 2020* (p. 21). https://d1wqtxts1xzle7.cloudfront.net/64623680/Doshi_rev_Singapore_EV__IAEE-libre.pdf?1602128248=&response-content-disposition=inline%3B+file

Barrionuevo, J. M., Berrone, P., & Costa, J. E. R. I. (2012). Smart Cities, Sustainable Progress: Opportunities for Urban Development. *IESE Insight*, *14*, 50–57. https://doi.org/10.15581/002.art-2152

Barth, M. J., Wu, G., & Boriboonsomsin, K. (2015). Intelligent Transportation Systems and Greenhouse Gas Reductions. *Current Sustainable/Renewable Energy Reports*, *2*(3), 90–97. https://doi.org/10.1007/s40518-015-0032-y

Benevolo, C., Dameri, R. P., & D'Auria, B. (2016). Understanding the concept of smart cities and devising transportation solutions for intelligent urban areas. *Advanced Science Letters, 22*(5-6), 1330-1333. https://www.researchgate.net/publication/379329325_Understanding_the_Concept_of_Smart_Cities_and_Devising_Transportation_Solutions_for_Intelligent_Urban_Areas

Bieliński, T., & Ważna, A. (2020). Electric Scooter Sharing and Bike Sharing User Behaviour and Characteristics. *Sustainability*, *12*(22), 9640. https://doi.org/10.3390/su12229640

Bock, P., Kreutz, K., & Lienkamp, M. (2019). Data-driven adaptive traffic simulation of an expressway. Technical University of Munich. Retrieved from https://mediatum.ub.tum.de/doc/1518517/db3zshye0xzntqv7er2exg14q.Data_driven_Adaptive_Traffic_simulation_of_an_expressway.pdf

Carbon tax. (n.d.). https://www.nccs.gov.sg/singapores-climate-action/mitigation-efforts/carbontax/#:~:text=Singapore%20implemented%20a%20carbon%20tax,period%20for%20emitters%20to%20adjust

Carey, C. (2022, 17 may). *Study shows smart traffic systems could cut CO2 emissions*. Cities Today. https://cities-today.com/study-shows-smart-traffic-systems-could-cut-co2-emissions/#:~:text=Global%20savings%20in%20CO2%20emissions,a%20growth%20of%2041%20percent.

Chang, F., & Das, D. (2020). Smart Nation Singapore: Developing Policies for a Citizen-Oriented Smart City Initiative. In *Developing National Urban Policies* (pp. 425–440). https://doi.org/10.1007/978-981-15-3738-7_18

Chang, Y. (2019). Green Finance in Singapore: Barriers and Solutions. *Social Science Research Network*. https://doi.org/10.2139/ssrn.3326287

Chen, Y., & Lee, C. (2020). Does technological innovation reduce CO2 emissions?Cross-country evidence. *Journal Of Cleaner Production*, *263*, 121550. https://doi.org/10.1016/j.jclepro.2020.121550

City in nature. (n.d.). https://www.greenplan.gov.sg/key-focus-areas/city-in-nature/

Cordero, E. C., Centeno, D., & Todd, A. M. (2020). The role of climate change education on individual lifetime carbon emissions. *PloS One*, *15*(2), e0206266. https://doi.org/10.1371/journal.pone.0206266

Deutch, J. M. (2020). Is net zero carbon 2050 possible? *Joule*, *4*(11), 2237–2240. https://doi.org/10.1016/j.joule.2020.09.002

Devihosur, S. C., Chidire, A., Massier, T., & Hamacher, T. (2024). Estimating the Energy Demand and Carbon Emission Reduction Potential of Singapore's Future Road Transport Sector. *Sustainability*, *16*(11), 4754. https://doi.org/10.3390/su16114754

Diao, M. (2019). Towards sustainable urban transport in Singapore: Policy instruments and mobility trends. *Transport Policy*, *81*, 320–330. https://doi.org/10.1016/j.tranpol.2018.05.005

Dong, H., Xue, M., Xiao, Y., & Liu, Y. (2021). Do carbon emissions impact the health of residents? Considering China's industrialization and urbanization. *Science Of The Total Environment*, *758*, 143688. https://doi.org/10.1016/j.scitotenv.2020.143688

Dyczkowska, J., Olkiewicz, M., Chamier-Gliszczynski, N., & Królikowski, T. (2023). Mobility-as-a-Service (MaaS) as a solution platform for the city and the region: case study. *Procedia Computer Science*, *225*, 4092–4100. https://doi.org/10.1016/j.procs.2023.10.405

