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"SUSTAINABLE MOBILITY, CLIMATE CHANGE AND GEOPOLITICS"

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ABSTRACT

The aim of the study is to investigate methods and tools for achieving sustainability in the mobility sector, addressing associated challenges and examining the geopolitical influences on this transformation. The research methodology involves a comprehensive review of international literature. The study focuses on the multifaceted challenges and strategies associated with achieving sustainable mobility in the broader context of the mobility sector, encompassing land, air, and sea transport, as well as urban mobility. Recognizing the environmental impact of the mobility industry, the paper explores avenues for making transportation more eco-friendly while enhancing efficiency, service quality, and accessibility. The pursuit of sustainability involves diverse approaches, including the adoption of alternative fuels, changes in travel patterns, and the integration of innovative technologies to reduce environmental footprints. However, the path to sustainable mobility is laden with challenges such as financial constraints, consumer attitudes, and the intricate environmental implications of renewable energy technologies. Social challenges related to accessibility and inclusivity, the complexity of the transport sector, and debates surrounding the concept of sustainability further complicate the issue. The study delves into the geopolitical dimensions of sustainable mobility, examining the roles of renewable energy, potential conflicts over critical materials, and the emergence of new players in the energy sector. Urban mobility, a crucial component of the broader mobility sector, receives special attention. The study explores sustainable and intelligent mobility systems in the context of urban development, emphasizing efficient, green, and accessible networks, digitalization, and intelligent transport management systems. Many cities globally are already adopting strategies to transform urban transport systems sustainably.

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Keywords/phrases: sustainability, mobility, alternative fuels, renewable energy sources, geopolitics, urban mobility

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CHAPTER 1

INTRODUCTION

1.1 Background

The mobility sector, which includes land, air and sea transport of passengers and freight, as well as urban mobility, i.e. travel in the urban environment, is one of the most environmentally harmful industry sectors. For this reason, the scientific community, organizations, relevant stakeholders and governments worldwide are looking for ways to make this sector greener and more sustainable. Sustainability in general, and of the mobility sector in particular, is not only about reducing the impact on the environment; it also involves increasing efficiency, quality of service and accessibility for all.

The ways in which the sustainability of the transport and mobility sector can be achieved are manifold; they include the use of alternative fuels such as electricity, hydrogen and biofuels, changing people's habits and promoting travel patterns such as public transport, walking, cycling, carpooling, etc., as well as the integration of innovative technologies that increase the efficiency of transport systems, reducing time, fuel requirements, etc. and ultimately reducing the environmental footprint.

However, sustainable mobility is not easy to achieve. There are a variety of challenges it brings, which include financial constraints, consumer attitudes, the environmental footprint of deploying auxiliary equipment that harnesses renewable energy sources. In addition, there are social challenges relating to whether it is feasible for sustainable mobility to be truly accessible and inclusive, challenges relating to the complexity of the transport sector, the ambiguity of the concept of sustainability and how it can be applied in each case, and the emergence of sustainability as the only solution to climate change that does not allow for a broader debate that includes other proposals.

There is also a strong debate on the role of renewable energy in the geopolitical scene, with the emergence of new players in the energy sector, the precariousness that a sustainable mobility system that has incorporated technologies to a very large extent may bring, and the possibility of conflicts to claim the critical materials needed for new technologies.

In addition to the transport of passengers and freight on a large scale, the mobility sector also includes urban mobility. Urban mobility refers to all movements that take place within cities. The city of the future has achieved the development of sustainable and intelligent mobility systems through the development of efficient, green and accessible networks, the digitalisation of processes, the integration of intelligent transport management systems, etc. Already many cities around the world are adopting strategies to make urban transport systems sustainable.

All of the above are discussed in the remainder of this paper. The purpose of the study is to explore the ways, methods and tools by which the sustainability of the mobility sector can be achieved, the challenges, barriers and constraints towards achieving this, as well as the role that geopolitics will play in achieving sustainable mobility. To achieve this purpose, a review of international literature was conducted.

1.2 Structure of thesis

The study is structured as follows:

The first chapter analyzes the background and provides an overview of the thesis structure, setting the context for the research and outlining the main areas of investigation.

The second chapter presents the definitions and goals of sustainable mobility, followed by an exploration of the European vision on the topic. It then delves into the various challenges associated with sustainable mobility, including the emphasis on it as a response to the climate crisis, social inclusiveness, the complexity of transport systems, and the ambiguity of sustainable mobility concepts. The chapter also reviews key approaches, policies, and initiatives aimed at promoting sustainable mobility, such as alternative vehicle fuels, electromobility, hydrogen-powered vehicles, and biofuels. Additionally, it examines government initiatives and people's habits, highlighting the promotion of cycling, walking, public transportation, eco-driving, and various pricing and incentive mechanisms. Finally, it discusses Intelligent Transport Systems (ITS), including Advanced Traveler Information Systems (ATIS), Advanced

Traffic Management Systems (ATMS), Advanced Public Transportation Systems (APTS), and Cooperative Intelligent Transport Systems (C-ITS).

The third chapter outlines the research questions, methods, and expected results, providing a roadmap for the empirical and theoretical exploration conducted in the thesis.

The fourth chapter introduces urban sustainable development and mobility, focusing on sustainable urban mobility, smart cities, and the integration of smart and sustainable mobility. It presents various case studies to illustrate these concepts in practice. The chapter also explores the role of geopolitics in achieving sustainable mobility, discussing issues such as conflicts and energy security, access to critical materials for new technologies, cross-border electricity trade, cyber attacks, and the emergence of new key players in the global energy market.

The fifth chapter summarizes the findings and conclusions of the thesis, addressing the limitations of the study and offering recommendations for future research and policy development.

The thesis concludes with a comprehensive list of references, providing the sources and literature reviewed throughout the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions and goals

Sustainable transport and mobility are key factors in achieving the objectives of the Paris Agreement, the New Urban Agenda and the Sustainable Development Goals. The transport and mobility sector, in addition to providing important services to society, has a decisive impact on a number of sustainability challenges, such as climate change, energy security, resource efficiency, air quality, travel safety, etc.

There is no clear and universal definition of sustainable mobility. Many scholars have attempted to define “sustainable mobility” and “sustainable urban mobility” based on the different disciplines they serve (Marsden et al., 2010). The general approach is that, just as the term “sustainability” refers to the development of society, the economy and the environment under conditions that will safeguard future generations, so too “sustainable mobility” refers to the development of travel and transport in a way that ensures economic prosperity, social cohesion and environmental protection (Litman, 2024).

The OECD (2000) report on urban mobility highlighted its impact on public health and stressed the need to develop it in such a way that the non-renewable energy sources used for transport are consumed at a rate that is lower than the rate of renewal of the sources that will replace them. The report stresses that a sustainable transport system is one which, over its entire life cycle, enables 75% of the objectives accepted by international bodies and organizations to be achieved. The same document recognizes the need to define indicators for assessing mobility in terms of its impact on the environment (OECD, 2000).

Sustainable transport can be defined as transport that is carried out in such a way that future generations bear less or equal social costs compared to today’s (Schipper, 1996). The World Bank’s Sustainable Development Council defines sustainable mobility as that which takes into account the needs of citizens to move freely, communicate, trade and develop relationships without sacrificing the values of the natural and man-made environment now and in the future.

According to Banister, in order to achieve sustainable travel, four key strategies should be implemented: reducing the number of trips, encouraging intermodal travel, reducing distances traveled and developing the form of cities in such a way as to reduce the need to transport and favor the development of public transport networks (Banister, 2008). Sustainable mobility is determined by a multitude of factors such as non-motorized travel and policies to promote it, the coupling of urban planning, especially land use planning, with urban traffic planning, compact urban development that favors the minimization of traveling within a city, the development of innovative tools, and citizen participation in all processes of planning and implementation of these principles (Hickman et al., 2013).

The Intergovernmental Twelfth Regional Environmentally Sustainable Transport (EST) Forum in Asia (2019) defines the objectives of sustainable mobility as follows:

- **Accessibility**. The successful transformation of the mobility sector to a sustainable mobility sector requires accessibility for all without exception to the innovative services that are being provided. Such services include high-quality public transport, as well as cycling and walking infrastructure. These services should be well integrated into society and be accessible and available to every person within the community, without discrimination.
- **Sharing**. Sharing should include carpooling, public transport feeder systems, shared cars etc.
- **Efficiency and electrification**. Efficiency refers to the optimal use of fuel to reduce losses. One approach in this direction is to drastically reduce the size and power of vehicles, which however is contrary to the trend of recent years. Electromobility should also aim at a more sustainable and efficient use of vehicles. The use of renewable energy sources reduces greenhouse gas emissions in the atmosphere.

The European Commission sets much more specific targets and deadlines for achieving them. The European Commission’s objectives, which are expected to be achieved through a smart, competitive, accessible, economical and safe transport system, include (European Commission, 2021):

- By 2030:
    - 100 cities in Europe will be able to qualify as “climate neutral”.

    - automated self-driving cars will be in operation on a large scale
    - at least 30 million zero-emission vehicles will be in operation in Europe
    - high-speed train mobility will double
    - transport by inland waterways and short sea shipping will increase by 25%
    - planned collective journeys of less than 500 km will be carbon-free
    - zero-emission vessels will be massively entering the market
    - all large cities in Europe will have their own sustainable urban mobility plan
- By 2035:
    - zero-emission large aircraft will be entering the market
- By 2050:
    - the emission from the transport sector will have been reduced by 90%
    - almost all land-based vehicles will be zero-emission
    - freight transport by rail will double
    - high-speed train mobility will triple
    - the multimodal Trans-European transport network (TEN-T) will be operational

2.2 The European vision about sustainable mobility

Travel within the EU has fostered increased unity and a stronger European identity, with the transport sector being the second-largest expense for European households, contributing 5% to European GDP and employing approximately 10 million individuals. However, this sector poses societal costs, including greenhouse gas emissions, air and noise pollution, accidents, road crashes, congestion, and biodiversity loss, negatively impacting health and well-being. Despite previous attempts, these costs remain inadequately addressed, with the transport sector's greenhouse gas emissions constituting a quarter of the EU's total emissions (European Commission, 2021).

The primary challenge for the transport sector is to substantially reduce emissions and promote sustainability, presenting opportunities for improving the quality of life, modernizing the European industry, creating jobs, developing innovative products and services, enhancing competitiveness, and striving for global leadership in zero-emission mobility. To achieve a 55% reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050, more ambitious policies are necessary, emphasizing a sustainable transport system as crucial for the success of the European Green Deal.

The COVID-19 crisis highlighted the critical role of transportation and associated social, health, and economic costs during limitations or halts to free movement. To overcome crises and reinforce EU autonomy and resilience, a coordinated European approach to connectivity and transport activity is essential. Therefore, EU transport policy should prioritize the development of a resilient transport system, promoting cohesion, reducing regional disparities, and enhancing connectivity and market access for all regions (European Commission, 2021).

Greening mobility is imperative for expanding the transportation industry in Europe, focusing on an efficient and interconnected multimodal transport system for passengers and freight. This involves investing in an affordable high-speed railway network, widespread recharging and refueling infrastructure for zero-emission vehicles, and the provision of renewable and low-carbon fuels. Digitalization and automation are crucial for modernizing the system, improving safety, security, reliability, and convenience, sustaining EU leadership, and enhancing global competitiveness through efficient logistics chains.

Decisive action is required to reduce reliance on fossil fuels by replacing current vehicle fleets with low- and zero-emission models and increasing the use of renewable and low-carbon fuels. Promoting sustainable forms of transportation, internalizing external costs, and implementing principles like "polluter pays" and "user pays," with a focus on carbon pricing and infrastructure charging mechanisms, is crucial. To achieve these goals, 82 initiatives within 10 flagships have been identified, with critical areas including sustainability, intelligence, and resilience in the transport and mobility sector (European Commission, 2021).

More specifically, with regard to sustainability, measures include:

- Expanding and consolidating the use of zero-emission vehicles, vessels and planes, and the use of renewable or low-carbon fuels in vehicles and related infrastructure (e.g. through the installation of 3 million public charging stations by 2030)
- Converting airports and ports to zero-emission (e.g. through the use of sustainable fuels)
- Making urban and interurban mobility healthy, safe and sustainable (e.g. through promoting the movement of people and freight by rail or encouraging cycling within urban environments)
- Greening freight and cargo transport (e.g. through increasing freight train movements)
- Pricing carbon and offering opportunities and incentives to users to use other fuels

In terms of intelligence, measures include:

- The interconnection and automation of multimodal mobility (e.g. through the issuance of a single ticket that can be used on different modes or the easy transfer of goods from one mode of transport to another)
- The integration of innovative technologies and artificial intelligence for the optimal operation of systems (e.g. through the use of unmanned drones and aircraft for surveillance and data recording)

In terms of resilience, measures include:

- Strengthening the Single Market (e.g. through investment in the Trans-European Transport Network (TEN-T) by 2030 and investment in the modernization of transport fleets)
- Increasing the accessibility and inclusiveness of transport modes
- Increasing safety in all modes of transport

2.3 Challenges

As the threat of climate change and its inevitable consequences become more than evident, the need for initiatives to reduce the extent of the phenomenon and the impact of its consequences is urgent. In this context, ways of reducing anthropogenic carbon dioxide emissions into the atmosphere are being sought. One of the most widespread methods is that of adopting sustainable mobility. Although the concept of sustainable mobility seems attractive, it hides a number of challenges in its adoption. Table 1 presents briefly the main challenges in the way of transforming the mobility systems. The topic is discussed in detail in the next paragraphs.

Table 1. Challenges to the sustainability of the mobility systems

Highlighting sustainable mobility as the only response to climate crisis	The singular emphasis on attaining sustainable mobility objectives precludes any consideration of alternative solutions or suitable adjustments for the future, such as those pertinent to the post-automotive era.
Inclusiveness and accessibility	Certain research indicates that policies supporting electric vehicles tend to disproportionately benefit middle-aged and higher-income men. Other studies propose that the widespread adoption of electric vehicles among the European populace reinforces consumerist and capitalistic patterns and behaviors.
Complexity of the transport and travel system	The ever-changing dynamics, continual integration of innovative technologies, and the intricate nature of transport systems—comprising three interacting subsystems: vehicles, infrastructure, and energy—render it challenging to formulate a specific mobility policy with distinct direction and objectives.
Ambiguity of the concept of sustainable mobility and subjective judgment	A universally applicable definition of sustainable mobility does not exist. Moreover, each community possesses distinct needs, resulting in the absence of a one-size-fits-all mobility model. Consequently, various policymakers and stakeholders employ different criteria to define, quantify, and assess sustainable mobility.
Limited focus on different aspects of the transports and travel systems	Contemporary literature and initiatives predominantly highlight the enhancement of existing mobility systems' efficiency, for example through the use of alternative fuels. However, there is a limited emphasis on exploring alternative mobility systems and strategies for reducing the overall need for transportation and travel.

2.3.1 Highlighting sustainable mobility as the only response to climate crisis

Many scholars have highlighted the risk of neglecting to address fundamental structural asymmetries, as sustainable mobility is projected as the key and perhaps the only solution to the climate crisis (Wasgaether et al., 2022). The emergence of electric vehicles as "winners of the future" undermines the discussion of the post-automotive era. In other words, the exclusive focus on achieving the goals of sustainable mobility leaves no room for discussion of other solutions or appropriate future adaptations (Remme et al., 2022).

2.3.2 Social challenges and inclusiveness

The social implications of sustainable mobility include concerns about reinforcing consumerist and capitalist patterns, exacerbating societal gaps, and favoring specific demographics, such as middle-aged and above-average income men, in the mass adoption of electric vehicles (Peters & Dütschke, 2014). Despite efforts, achieving socially inclusive sustainable urban mobility systems faces challenges, and there are no straightforward solutions (Remme et al., 2022).

Implementing policies for sustainable mobility involves addressing the confusion between shift and avoid approaches, exemplified by the policy of car-free zones (CFZs). The avoid approach requires a shift in land use and planning for local service provision, while the shift approach necessitates infrastructure development supporting alternative modes of travel, like public transport or cycling (Peters & Dütschke, 2014). Realizing the vision of sustainable mobility requires complementary policy mixes (Remme et al., 2022).

The transformation of transport and mobility systems poses the challenge of integrating technological innovations into the daily lives of citizens to change population habits (Martinez-Harms et al., 2018). This shift necessitates a strong vision for successful implementation.

2.3.3 Complexity of the transport and travel system

In recent decades, the transport and mobility sector has grown and expanded rapidly. Its dynamic nature and the constant incorporation of innovative technologies make the sector fast and easy to change. Such a condition makes its study and analysis quite a complex process. Moreover, the transport system itself is quite complex. It already consists of three subsystems, which affect the environment in different ways and should be studied separately, but always bearing in mind that they are interdependent interacting systems. These subsystems are: the transport vehicles, the transport infrastructure and the energy subsystem. Sustainability should be achieved in each of the subsystems (Berger et al., 2014).

In mobility systems, all technical aspects interact with each other: organizational frameworks, vehicles, infrastructure, embedded technologies, legislation, social attitudes, etc. These dynamic interactions create dependencies which make it difficult to develop a specific policy with clear objectives and direction. In order to make the transport and travel sector sustainable, a long-term and coordinated change is required (Geels et al., 2012; Berger et al., 2014).

2.3.4 Ambiguity of the concept of sustainable mobility and subjective judgment

As already mentioned, there is no universally applicable definition of sustainable mobility. By extension, the concept is subject to the subjective judgment of each competent authority, each policy maker and each other potential stakeholder as to what constitutes sustainable mobility, what the objectives that should be set are, and what the means to achieve these objectives are (Litman & Burwell, 2006). Often, sustainable mobility aims to solve immediate and local problems, ignoring global challenges.

In recent decades, international literature, in studying sustainable mobility, has incorporated a variety of other disciplines (anthropology, sociology, psychology) and research tools (Berger et al., 2014). The concept of sustainability of the transport sector has been transformed to incorporate all the different aspects of transport and mobility, such as land, sea and air transport, freight and goods transport, the movement of people within a city, etc. (Holden & Linnerud, 2011). The broadening of the concept of sustainable mobility has helped in understanding and interpreting it, but at the same time has increased the complexity of its definition, evaluation and quantification (Berger et al., 2014).