Energy reset. (n.d.). https://www.greenplan.gov.sg/key-focus-areas/energy-reset/

Environmental and Energy Study Institute (EESI). (n.d.). *Fact Sheet | Climate, Environmental, and Health Impacts of Fossil Fuels (2021) | White Papers | EESI*. https://www.eesi.org/papers/view/fact-sheet-climate-environmental-and-health-impacts-of-fossil-fuels-2021

Faisal, A., Kamruzzaman, M., Yigitcanlar, T., & Currie, G. (2019). Understanding autonomous vehicles: A systematic literature review on capability, impact, planning and policy. *Journal of Transport and Land Use*, *12*(1), 45–72. https://www.jstor.org/stable/26911258

Forrest, J. A. (2022). Urban space and the engineers of time : assembling an intelligent transportation system in Los Angeles, California. *UBC Library Open Collections*. https://doi.org/10.14288/1.0421803

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science*, *357*(6357), 1242–1244. https://doi.org/10.1126/science.aao3760

Ghawate, N., Biradar, G., Kadus, N., Patil, P., & Tayade, A. (2023). Intelligent Traffic Management System Based on Traffic Density. *International Journal For Multidisciplinary Research*, *5*(6). https://doi.org/10.36948/ijfmr.2023.v05i06.8511

Gopalakrishnan, K., Chitturi, M., & Prentkovskis, O. (2015). SMART AND SUSTAINABLE TRANSPORT: SHORT REVIEW OF THE SPECIAL ISSUE. *Transport*, *30*(3), 243–246. https://doi.org/10.3846/16484142.2015.1099407

Government of Canada, Canadian Institutes of Health Research,. (2010, 8 april). *A Guide to Knowledge Synthesis - CIHR*. https://www.cihr-irsc.gc.ca/e/41382.html

Green economy. (n.d.). https://www.greenplan.gov.sg/key-focus-areas/green-economy/

GreenBiz. (2023). Micromobility and transit pave the way to net zero. GreenBiz. Retrieved from https://www.greenbiz.com/article/micromobility-and-transit-pave-way-net-zero#:~:text=One%20analysis%20found%20that%20if,of%20all%20U.S.%20transport%20emissions.

Handayani, K., Anugrah, P., Goembira, F., Øverland, I., Suryadi, B., & Swandaru, A. (2022). Moving beyond the NDCs: ASEAN pathways to a net-zero emissions power sector in 2050. *Applied Energy*, *311*, 118580. https://doi.org/10.1016/j.apenergy.2022.118580

Haque, M., Chin, H., & Debnath, A. (2013). Sustainable, safe, smart—three key elements of Singapore's evolving transport policies. *Transport Policy*, *27*, 20–31. https://doi.org/10.1016/j.tranpol.2012.11.017

Hinchly, C. (2024, 17 may). *Electric Cars - Do They Really Reduce Carbon Emissions? - Auditel*. Auditel. https://auditel.co.uk/electric-cars-reduce-carbon-emissions/#:~:text=According%20to%20a%20report%20from,of%20the%20vehicles%20being%20compared.

Holguín-Veras, J., Amaya-Leal, J., Wojtowicz, J., Jaller, M., González-Calderón, C., Sánchez-Díaz, I., ... & Browne, M. (2016). The promise of the sharing economy among urban freight systems. Transportation Research Part A: Policy and Practice, 86, 53-68. https://doi.org/10.1016/j.tra.2016.02.004

Infra Journal. (n.d.). Oslo, capital of EV cars. Retrieved June 12, 2024, from https://www.infrajournal.com/en/w/oslo-capital-ev-cars#:~:text=Promoting%20electric%20vehicles%2C%20restricting%20the,and%20acquisition%20of%20electric%20buses.

Intelligent Transport Systems. (n.d.). Google Books. https://books.google.nl/books?hl=en&lr=&id=93JXCQAAQBAJ&oi=fnd&pg=PA5&dq=intelligent+transport+systems+definition&ots=LIYX4rzIdy&sig=LnxzxaDOQQbv68RLc0OGQf-fVv8#v=onepage&q=intelligent%20transport%20systems%20definition&f=false

Intelligent Transport. (2024, 18 april). *MaaS Global, creator of Whim app, acquired by umob*. https://www.intelligenttransport.com/transport-news/180138/maas-global-whim-app-umob/

Introduction to Intelligent Systems in Traffic and Transportation. (n.d.). Google Books. https://books.google.nl/books?hl=en&lr=&id=p4RyEAAAQBAJ&oi=fnd&pg=PR1&dq=what+intelligent+transportation+systems+exist+&ots=IuBMj9vCMm&sig=nedlIhzmsaCfdm2P27jbuIh5Tq0&redir_esc=y#v=onepage&q=what%20intelligent%20transportation%20systems%20exist&f=false