Finally, it should be noted that every community has different needs, and therefore the sustainability of the transport and travel sector has different objectives and is achieved in different ways. All the above-mentioned reasons create a confusion around the concept of sustainable mobility, making it extremely difficult to create a model that is completely effective and guarantees the achievement of sustainability in any transport or mobility system (Berger et al., 2014).

2.3.5 The key approaches to sustainable mobility

Sustainability in the transport sector is approached through three main strategies: transport and travel system efficiency, system change, and reduction in system usage (Berger et al., 2014). System efficiency improvement involves adopting alternative fuels and smart traffic management technologies to reduce emissions and enhance passenger and freight transport. System change advocates for a shift to alternative modes like public transport, carpooling, and car sharing. Reducing system usage focuses on changing behaviors, encouraging necessary travel only, and adopting habits like teleworking (Berger et al., 2014).

Banister (2008) emphasizes achieving sustainable mobility by transitioning to more efficient and environmentally friendly transport modes, incorporating greener technologies, and decreasing overall transport usage. Peters & Dütschke (2014) suggest three options: enhancing existing transport systems' efficiency, increasing the share of efficient modes (e.g., mass transit), and reducing overall transport and travel. Banister (2011) supports efficient transport system shifts like mass transit, walking, and cycling, integrating innovative technologies, minimizing distances in cities, and reducing commuting needs through information and telecommunication systems.

The current literature and global initiatives focus on improving transport system efficiency, notably through alternative fuel usage. While discussions about shifting to alternative transport systems exist, a universal and massive shift is not widespread (Berger et al., 2014). The debate on limiting the need for transport modes is less common, with a reluctance among scientists and policymakers to intervene in people's lifestyles and travel choices.

2.4. Policies and initiatives to promote sustainable mobility

Table 2 presents the main policies and initiatives that can promote sustainable mobility effectively. The topic of such policies and initiatives is discussed in detail in the following paragraphs.

Table 2. Policies and initiatives to promote sustainable mobility

Alternative vehicle fuels	**Government initiatives and people's habits**	**Intelligent Transport Systems (ITS)**
Electromobility	Cycling and walking promotion	Advanced Traveler Information System (ATIS)
Hydrogen powered vehicles	Collective and public transportation systems promotion	Advanced Traffic Management System (ATMS)
Biofuels	Eco-driving	Advanced Public Transportation System (APTS)
	Pricing, taxation and incentives	Cooperative Intelligent Transport Systems (C-ITS)

2.4.1 Alternative vehicle fuels

In order to achieve the objectives of sustainable mobility, it is important to explore and test alternative fuels that can be used for transport within and outside cities. The use of alternative fuels such as electricity, hydrogen and biofuels can contribute to reducing greenhouse gas emissions. The advantages of these alternative fuels over conventional fuels are obvious: they are fuels that are significantly less harmful to the environment and therefore do not contribute to climate change. However, there are certain limitations to their use; these include availability, cost and the constraints imposed by existing infrastructure, which would have to be modified accordingly, incurring additional costs (Sandaka & Kumar, 2023). The purpose of this chapter is to describe the benefits and challenges of implementing alternative fuels in the transport sector.

Global energy needs amounted to about 14,282 Mtoe (million tonnes of oil equivalent) in 2019, decreased to 13,710.72 (4% decrease) in 2020 due to the effect of the restrictions imposed in the midst of the pandemic, and increased again to 14,341.41 in 2021 (Amaya et al., 2021). It is projected that global energy needs will amount to about 15,000, 16,000 and 18,000 Mtoe for the years 2025, 2030 and 2040 respectively (International Renewable energy Agency, 2019). It should be noted that these estimates may also be conservative, especially if one takes into account the recovering industrial sectors (after the health crisis) and local economic as well as geopolitical turbulences which always affect energy security.

The transport sector, which includes passenger movement, freight transport, supply chains, logistics, etc., is one of the most energy-intensive sectors, with gasoline and diesel being the main fuels (Amaya et al., 2021). The transport sector is one of the most polluting sectors; the reason lies in the tremendous growth of transport vehicles in recent decades, with estimates of more than 1.2 operational billion vehicles (Sioshansi & Webb, 2019). Petrofuels used as the main fuels in the transport sector lead to vehicular smoke, soot, unburnt hydrocarbons, COx, SOx, NOx, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), aldehydes and PM2.5 particles. Global GHG emissions are estimated to reach 12 gigatonnes of CO_2EQ by 2050 from the transport sector with significant impacts on the global economy, health and food security (Sandaka & Kumar, 2023). It is becoming clear that the transport sector is placing a significant burden on the environment and exacerbating the climate crisis. Decisive policies and initiatives are therefore needed to reduce emissions of harmful gasses from transport and pave the way for the vision of sustainable mobility.

In order to achieve the objectives of the Paris Agreement and the UNFCCC, emissions of air and air pollutants must be reduced, starting with the most polluting sectors, including the transport sector. In order for this to happen, the use of conventional fuels must be replaced by alternative fuels. This, of course, requires the development of green technologies and climate-resilient mobility capabilities. The use of electricity, hydrogen and biofuels are all very good alternatives that can lead to a reduction in GHG emissions from the transport sector; however, each of these fuels has its own challenges in implementation (Bekiaris et al., 2018).

2.4.2 Electromobility and related challenges

Electric vehicles are powered by one or more electric motors which are powered by electric batteries, electric generators or fuel cells. Electric vehicles are generally classified as zero-emission vehicles, however the low energy content has made electricity an unpopular fuel for propulsion and transportation. In modern times, the need to shift to more sustainable modes of transportation, as well as the desire for countries to not depend on exporting countries for transportation fuel, has given a new impetus to the use of electricity as a transportation fuel (Sandaka & Kumar, 2023).

The main difference between electric vehicles and conventional vehicles is that the former have batteries, which have different chemistry, higher energy density and are more efficient. An electric vehicle can be fully electric or hybrid, where the battery coexists with the internal combustion engine and provides extra power to the drive.

As the replacement of conventional vehicles with electric ones is expected to reduce climate change and reduce countries' dependence on conventional fuel imports, governments around the world have taken steps to encourage a shift to a greener and more sustainable mobility and transport sector. Through compensation for the retirement of old internal combustion engine vehicles, subsidies for the acquisition of electric vehicles, tax exemptions or reduced taxes for manufacturers of electric vehicles, reduced road pricing, free parking, etc. policies and initiatives, governments hope to pave the way to a more sustainable mobility (Ogunkunbi et al., 2022). The electric vehicle manufacturing industry is expanding year by year, and full electrification of the transport sector is expected to be achieved by 2050 (Caulfield et al., 2022).

However, the electrification of the transport, transport and mobility sector is not without its challenges. Despite the efforts of the automotive industry and governments taking action to promote electrification, it appears to be happening at a slow pace, at least less than expected. The following section presents and analyzes the constraints and challenges to the electrification of the transport and mobility sector.

The electrification of the transport and mobility sector brings about various technical, environmental, economic, and behavioral challenges. From a technical standpoint, manufacturing components for electric vehicles faces limitations due to resource demands, including concerns about resource extraction in politically unstable regions and oligopoly control of resource economics (Li, Co, Ni, Cu, Al, Fe, Mn, Nd, Dy) (Cheng et al., 2021; Gulley et al., 2019). Electric vehicles also encounter challenges in terms of charging time, especially for cargo transport vehicles, impacting overall performance, with recommendations for ranges exceeding 500 km but at higher costs. Fast-charging technologies may affect battery temperature (Sandaka & Kumar, 2023). The widespread adoption of electric vehicles puts pressure on electricity grids, necessitating significant infrastructure investments and a transition to renewable energy sources (Sandaka & Kumar, 2023).

Environmental challenges arise from the substantial environmental footprint associated with the production of electric vehicle components, despite their operational benefits in reducing greenhouse gas emissions. Automation of mass production is identified as crucial to mitigating this impact (Sandaka & Kumar, 2023; Qiao et al., 2017). Materials used in electric vehicle batteries, along with mining processes, generate pollution of air, water, and soil, requiring better recycling infrastructure (Kaunda, 2020; Xu et al., 2021). Sustainable battery design is emphasized to address extraction, reuse, efficiency, and environmental concerns (Xu et al., 2021).

Economic challenges stem from the unconventional design of cathodes, the use of materials not widely available underground, and the overall expense of manufacturing batteries for electrification. Affordability remains a significant barrier for middle and lower-middle-income groups, necessitating mass production to reduce costs. However, mass production depends on demand, creating a challenging cycle (Sandaka & Kumar, 2023).

Consumer behavior and beliefs also play a crucial role in the success of electrification. Overcoming challenges such as the cost of electric vehicles, availability of charging infrastructure, autonomy concerns, and promoting domestic electricity generation through renewable sources require addressing consumer perceptions and attitudes. There is a prevailing belief among consumers that electric vehicles are still under development, influencing their preference for alternative transport methods (Carattini et al., 2019).

2.4.3 Hydrogen powered vehicles and challenges

The ease of hydrogen synthesis and storage, high values of the energy density of H2 (143 MJ/kg), heat of combustion (141.9 MJ/kg), heat of evaporation (444 kJ/kg), calorific value (120 MJ/kg), octane number (130), ignition energy (0.02 mJ) and auto-ignition temperature (585 ℃) make hydrogen an ideal energy source for vehicle propulsion, ship propulsion, etc.

The technology of hydrogen powered vehicles includes hydrogen-fuel cell powered electric propulsion systems. Fuel cells convert the chemical energy contained in hydrogen into usable electricity to drive the vehicles. Ultimately, the energy that drives the vehicle is the electricity. The difference with pure electric cars is that they store the chemical energy in the battery which is then converted to electricity, whereas hydrogen fuel cells store the hydrogen itself, which is used to directly generate electricity for propulsion. H_2 powered vehicles are much lighter than pure electric vehicles and therefore, for the same amount of power, have a greater range (Sandaka & Kumar, 2023). In this case, too, however, certain challenges and limitations are identified that prevent the widespread use of hydrogen in the transport and mobility sector.

The production, storage, transport, and distribution of hydrogen present multifaceted challenges and constraints, encompassing technical, environmental, economic, and consumer-related aspects. Mass production of hydrogen for vehicle fuel demands substantial investments in infrastructure, equipment, and personnel training, with a need for enhanced chemical process efficiency (Kurtz et al., 2018). However, the environmental footprint of using hydrogen is substantial if not sourced from renewables or nuclear power, and concerns exist regarding the efficiency of the lengthy production process (Gomez-Capacho & Ruggeri, 2019).

Hydrogen storage poses challenges due to diffusion issues, requiring storage in composite material tanks reinforced with carbon fibers. The use of liquid hydrogen in electromobility introduces complexity, with cryogenic requirements during transport making the system unstable and risky. Transportation through pipelines is difficult, and safety measures, including cryo-tolerant tubes and monitoring, are essential due to hydrogen's high flammability (Hirayama et al., 2018).

In the use of hydrogen as a vehicle fuel, challenges include complex combustion and energy extraction processes, with fuel cell efficiency affected by impurities and gasses like CO and SOx

(Sandaka & Kumar, 2023). The overall processes of production, storage, transport, and distribution lead to unreliable hydrogen availability, limiting its dependability as a transportation fuel (Sandaka & Kumar, 2023). While hydrogen provides greater autonomy than exclusive electricity use, limited refueling infrastructure reduces vehicle autonomy, especially over long distances and outside urban areas. Hydrogen refueling cannot occur domestically, except for aircraft, where hydrogen is considered inevitable for future use, requiring careful design and adaptation (Dincer & Acar, 2016).

From an environmental perspective, hydrogen's sustainability depends on production using renewable energy sources, as certain methods diminish its environmental benefits. Economic challenges stem from the high cost of hydrogen-powered cars due to safety and efficiency requirements in production, storage, transport, and distribution (Sandaka & Kumar, 2023).

Consumer psychological issues further impact hydrogen adoption, with safety concerns compared to electric cars and apprehension about storage and transportation. Limited refueling stations contribute to range anxiety among potential buyers of hydrogen-powered vehicles (Itaok et al., 2017; Sandaka & Kumar, 2023).

2.4.4 Biofuels

Biofuels are a sustainable, eco-friendly, and biodegradable energy source that is both safe and environmentally friendly. Their elevated oxygen content enhances combustion and reduces the release of harmful pollutants like soot, unburnt hydrocarbons, $PM_{2.5}$, CO_X, and SO_X. Consequently, the adoption of "carbon neutral" biofuels in current vehicles could contribute to long-term efforts to combat air pollution from the transportation sector (Ramesh et al., 2019).

The generation of biofuels faces multifaceted challenges encompassing technical, environmental, and economic dimensions. Technical limitations in biofuel generation stem from the primary obstacle of securing suitable feedstock. Historically, biofuels have been derived from edible sources such as corn, sugarcane, palm oil, sunflower oil, and soybean oil. The growing global population and increasing demands on agricultural resources, coupled with limited arable land and water for irrigation, intensify debates about the trade-off between food and fuel (Meijaard & Sheil, 2019).

Environmental challenges and restrictions arise from the expansion of biofuel production, leading to direct and indirect alterations in land use, including deforestation of fertile forested areas instead of utilizing arid or semi-arid lands. This deforestation, often supported by governmental initiatives for biofuel exports' profitability, places responsibility for green cover and biodiversity loss on importing countries (Freitas et al., 2018). Beyond land use changes, the depletion of forest cover for energy crops results in the displacement of indigenous populations, subsistence farmers, and loss of habitats for endangered species, irreversibly impacting biodiversity (Freitas et al., 2018). Biofuel production's high demand for water, especially in water-scarce contexts, raises concerns about prudent water resource use in various production stages (Delrue et al., 2016).

Economic challenges and restrictions center on the higher cost of biofuels compared to petroleum-based fuels. This cost disparity is attributed to expenses in feedstock sourcing and the diverse processes involved in biofuel production. The enzymatic approach further elevates costs due to expenses associated with enzymes, contributing to the overall production expenses (Sandaka & Kumar, 2023).

2.5 Government initiatives and people's habits

2.5.1 Cycling and walking promotion

The promotion of cycling and walking as a sustainable and healthy way to travel, both for citizens and the environment, is perhaps the most popular policy and initiative for the transition to a greener mobility sector (Arroyo et al., 2018). However, cycling and walking cannot fully replace citizens' travel by other means of transport, as there is a limit to the distance one can travel by walking or cycling. However, promoting these alternative means of transport for short distances within cities is crucial to reducing the environmental footprint of the urban transport sector. Measures to promote these alternative modes of transport include (Binetti et al., 2019):

- Creation of pedestrian areas
- Establishment of reduced traffic areas
- Maintenance of pavements

- Creation of “pedestrian routes” in the city, with widening of pavements, planting of trees, etc.
- Creation of cycle routes
- Creation of bicycle parking spaces
- Possibility of renting bicycles from various points in the city
- Bike-sharing systems
- Incentives to buy bicycles

2.5.2 Collective and public transportation system promotion

Investing in the quality and quantity of public transport is the most effective way to encourage city dwellers to use public transport rather than their private cars, reducing environmental costs. A variety of studies have shown that countries that invest significant amounts in the public transport system are those that record the largest share of modal split. The low cost of using public transport, or even using it for free, is another good incentive for residents to use these means for their urban travel (Beaudoin & Lawell, 2018; Papagni et al., 2020).

2.5.3 Eco-driving

Eco-driving refers to the way in which private or public transport drivers save fuel and thus reduce harmful emissions through the efficient use of the means of transport. Van Mierlo et al. (2004) have shown that reductions in fuel consumption of up to 25 % can be achieved through eco-driving; in the study of Wang & Boggio-Marzet (2018) the corresponding figure was 6.8%. De Vlieger (2007) showed that aggressive driving can lead to an increase in fuel consumption of up to 40% and an increase in harmful gas emissions of up to 50%.

Some good practices for eco-driving include (Gallo & Marinelli, 2020):

- Driving smoothly at a constant speed, without sudden acceleration and deceleration (where possible)
- Appropriate use of gears
- Whenever possible, when driving smoothly and at all times
- Limiting the use of air conditioning

Eco-driving can also be applied to trains, with a wealth of research exploring the various driving protocols that can lead to savings in fuel consumption and reductions in harmful emissions to the atmosphere (D'Acierno & Botte, 2020).

2.5.4 Pricing, taxation and incentives

Pricing is widely used to achieve sustainable mobility. The rationale is to require payment of traffic fees in the city center for parking at specific locations. The aim is to reduce the flow of private car traffic and encourage the use of other alternative means of transport (Gallo & Marinelli, 2020).

Another method of promoting sustainability in the transport sector is the taxation of transport modes and fuels with a high environmental footprint. The aim is to invite consumers to become aware, informed and ultimately make more environmentally friendly decisions when it comes to their travel.

Another effective method is to provide incentives to encourage consumers to switch to more environmentally friendly means of transport. These incentives include financial or other facilities for retiring old vehicles and acquiring new, more environmentally friendly ones, acquiring vehicles that use low-emission fuels such as electric vehicles, and converting conventional vehicles to vehicles that run on liquefied petroleum gas (Gallo & Marinelli, 2020).

2.6 Intelligent Transport Systems (ITS)

The incorporation of communication and information technologies into transportation and mobility systems has given rise to what are known as Intelligent Transport Systems (ITS). As per the European Union (2010), these are advanced applications designed to offer innovative services related to various modes of transport and traffic management. Their goal is to provide better information to users, enabling safer, more coordinated, and smarter use of transport networks. Intelligent systems, broadly applicable to land, air, or sea transportation, emerged as a response to the expansion of travel networks, leading to increased traffic flow, congestion, and lower safety levels. The primary objectives of intelligent transport systems are to enhance efficiency, safety, and sustainability in the mobility sector (Gallo & Marinelli, 2020). Key technologies integrated into these systems include Global Positioning System (GPS), Dedicated Short-Range Communications (DSRC), wireless networks, mobile telephony, probe vehicles or devices, radio wave or infrared beacons, roadside cameras, Variable Message Signs (VMS), and traffic signals (European Commission, 2017). While the collaboration of these systems ensures effective management, their widespread adoption has been limited, mainly due to concerns related to handling individuals' personal data.