Jalaney, J., & Ganesh, R. S. (2019). Review on IoT Based Architecture for Smart Public Transport System. *International Journal Of Applied Engineering Research*, *14*(2), ISSN0973-4562. https://www.ripublication.com/ijaer19/ijaerv14n2_19.pdf

Jimenez, J. A. (2017). Smart transportation systems. In *Springer eBooks* (pp. 123–133). https://doi.org/10.1007/978-3-319-59381-4_8

Kang, N., Yoo, S., & Kim, H. (2020). Examining the role of technology diffusion in urban transportation planning. *Transport Reviews, 40*(4), 433-452.

Kazancoglu, Y., Ozbiltekin-Pala, M., & Ozkan-Ozen, Y. D. (2021). Prediction and evaluation of greenhouse gas emissions for sustainable road transport within Europe. *Sustainable Cities And Society*, *70*, 102924. https://doi.org/10.1016/j.scs.2021.102924

Kim, J., Park, H., & Lee, S. (2019). Understanding the long-term effects of smart transportation systems on urban environments. Urban Studies, 56(12), 2458-2475.

Lee, S. A., & Qian, J. (2017). The evolving Singaporean Welfare State. *Social Policy & Administration*, *51*(6), 916–939. https://doi.org/10.1111/spol.12339

Lehtilä, A., Savolainen, I., & Syri, S. (2005). The role of technology development in greenhouse gas emissions reduction: The case of Finland. *Energy*, *30*(14), 2738–2758. https://doi.org/10.1016/j.energy.2004.07.019

Lei, W., Alves, L. G. A., & Amaral, L. A. N. (2022). Forecasting the evolution of fast-changing transportation networks using machine learning. *Nature Communications*, *13*(1). https://doi.org/10.1038/s41467-022-31911-2

Lin, B. B., Ossola, A., Alberti, M., Andersson, E., Bai, X., Dobbs, C., Elmqvist, T., Evans, K. L., Frantzeskaki, N., Fuller, R. A., Gaston, K. J., Haase, D., Jim, C. Y., Konijnendijk, C., Nagendra, H., Niemelä, J., McPhearson, T., Moomaw, W. R., Parnell, S., . . . Tan, P. Y. (2021). Integrating solutions to adapt cities for climate change. *The Lancet. Planetary Health*, *5*(7), e479–e486. https://doi.org/10.1016/s2542-5196(21)00135-2

Mo, B., Cao, Z., Zhang, H., Shen, Y., & Zhao, J. (2021). Competition between shared autonomous vehicles and public transit: A case study in Singapore. *Transportation Research. Part C, Emerging Technologies*, *127*, 103058. https://doi.org/10.1016/j.trc.2021.103058

Mo, J. Y. (2021). Technological innovation and its impact on carbon emissions: evidence from Korea manufacturing firms participating emission trading scheme. *Technology Analysis & Strategic Management*, *34*(1), 47–57. https://doi.org/10.1080/09537325.2021.1884675

Ng, V., & Kim, H. M. (2021). Autonomous vehicles and smart cities: A case study of Singapore. In *Elsevier eBooks* (pp. 265–287). https://doi.org/10.1016/b978-0-12-818886-6.00014-9

Nielsen, K. S., Nicholas, K. A., Creutzig, F., Dietz, T., & Stern, P. C. (2021). The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions. *Nature Energy*, *6*(11), 1011–1016. https://doi.org/10.1038/s41560-021-00900-y

Oh, S., Seshadri, R., Azevedo, C. L., Kumar, N., Basak, K., & Ben-Akiva, M. (2020). Assessing the impacts of automated mobility-on-demand through agent-based simulation: A study of Singapore. *Transportation Research. Part A, Policy And Practice*, *138*, 367–388. https://doi.org/10.1016/j.tra.2020.06.004

Omase, N. N., Mittal, N. S. K., Palaniraja, N. S., Guchhait, N. P., Patil, N. M., & Mundra, N. P. (2023). A comprehensive review of electric vehicle charging infrastructure and associated challenges. *International Journal Of Science And Research Archive*, *10*(1), 834–840. https://doi.org/10.30574/ijsra.2023.10.1.0832

Open Data & Analytics for urban transportation. (n.d.). https://www.smartnation.gov.sg/initiatives/open-data-analytics/

Our vision. (n.d.). https://www.greenplan.gov.sg/vision/#:~:text=Singapore's%20urban%20environment%20makes%20us,cleaner%2Denergy%20models%20by%202030.