2.6.1 Advanced Traveler Information System (ATIS)

The aim of ATIS is to ensure efficient, timely and accurate information for travelers. ATIS provides both static pre-trip information, which includes expected travel distance, mode of transport, expected time of arrival, etc., and dynamic information on road blockage, weather conditions, traffic, etc. The user, after receiving the information, is asked to make the best decision. Because of the uncertain nature of both the dynamic information that may come from the ATIS and the way in which the user perceives and interprets it, various methods to model uncertainty have been developed (Kiec et al., 2019).

2.6.2 Advanced Traffic Management System (ATMS)

An ATMS, or Advanced Traffic Management System, operates with a top-down perspective, consolidating real-time traffic information from roads, whether within urban areas or beyond. This information is then transmitted to a Transportation Management Center to enhance traffic management efficiency. Two primary equipment categories are employed: in-roadway, which involves intrusive technologies like pneumatic tubes, loops, magnetic sensors, and piezoelectric sensors, and over-roadway, which employs non-intrusive technologies such as cameras, radio radar, and infrared sensors positioned off the pavement. A notable emerging technology in this field is the installation of sensors directly on vehicles, enabling instant data collection regarding the vehicle's position, speed, etc. This integration of vehicle sensors, along with interconnecting vehicles and utilizing information from road sensors, not only enhances travel safety but also facilitates effective traffic management (He et al., 2019; Kiec et al., 2019).

2.6.3 Advanced Public Transportation System (APTS)

Intelligent transport systems and information and telecommunication technologies are widely used in urban public transport systems. The aim is to maximize functionality, efficiency and safety, while ensuring sustainable use of fuel. A plethora of research has addressed this issue, in particular the estimation of the optimal route for mass transit, telematics and various algorithms that provide accurate information to users (Kumar et al., 2017).

2.6.4 Cooperative Intelligent Transport Systems (C-ITS)

Cooperative Intelligent Transport Systems (C-ITS) utilize technologies enabling communication among road vehicles, traffic signals, roadside infrastructure, and other road users. These systems, also referred to as vehicle-to-vehicle and vehicle-to-infrastructure communications, leverage innovative technologies for in-vehicle data transmission and automation in traffic management. The collaborative nature of these systems facilitates real-time communication and information exchange between technologies, aiming to enhance safety levels and decrease the emission of harmful gasses into the atmosphere (Gallo & Marinelli, 2020).

CHAPTER 3

METHODOLOGY

3.1 Research questions

The aim of this paper is to investigate the issue of sustainability of the urban mobility sector. More specifically, it attempts to study the ways in which cities around the world are attempting to enhance the sustainability of urban mobility. Consequently, the following research questions arise:

- In which individual areas, by taking appropriate initiatives, can the sustainability of urban mobility be enhanced?

- What specific initiatives have been taken by the authorities of various cities around the world to enhance the sustainability of urban mobility, in each of the individual areas?

3.2 Methods and expected results

In order to answer the above research questions, a literature review is conducted, which examines specific case studies from around the world, aiming to highlight best practices that enhance the sustainability of the urban mobility sector.

The specific areas examined separately include: infrastructure, electronic and information systems, alternative transport systems, intelligent transport and traffic management, and pricing, taxation and government initiatives. The specific areas emerged from the collection, processing, analysis and categorisation of the data from the review, which are related to the various practices, tactics and initiatives aimed at the sustainability of mobility within cities.

The cities studied are Krakow, Songdo, Ljubljana, Nanjing, Rotterdam, Barcelona, Santander and Turin. These cities were chosen as they are typical examples of cities that have policies in place to enhance the sustainability of mobility within their borders. The authorities of cities wishing to enhance their sustainability (in the field of mobility) should study the policies implemented by these cities, as these policies have proven to be highly effective in the context in which they have been implemented.

CHAPTER 4

RESULTS

4.1 Introduction

This chapter presents the results of the review and analysis of practices followed by cities around the world to enhance the sustainability of urban mobility. The cities examined are Krakow, Songdo, Ljubljana, Nanjing, Rotterdam, Barcelona, Santander and Turin. The specific areas observed and focused on by the authorities of these cities include infrastructure, electronic and information systems, alternative transport systems, intelligent transport and traffic management, and pricing, taxation and government initiatives. These practices make cities, at least in part, sustainable in terms of mobility within their borders, but also smart, as through the use of technologies and the implementation of specific strategies, they manage to reduce their environmental footprint, manage traffic flow efficiently, reduce energy consumption, enhance the quality of mobility and transportation systems and promote a healthier lifestyle.

4.2 Urban sustainable development and mobility

Sustainable urban mobility refers to the development and implementation of transportation systems that prioritize environmental health, economic viability, and social equity. This approach seeks to reduce carbon emissions, minimize traffic congestion, and promote the use of public transit, cycling, and walking over reliance on private vehicles. It encompasses strategies such as improving public transportation networks, creating pedestrian-friendly infrastructures, and encouraging the use of eco-friendly vehicles.

Smart cities in terms of mobility leverage advanced technologies and data analytics to enhance the efficiency and sustainability of urban transportation systems. These cities integrate Internet of Things (IoT) devices, real-time data, and intelligent transportation systems to optimize traffic flow, reduce energy consumption, and improve the overall mobility experience for residents.

Examples include smart traffic lights that adapt to real-time conditions, app-based ride-sharing services, and digital platforms that provide up-to-date information on public transit schedules and availability.

4.2.1 Sustainable urban mobility

Effective urban development is crucial for sustaining cities amidst global urbanization. Sustainable urban development, encompassing various aspects like quality of life, air and water quality, and efficient transportation, is vital. The transport sector, serving as the foundation for societal functioning, plays a crucial role in providing access to essential services (Giffinger & Gudrun, 2010). However, the current transport structure significantly impacts the environment, necessitating its transformation into a sustainable one to reduce pollutants (European Environment Agency, 2019).

Sustainable mobility is integral to a sustainable city, aiming to reduce greenhouse gas dependence through environmentally friendly technologies, urban planning, and increased social responsibility (Banister, 2008). Four key elements for achieving sustainable mobility include the integration of innovative technologies, consideration of transport costs, reduction of transport needs through urban design, promotion of public transport, walking, and cycling, and incorporation of personalized information (Banister, 2008).

Policy makers are urged to prioritize the transition toward sustainable and intelligent mobility. Sustainable mobility emphasizes safe, comfortable, accessible, and environmentally friendly transport services, while intelligent mobility involves automation, multimodal mobility, safety enhancements through technology, and intelligent traffic management (Bielinska-Dusza et al., 2021).

Meaningful progress in sustainable mobility requires radical changes in urban development, with cities leading the way. The Sustainable Urban Mobility Plan (SUMP) assists authorities in transforming urban transport sustainably, emphasizing a holistic perspective, and active collaboration among citizens, authorities, and stakeholders (Bielinska-Dusza et al., 2021).

4.2.2 Smart cities and mobility

Around 100 cities globally are competing for the designation of a smart city, but a universal definition remains elusive, resulting in subjective categorizations in research (Zhao & Zhang, 2020; Bielinska-Dusza et al., 2021). Existing literature predominantly adopts two approaches: a holistic perspective and a technocentric focus on technological aspects (Mora et al., 2017). Innovative technologies play a crucial role in enhancing a city's intelligence by addressing issues in urban planning and development, emphasizing sustainability, quality of life, and efficient public services.

The concept of a smart city is multidimensional, requiring a holistic approach to urban design and development for sustainability, meeting residents' needs, and reducing environmental impact (Bielinska-Dusza et al., 2021; Stubinger & Schneider, 2020). Effective transformation into a smart city is complex, with no one-size-fits-all model for authorities, urban planners, and stakeholders.

City intelligence encompasses interconnected components, including economy, people, environment, mobility, sustainability, and governance (Albino et al., 2015). Smart city management involves effective coordination of these components, with a focus on all aspects to achieve desirable results.

A broader perspective identifies three main components of a smart city: people, institutions, and technology. Technology encompasses innovations for efficient city functionality, institutions involve decision-making initiatives, and the people component includes residents enjoying smart city benefits, encompassing education, training, accessibility, and inclusiveness (Bielinska-Dusza et al., 2021).

Investment in social and human capital is essential to increase a city's intelligence. Seeking innovative solutions is crucial to address emerging and existing challenges, such as the climate crisis (Lima et al., 2020).

4.2.3 Smart and sustainable mobility

As already mentioned, the international literature lists six different components related to the concept of city intelligence: economy, people, environment, mobility, sustainability and governance (Albino et al., 2015). Mobility is an extremely important component and it is the subject of this paper. In this chapter, the concept of smart mobility is discussed. This is mobility that incorporates innovative technologies in order to provide safe, high quality, affordable and accessible transport and mobility services and to reduce the environmental footprint of transport use (Bielinska-Dusza et al., 2021).

There are many initiatives that can pave the way for achieving smart and naturally sustainable mobility. These initiatives can be categorized into initiatives to improve and integrate public transport and environmental actions to reduce the environmental footprint of transport systems.

Improving the transport system can be achieved through (Bielinska-Dusza et al., 2021):

- The improvement of transport infrastructure, which includes roads, railways, stations, transport nodes and transport hubs, etc.
- Increasing the safety and accessibility of transport and reducing costs
- Improving the networking of the different parts of the city
- The creation of a digital application providing real-time information on the location of transport, delays and accidents
- The integration of intelligent traffic management systems through the collection of real-time data

Reducing the environmental footprint can be achieved through (Bielinska-Dusza et al., 2021):

- The use of alternative fuels, such as electricity, hydrogen and biofuels
- The use of renewable energy sources
- Optimizing the movement of vehicles through the collection and analysis of real-time data in order to reduce distances and unnecessary fuel use
- The construction and improvement of infrastructure to enable the use of alternative means of transport, such as bicycles or electric scooters
- Promoting and encouraging the use of alternative means of transport, such as walking, cycling, carpooling, car sharing, etc.

- Integrating modern logistics systems based on real-time data collection

4.3 Cases studies

4.3.1 Krakow (Poland)

The city of Krakow stands as a notable example of an endeavor to build a metropolitan area that intertwines scientific and academic prowess with sustainability, intelligence, historicity, and tradition. Initiated in 1993 with the adoption of a sustainable transport policy, Krakow's authorities have diligently integrated day-to-day city management with strategic planning to address both current and future global challenges (Bielinska-Dusza et al., 2021). Key initiatives include the establishment of transport hubs and transfer points, development of a comprehensive online platform with real-time information on regional transport departures, implementation of an electronic ticket system, and the introduction of online tools like a connection search engine and a mobile app for synchronized transport schedules.

Moreover, Krakow has embraced innovative systems such as the Traffic Supervision System, offering real-time monitoring, alternate routes during difficulties, and electronic displays for passenger information. The city has implemented a Local Traffic Control System (UTCS) focused on regulating automobile and pedestrian traffic, incorporating dynamic traffic lights responsive to traffic conditions. The transportation infrastructure also features low-floor buses and trams with modern amenities, real-time vehicle tracking through GPS transmitters, and a commitment to electromobility, aiming to have one-third of the city's bus fleet as zero-emission vehicles. Additionally, Krakow actively promotes initiatives to reduce exhaust emissions, encouraging bicycle use, organizing events like Parking Day, and participating in the European Sustainable Transport Week to foster positive changes in transportation habits (Bielinska-Dusza et al., 2021).

4.3.2 Songdo (South Korea)

Songdo, located 60 kilometers west of Seoul along the Incheon waterfront, is a pioneering smart and green city in South Korea. Spanning 6,000 hectares, it was intentionally designed for intelligent and environmentally friendly urban development, distinguishing itself as the country's third-largest urban area. The project gained momentum in 2000 when Incheon secured free economic zone status, positioning Songdo as a strategic hub for investments, international corporations, universities, and expatriate professionals. By 2004, Songdo was designated as the nation's pilot "smart city" or "ubiquitous city," marking it as a region where technological initiatives would transform daily life. The Incheon Free Economic Zone oversaw the city's development, engaging in partnerships with various companies in construction, electronic products, services development, and telecommunications (Benedikt, 2016).

The city's goal was to be compact, green, and smart, fully connected through broadband networks, fiber optic cables, sensors, interconnected devices, smart screens, and camera networks. It aimed to provide innovative, automated services to residents, with a particular focus on the mobility sector. Initiatives included automatic traffic light adaptation, real-time traffic monitoring, and RFID sensors on cars for congestion reduction decisions. Pedestrian and cycling traffic, public transport, and electric vehicles were facilitated, with electric charging stations installed. The city was designed to use 40% less energy than a similarly sized urban area. Critics argue that despite successful elements, Songdo is a top-down project lacking resident involvement in planning and addressing their needs. Concerns about privacy violations have also surfaced. Planners contend that residents choose to live under the city's norms, emphasizing the city's technological and innovative dimensions (Benedikt, 2016; Carvalho, 2015).

4.3.3 Ljubljana (Slovenia)

Since 2007, the city of Ljubljana has been committed to sustainable development, particularly focusing on sustainable mobility. The city's transport policy aims to shift towards greater sustainability, with a target for only one third of transport to be carried out by private vehicles by 2027. The remaining two thirds are envisioned for public transport, cycling, and walking. Ljubljana has prioritized a green transport strategy by reorganizing main roads, creating pedestrian and cycle paths, and promoting environmentally friendly modes of transport. This initiative has resulted in a remarkable 70% reduction in carbon dioxide concentrations and a significant decrease in vehicle noise. The city's efforts include a successful awareness campaign encouraging residents to opt for alternative means of transport and discouraging solo travel in private vehicles (City of Ljubljana, 2023).

Ljubljana's impactful initiatives were recognized in 2016 when it received the European Green Capital Award from the European Commission. This prestigious distinction acknowledges cities that excel in sustainable development, address environmental challenges innovatively, set high environmental improvement standards, and serve as examples for others (European Environment Agency, 2017). One of the city's notable actions under its Sustainable Mobility Plan is the "Urbana smart city card." Initially designed for public transport fare payments, the card has evolved to offer various conveniences. In addition to facilitating public transport use, it allows cardholders to rent public bicycles, visit museums, libraries, and sports facilities, reflecting a comprehensive and integrated approach to sustainable urban living (City of Ljubljana, 2023· Observatory of Public Sector Innovation, 2009).

4.3.4 Nanjing (China)

Nanjing, a historic city in China and the capital of Yangshuo province, has emerged as a global pioneer in promoting the electrification of road transport. In a remarkable feat, the city achieved the most rapid adoption of electric vehicles within just one year, boasting a fleet of 4,332 operational electric vehicles, including 1,208 buses and 940 taxis, by 2015 (Keaney & Pernille, 2015). Nanjing's initiative resulted in the establishment of 14 battery changing stations and 791 vehicle charging points. In a city grappling with air pollution issues, the shift to electrification led to a substantial reduction of 246 thousand tons of carbon dioxide (CO2) emissions and savings of 61 million liters of oil within a year. Given that air pollution is a significant contributor to premature deaths in China, Nanjing's swift adoption of electric vehicles garnered global recognition and earned the city the prestigious "C40 Urban Transportation Leadership Award" in 2015.

While Nanjing may not have the largest electric vehicle fleet, its rapid adoption makes it a model for energy conservation and emission reduction. Government incentives, such as fixing vehicle purchase prices, cooperative schemes to limit electricity costs, and the creation of a favorable framework for charging station setup, played a pivotal role in encouraging the adoption of electric vehicles. The city allocated $168 million for this initiative, quickly offset by savings on oil imports (Rohde & Muller, 2014). The benefits of Nanjing's electromobility development extend beyond environmental improvements to include enhanced public infrastructure, reduced exhaust and noise emissions for public health protection, and economic gains from savings on oil imports. Nanjing has transformed into an "industry lab," attracting forty-six companies in the electric vehicle sector, contributing approximately sixteen million per year in state revenues through taxation (Keaney & Pernille, 2015).

4.3.5 Rotterdam (Netherlands)

Rotterdam, Europe's largest and one of the world's largest ports, has evolved into a "smart port city" to address the challenges of competitiveness, efficiency, and environmental sustainability. Functioning as a crucial gateway to the continent and a key transit point for goods between Europe and third countries, Rotterdam has embraced the concept of a smart port city to enhance its operations (Mandra, 2018). A pivotal element in this transformation is an application that leverages Internet of Things (IoT) technology, collecting and processing real-time weather and communications data. This application facilitates faster decision-making, safer traffic management within the port, and lays the groundwork for accommodating connected ships in the future. The data is sourced from a network of sensors strategically installed along docks, berths, and roads, utilizing the dedicated IoT service in the Netherlands' mobile network since 2016 (Jablonska, 2019).

The digitization of the shipping industry, exemplified by Rotterdam's smart port initiative, yields various benefits, including reduced waiting times for ships, improved communication among port stakeholders, streamlined traffic flow, and enhanced efficiency in supply chains and businesses. As part of its forward-looking strategy, Rotterdam aims to achieve a 55% reduction in CO_2 emissions by 2030 and aims to become CO_2 neutral by 2050, aligning with environmental sustainability goals (Port of Rotterdam, 2020). However, the adoption of innovative technologies and data-driven solutions also poses significant challenges, particularly in terms of data privacy and security risks. Decision-makers must respond proactively by implementing high-security standards to safeguard against potential threats (Mandra, 2018).

4.3.6 Barcelona (Spain)

Barcelona stands out as a prime example of a city committed to the long-term implementation of the smart city concept. Its transformation into a smart city is driven not only by cutting-edge technologies but by a vision that emphasizes social well-being, environmental protection, and sustainable urban development within the framework of a new real economy (Schaffers et al., 2012). The city's model is built on four fundamental pillars: Infrastructure, Information, Smart Services, and Human Capital (Gavalda & Ribera-Fumaz, 2012). These pillars encompass various interventions in areas such as e-government, transport, security, public infrastructure, mobility, entrepreneurship, and cultural heritage management.