Paris La Défense. (2023, February 2). More Vélib’ stations in La Défense by 2025. Paris La Défense. https://parisladefense.com/en/news/article/transport/velib-stations-2025

Peters, M. D., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., & Soares, C. B. (2015). Guidance for conducting systematic scoping reviews. *International Journal Of Evidence-based Healthcare*, *13*(3), 141–146. https://doi.org/10.1097/xeb.0000000000000050

Prakasam, S. (2008). IC CARDS: The Evolution of e-payments in Public Transport—Singapore’s Experience. In Japan Railway & Transport Review, *Japan Railway & Transport Review* (Nummer No. 50). http://www.ejrcf.or.jp/jrtr/jrtr50/pdf/36_39_web.pdf

Rajput, P., Chaturvedi, M., & Patel, V. (2022). Development of advanced public transportation system with limited infrastructure support. *Software Impacts*, *14*, 100434. https://doi.org/10.1016/j.simpa.2022.100434

Research Guides: Scoping Reviews: Data extraction. (n.d.). https://libguides.wustl.edu/c.php?g=1316625&p=9681258#:~:text=For%20scoping%20reviews%2C%20data%20extraction,the%20questions%20of%20the%20review

Saharan, S., Bawa, S., & Kumar, N. (2020). Dynamic pricing techniques for Intelligent Transportation System in smart cities: A systematic review. *Computer Communications*, *150*, 603–625. https://doi.org/10.1016/j.comcom.2019.12.003

Schulz, W., & Geis, I. (2015). Future role of cost–benefit analysis in intelligent transport system-research. *IET Intelligent Transport Systems*, *9*(6), 626–632. https://doi.org/10.1049/iet-its.2014.0203

Singapore Green Plan 2030. (z.d.). https://www.greenplan.gov.sg/

Singh, G., Misra, S. C., Daultani, Y., & Singh, S. (2024). Electric vehicle adoption and sustainability: Insights from the bibliometric analysis, cluster analysis, and morphology analysis. *Operations Management Research/Operations Management Research : Advancing Practice Through Research*. https://doi.org/10.1007/s12063-024-00442-y

Smart transport Initiatives. (n.d.). https://www.smartnation.gov.sg/initiatives/transport/

Smart transportation system using IoT. (2017, 1 August). IEEE Conference Publication | IEEE Xplore. https://ieeexplore.ieee.org/abstract/document/8358540

Sources of Greenhouse Gas Emissions | US EPA. (2024, 15 May). US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#:~:text=The%20largest%20sources%20of%20transportation,%2C%20pickup%20trucks%2C%20and%20minivans

Sovacool, B. K. (2016). How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Research & Social Science*, *13*, 202–215. https://doi.org/10.1016/j.erss.2015.12.020

Sun, C., Zhang, Y., Ma, W., Wu, R., & Wang, S. (2022). The Impacts of Urban Form on Carbon Emissions: A Comprehensive Review. *Land*, *11*(9), 1430. https://doi.org/10.3390/land11091430

Tan, S. Y., & Taeihagh, A. (2021). Adaptive governance of autonomous vehicles: Accelerating the adoption of disruptive technologies in Singapore. *Government Information Quarterly*, *38*(2), 101546. https://doi.org/10.1016/j.giq.2020.101546

Tarulescu, S., Tarulescu, R., Soica, A., & Leahu, C. I. (2017). Smart Transportation CO2 Emission Reduction Strategies. *IOP Conference Series. Materials Science And Engineering*, *252*, 012051. https://doi.org/10.1088/1757-899x/252/1/012051

Team, R. X., & Team, R. X. (2024, 18 June). *Why is Public Transport Better for the Environment? The Truth Revealed*. Road XS. https://www.roadxs.com/transport/why-is-public-transport-better-for-the-environment/#:~:text=It%20is%20a%20potent%20tool,the%20removal%20of%2075%20cars.

The ASEAN Post. (2019, November 9). Smart Nation: Singapore's intelligent transport system and ITS. The ASEAN Post. https://theaseanpost.com/article/smart-nation-singapores-intelligent-transport-system-its

Transport and mobility. (2024b, January 19). European Environment Agency's Home Page. https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility#:~:text=The%20transport%20sector%20causes%20substantial,noise%20pollution%20and%20habitat%20fragmentation

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., Levac, D., Ng, C., Sharpe, J. P., Wilson, K., Kenny, M., Warren, R., Wilson, C., Stelfox, H. T., & Straus, S. E. (2016). A scoping review on the conduct and reporting of scoping reviews. *BMC Medical Research Methodology*, *16*(1). https://doi.org/10.1186/s12874-016-0116-4