The Barcelona Smart City model is structured around key areas: Smart Governance, Smart Economy, Smart Living, and Smart Citizens. Smart Governance focuses on open data to ensure free access to public information. Smart Economy emphasizes collaboration among businesses, universities, research institutions, and citizens to foster innovation. Smart Living initiatives incorporate new technologies in areas like security, transport, and the environment. Under the Smart Citizens pillar, educational programs aim to equip the population with digital and technological skills.

In the realm of transport, Barcelona's smart city initiatives include intelligent lighting activated by traffic detection, energy-independent city blocks with bioclimatic buildings and electric vehicles, a smart bus network with hybrid buses and solar-powered displays, a bike-sharing system (Bicing), smart parking with sensor networks displaying space availability, and the promotion of zero-emission mobility through electric charging stations and electric vehicle rentals (Papapanagiotopoulou et al., 2014). Other initiatives span smart waste management, cultural workshops, open government, and more, reinforcing Barcelona's status as a smart city.

4.3.7 Santander (Spain)

Since 2009, Santander has been striving to become the most innovative smart city in Europe through the implementation of the European SmartSantander project. This initiative is a crucial component of the city's strategic plan "Santander 2020," aiming to enhance citizens' daily lives and efficiently manage city services (Gutierrez & Munoz, 2016).

At the core of SmartSantander is the creation of an innovative experimental research infrastructure for the development of Internet of Things (IoT) applications and services. This infrastructure is globally unique, distributed across the city, and serves as a fundamental tool for Europe's leadership in IoT technologies. Comprising sensors, actuators, cameras, monitors, and communication facilities, the platform allows large-scale experimentation and evaluation of IoT concepts under real-world conditions (Gutierrez & Munoz, 2016).

The expansive and flexible infrastructure enables Santander to connect with other experimental facilities worldwide, forming a vast network of real-time control nodes for IoT research. The project envisages the installation of 12,000 sensors, including IEEE 802.15.43 devices, GPRS modules, RFID tags, and QR codes, strategically placed in static locations and moving vehicles (Gutierrez & Munoz, 2016).

Initiatives under SmartSantander encompass environmental data monitoring with 2,000 static sensors measuring variables like temperature, CO_2, and noise levels. An additional 150 sensors on public vehicles extend environmental monitoring citywide. Traffic volume monitoring, outdoor parking management, and free parking guidance are facilitated by 60 devices at main entrances, 400 sensors in parking areas, and 10 displays at road junctions. The "Smart travel" initiative offers real-time traffic information to optimize travel efficiency and avoid congestion and incidents, contributing to a smarter and more connected urban environment.

4.3.8 Turin (Italy)

Since late 2011, Turin has embraced the smart city concept, propelled by the European Smart Cities and Communities initiative, and operationalized through the Fondazione Torino Smart City. This organization, established for the city's transformation, utilizes the Matching Board tool to connect technological expertise with companies interested in collaborative projects with municipal authorities (Caballini et al., 2023).

Guided by the SMILE (Smart Mobility, Inclusion, Life and health, Energy) program initiated in 2013, the smart city model focuses on five key areas: energy, mobility, social inclusion, environmental sustainability, and digital city and innovation. The comprehensive plan, developed through stakeholder consultations, aims to simplify, modernize, and harmonize municipal activities for a seamless transition to a smart city reality (Cavallini et al., 2023).

Noteworthy sustainable mobility initiatives in Turin include the Sustainable Energy Action Plan, targeting CO_2 reduction through enhanced energy efficiency, renewable energy use, and an efficient transport plan emphasizing public transport and district heating network expansion. The Traffic Management Centre, integrated with public transport monitoring, enhances traffic flow and reduces air pollutant emissions. BIP - Business Integrated Piedmont introduces an electronic ticketing system for seamless access to all public transport modes across the city. Biciplan encourages bicycle usage through technical solutions, promotional activities, and cultural initiatives. The Geoportal provides access to geographical information, while the Map of Turin offers a Web 2.0 service allowing users to create and share city maps (Caballini et al., 2023).

Table 3 presents the main initiatives and policies that promoted sustainable urban mobility in the eight cities discussed in detail in the previous paragraphs (Krakow, Songdo, Ljubljana, Nanjing, Rotterdam, Barcelona, Santander and Turin):

Table 3. Initiatives and policies that promoted sustainable urban mobility in certain cities

	Infrastructure	Electronic and information systems	Alternative transport systems	Intelligent transport and traffic management	Pricing, taxation and government initiatives
Krakow	Transport hubs and transfer points Map of transportation nodes Low-floor buses and trams featuring air conditioning, ticket machines and a dynamic information systems for passengers Electric buses	Online platform offering information on transport departures Electronic ticket system Online connection search engine	Shared car and bike usage models Transport options for individual with limited mobility	Traffic supervision system (information on busy locations, road junctions etc.) Local traffic control systems with traffic lights responding to traffic volume, speed and transport mode Real-time vehicle tracking	
Songdo	Smart and sustainable development of the city from scratch Electric public transportation		Facilitation of pedestrian and cycling traffic Promotion of walking and cycling	Traffic lights with automatic adaptation to road traffic Traffic management from a systems of cameras throughout the city	

	Infrastructure	Electronic and information systems	Alternative transport systems	Intelligent transport and traffic management	Pricing, taxation and government initiatives
Ljubljana	- Reorganization of the main roads	Urbana smart city card: cashless payment, rent public bicycles, visit museums, libraries and sports facilities	Creation of more pedestrian and cycle paths Campaign to raise awareness about the use of alternative means of transport		
Nanjing	Battery changing stations and vehicle charging points				Fixation on the purchase price of the vehicles Facilitation of the creation of cooperative schemes to limit the price of electricity Favorable framework for the setting up of charging stations and charging points

	Infrastructure	Electronic and information systems	Alternative transport systems	Intelligent transport and traffic management	Pricing, taxation and government initiatives
Rotterdam		IoT technologies: real-time weather and other data process, efficient management of traffic of ships, informed decision-making, connected ships			
Barcelona	Sustainable urban development Reconfiguration of the bus network Smart bus stops Hybrid buses Installation of electric charging stations	Online platforms for direct access to networks, information and services Transparency and efficiency of public processes and services Encouragement for the use and processing of public data by citizens	Bicing: bicycle sharing system	Smart Parking: network of sensors that display the availability of parking spaces, enhancing mobility management Intelligent traffic lights	
Santander		IoT technologies consisting of sensors, actuators, cameras, monitors and communication facilities		Outdoor parking management Free parking guidance Traffic volume monitoring SmartSantander platform that provides real-time traffic data	

	Infrastructure	Electronic and information systems	Alternative transport systems	Intelligent transport and traffic management	Pricing, taxation and government initiatives
Turin	Sustainable energy action plan: increasing the efficiency of existing infrastructure and enhancing the public transport system	Business Integrated Piedmont (BIP): electronic ticketing system Map of Turin: allowing users to create maps of the city and share it with others	Biciplan: providing technical solutions and promoting biking within the city	Traffic Management Centre	

4.4. The role of geopolitics in achieving sustainable mobility

4.4.1 Introduction to geopolitics in the sector of sustainable mobility

In recent years, a new theory has emerged, emphasizing the interdependence of geoeconomics, geopolitics, and local/national policies as a novel approach to addressing climate change and ensuring global security (Pascual & Zampetakis, 2008). The shift from fossil fuels to renewable energy sources is crucial for global energy security and economic benefits, especially in developing countries, but concerns arise regarding the equitable distribution of benefits, potential energy dependencies, and geopolitical contests (Martiskainen et al., 2020; Pascual & Zampetakis, 2008).

While the renewable energy sector, particularly in mobility, has witnessed significant growth, challenges such as energy storage, meeting high demand, and geopolitical complexities need nuanced examination (Stergiou, 2023). The EU's ambitious environmental targets, embodied in the Clean Energy for all European Package and the Green Deal, highlight a commitment to transitioning from fossil fuels to renewable energy (Stergiou, 2023; European Commission, 2019).

Geopolitical dynamics in the mobility sector differ significantly from conventional fuels, with competition for battery components and rare earth elements shaping the landscape. China's dominance in this space raises concerns, prompting efforts to diversify sources (Bartekova & Kemp, 2016; Habib et al., 2015; Johansson, 2013). Energy independence gains prominence, influencing strategic shifts toward electric vehicles and renewable energy, potentially altering global energy alliances (Johansson, 2013).

Investments in renewable energy infrastructure position countries as energy exporters, reshaping geopolitical relationships and creating new centers of influence. The integration of AI and autonomous technologies in transportation adds complexity, with nations investing in global connectivity projects enhancing their geopolitical standing. Economic shifts resulting from the transition to sustainable mobility introduce complexities, disrupting traditional industries and potentially leading to social and political consequences (Scholten et al., 2020). Navigating this transition is crucial for shaping a country’s geopolitical influence, with investment in green technologies offering economic growth and job creation opportunities (Scholten et al., 2020).

The geopolitics of the energy transformation in the mobility sector involves multifaceted factors, and countries strategically navigating these elements are poised to play key roles. Geopolitical issues arising from sustainability in the mobility sector, driven by the introduction of renewable energy sources and related technologies, are explored in the subsequent analysis.