Tu, R., Gai, Y., Farooq, B., Posen, D., & Hatzopoulou, M. (2020). Electric vehicle charging optimization to minimize marginal greenhouse gas emissions from power generation. *Applied Energy*, *277*, 115517. https://doi.org/10.1016/j.apenergy.2020.115517

United Nations. (n.d.). *Net Zero Coalition | United Nations*. https://www.un.org/en/climatechange/net-zero-coalition

Vijayaraghavan, V., & Leevinson, J. R. (2020). Intelligent Traffic Management Systems for Next Generation IoV in Smart City Scenario. In *Springer eBooks* (pp. 123–141). https://doi.org/10.1007/978-3-030-36167-9_6

Wan, F., & Li, M. (2020). Research on Coordinated Processing Scheme of Intelligent Transportation under Big Data Structure. *2020 5th International Conference On Electromechanical Control Technology And Transportation (ICECTT)*. https://doi.org/10.1109/icectt50890.2020.00142

Wan, P. (2022). Traffic congestion improvement through an intelligent traffic control system. *IEEE Xplore*. https://doi.org/10.1109/ITSC55140.2022.10305786

Wan, X. (2020). Intelligent traffic management systems and their role in urban emission reduction. *Urban Transport*, *10*(3), 45-60.

What is a Smart Traffic Management System? (n.d.). Symmetry Electronics. https://www.symmetryelectronics.com/blog/what-is-a-smart-traffic-management-system/#:~:text=Defining%20Smart%20Traffic%20Management%20Systems&text=Intelligent%20transportation%20systems%20(ITS)%2C,city%20streets%20through%20connected%20technology

Wolfram, P., Lutsey, N., & INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION. (2016). Electric vehicles: Literature review of technology costs and carbon emissions. In *INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION WORKING PAPER*. https://theicct.org/sites/default/files/publications/ICCT_LitRvw_EV-tech-costs_201607.pdf

Xiang Zhang, Haojie Sun, Xiaoyang Pei, Linghui Guan, Zihao Wang, Evolution of technology investment and development of robotaxi services, Transportation Research Part E: Logistics and Transportation Review, Volume 188, 2024, 103615, ISSN 1366-5545, https://doi.org/10.1016/j.tre.2024.103615.

Yang, A., Liu, C., Yang, D., & Lu, C. (2023). Electric vehicle adoption in a mature market: A case study of Norway. *Journal Of Transport Geography*, *106*, 103489. https://doi.org/10.1016/j.jtrangeo.2022.103489

Yiğitcanlar, T., & Kamruzzaman, M. (2018). Does smart city policy lead to sustainability of cities? *Land Use Policy*, *73*, 49–58. https://doi.org/10.1016/j.landusepol.2018.01.034

Yu, L., Jia, S., & Shi, Q. (2009). Research on Transportation-Related Emissions: Current Status and Future Directions. *Journal Of The Air & Waste Management Association*, *59*(2), 183–195. https://doi.org/10.3155/1047-3289.59.2.183

Zhang, K., & Batterman, S. (2013). Air pollution and health risks due to vehicle traffic. *The Science of the total environment*, *450-451*, 307–316. https://doi.org/10.1016/j.scitotenv.2013.01.074

Zhang, M., Li, B., & Yin, S. (2020b). Is Technological Innovation Effective for Energy Saving and Carbon Emissions Reduction? Evidence From China. *IEEE Access*, *8*, 83524–83537. https://doi.org/10.1109/access.2020.2990678

7 Appendix

Appendix A

Standardized data extraction form

Data	Value	Notes	Research question/subQ
Study identification			
Title of the study			
Authors			
Publication year			
Journal/source			
Country of study			
Study characteristics			
Study objectives		Primary and secondary objectives	
Study design			
Describe design		Qualitative study, randomized controlled trial, observational study, quantitative study	
Setting			
Specify the setting and location			
Sample characteristics, if applicable			
Sample size			
Population details		Demographic details; age, gender, socioeconomic status	
Inclusion/exclusion criteria		Criteria used to select participants	
Methodology			
Interventions used		Interventions or exposures being used	
Data collection methods		Tools and procedures used for data collection	
Outcome measures		Primary and secondary outcomes measured in study	
Results			
Key findings		Main findings relevant for this study	
Statistical analysis		Statistical methods used and significance of the results	
Contextual information			
Setting characteristics		Additional information that may influence results	
Study limitations		Noted by authors or identified during extraction	
Funding source and conflicts of interest			

Additional information			
Key quotes		Significant quotes from study relevant to review	
Supplementary materials		Materials or appendices provided by study	