4.4.2 Conflicts and energy security

Scholars studying renewable energy, sustainability in the mobility sector, and geopolitics often focus on the implications for energy security. Two main approaches exist in predicting energy-related conflicts in a future dominated by renewable energy sources. The first approach suggests that the energy transition is unlikely to decrease such conflicts, while the second contends that increased self-sufficiency will reduce energy-related conflicts between states (Johansson, 2013).

Proponents of the first approach argue that a world predominantly powered by renewable sources may not be less prone to conflict than one relying on fossil fuels. They posit that new energy security vulnerabilities, such as dependence on critical materials, will emerge. Moreover, they argue that existing vulnerabilities, like disruptions in energy supply chains or geopolitical instability in energy-producing countries, will persist (Capellan-Perez et al., 2017).

In contrast, the second group of scholars asserts that the prevalence of conflicts may decrease in a world where renewable energy is the primary source. They argue that it is more challenging to control, manipulate, or reduce the price of renewables compared to fossil fuels. The expansion of renewables, according to this perspective, would lead to greater energy self-sufficiency and, consequently, less conflict. A critical factor in reducing potential conflicts is seen as a shift in the focus of energy security from external factors to the internal environment of states (Johansson, 2013; Lacher & Kumetat, 2011).

4.4.3 Access to the critical materials of new technologies

One prominent concern raised by scholars and scientists in the context of the energy transition, especially in the mobility sector, revolves around the potential intensification of geopolitical competition for critical materials essential to renewable energy technologies. The term "critical" is applied to metals facing an imbalance between growing demand and limited supply, with a particular focus on the 17 rare earth elements. China's significant holdings of these elements and its strategic use of them for foreign policy objectives have solidified its position in the global energy landscape (Habib et al., 2015; Bartekova & Kemp, 2016).

The potential emergence of a new form of dependence on countries that control the extraction of critical materials needed for renewable energy production, distribution, or storage technology is a key worry. While renewable energy sources aim to reduce dependence on traditional fossil fuels, concerns are raised about the geopolitical competition arising from the demand for various critical materials (Bazilian, 2018). This competition is seen as having the potential to impact energy security and lead to geopolitical instability. However, contrasting views argue that many critical materials are geologically abundant, albeit in sparse concentrations, making extraction expensive. Recent successes in developing technologies using more widespread materials suggest that the perceived criticality of these materials may evolve with advancements in clean energy technologies (Pavel et al., 2017; Hache & Palle, 2019).

The importance of considering recycling as a crucial factor in assessing material availability is emphasized. Unlike fossil fuels, critical materials used in renewable energy technologies can be recycled. While the current cost of recycling may be high for some materials, the expectation is that increased demand will drive technological advancements, ultimately reducing recycling costs over time. Overall, the risk of geopolitical competition for critical materials during the transition to renewable energy is considered limited (Overland, 2019).

4.4.4 Cross-border electricity trade and power cuts as a foreign policy tool

During the transition of the mobility sector, increased use of renewables will lead to higher levels of electrification and increased cross-border trade of electricity (Fragkos & Paroussos, 2018). So it is becoming imperative to study the possibility in which transnational blackouts could become a significant foreign policy tool between states (Moore-O'Leary et al., 2017). This possibility is often supported by past experiences, when energy, and particularly oil, was used as a foreign policy tool.

Electricity that is produced using the renewable sources of wind and sun is distributed by cables and unlike oil which is distributed by tankers or natural gas by pipelines, it cannot be redirected or held and saved for future use. International trade in solar and wind electricity in the future is likely to involve more two-way relationships between different countries (producer-consumer) than the one-way relationships in gas and oil trade. Many countries will produce domestically much of the renewable energy they consume and will trade with neighboring countries to balance their grid demands. Given the decentralized, bidirectional and limited scale of electricity generation, it is estimated that the use of cross-border power outages will be a mostly an unsuccessful tool for geopolitical pressures (Overland, 2019).

4.4.5 Cyber attacks and security

Scholarly attention has been drawn to cybersecurity challenges in renewable energy infrastructure, particularly within the mobility sector. The integration of complex electricity control systems in renewable energy grids raises concerns about vulnerability to cyber attacks. The simultaneous development of renewable energy and digitization, aimed at balancing fluctuating generation, has prompted apprehensions among academics, security agencies, and policymakers. The fear is that hostile entities might exploit vulnerabilities in electronic networks controlling utilities and transport systems. However, there is recognition that decentralized and small-scale renewable electricity generation can help mitigate cybersecurity risks (Canzler & Wittowski, 2016; Mansson, 2015).

It is crucial to note that cybersecurity risks in electricity transmission are not exclusive to renewable energy sources; they affect all internet-connected infrastructure, including transport for people and goods. In the current digital era, various fossil fuel infrastructure components, such as oil and gas platforms, pipelines, tanker shipping, refineries, and nuclear power plants, are also digitized. This raises questions about whether renewable electricity transmission grids are inherently more susceptible to cyber attacks compared to existing fossil fuel infrastructure (Overland, 2019).

Concerns about the cybersecurity of electricity grids often refer to the 2015 cyber attack on three energy distribution companies in Ukraine. This incident disrupted electrical substations in multiple locations for a relatively short period. However, it's crucial to consider Ukraine's unique circumstances, including infrastructure challenges, corruption levels, military conflicts, and historical ties with Russia, when evaluating the implications of this specific event (Zetter, 2016).

4.4.6 Emerging of new key-players in the global energy market

The geographical and technical characteristics of renewable energy transmission systems differ significantly from traditional fossil fuels, raising implications for transnational energy relations that require timely attention (Scholten et al., 2020). In the era of renewable energy, states with abundant resources, achieving energy self-sufficiency and excelling in energy exports will gain geopolitical influence. For instance, the EU, with proximity to Africa and the Middle East, stands to benefit and enhance relations by supporting the energy transition in fossil fuel-producing countries (Cienski & Hernandez, 2020). Conversely, countries lagging in renewables and tied to hydrocarbon supplies risk losing energy influence (Blondeel et al., 2021).

The "GeGaLo" index predicts geopolitical gains and losses post a full transition to renewable energy, encompassing variables like fossil fuel production, reserves, renewable energy, governance, and conflict. Research indicates that fossil fuel importers are likely to experience geopolitical gains, while oil-exporting states may see a weakening of their energy-related geopolitical positions (Overland et al., 2019). International events, such as the Russian military invasion of Ukraine, play a role as catalysts or obstacles to the energy transition, alongside socio-economic factors shaping the global energy system's trajectory.

4.5 Discussion

Urban sustainable mobility aims to develop transportation systems that are environmentally friendly, economically sustainable, and socially inclusive. The primary goal is to enhance the quality of urban life by reducing pollution, decreasing traffic congestion, and promoting healthier modes of transportation such as walking and cycling. This approach emphasizes the need for a shift from reliance on private vehicles to more sustainable modes of transport.

The European vision for sustainable mobility, as outlined in policies like the European Green Deal, emphasizes the integration of sustainable practices across all modes of transport. Europe aims to achieve significant reductions in greenhouse gas emissions and decrease dependence on fossil fuels through the promotion of green mobility. This vision includes enhancing public transportation networks, encouraging the use of alternative fuels, and investing in new technologies.

However, achieving sustainable urban mobility faces several challenges. One of the key challenges is highlighting sustainable mobility as the only effective response to the climate crisis. Reducing emissions and promoting cleaner transportation options are critical in combating climate change. Another challenge is ensuring social inclusiveness, making sure that sustainable mobility solutions are accessible to all social groups to prevent inequalities. Additionally, the complexity of the transport and travel system requires comprehensive planning and coordination. There is also ambiguity in the concept of sustainable mobility, leading to subjective judgments and varied interpretations.

Policies and initiatives to promote sustainable mobility include the development and promotion of alternative vehicle fuels such as biofuels, hydrogen-powered vehicles, and electromobility. Each of these alternatives comes with its own set of challenges, such as infrastructure requirements and technological advancements. Government initiatives also play a crucial role in changing people's habits. Promoting cycling and walking, enhancing the collective and public transportation systems, encouraging eco-driving practices, and implementing pricing, taxation, and incentive strategies are essential steps towards sustainable mobility.

Intelligent Transport Systems (ITS) are pivotal in modernizing urban mobility. Advanced Traveler Information Systems (ATIS), Advanced Traffic Management Systems (ATMS), Advanced Public Transportation Systems (APTS), and Cooperative Intelligent Transport Systems (C-ITS) utilize technology to improve the efficiency and effectiveness of transportation networks. These systems help optimize traffic flow, provide real-time information to travelers, and enhance the overall transportation experience, making urban mobility more sustainable.

In conclusion, sustainable urban mobility is a multifaceted approach aimed at creating transportation systems that are environmentally friendly, economically viable, and socially inclusive. The European vision underscores the importance of transitioning to green mobility through comprehensive policies and innovative practices. Despite facing challenges such as climate crisis responses, social inclusiveness, system complexity, and conceptual ambiguities, sustainable urban mobility remains a critical objective.

Policies and initiatives focused on alternative fuels, electromobility, and the promotion of non-motorized transportation are essential steps toward achieving this goal. Government efforts to alter public habits through incentives and infrastructural improvements are equally important. Additionally, the integration of Intelligent Transport Systems (ITS) plays a vital role in enhancing the efficiency and sustainability of urban transportation networks.

Ultimately, the successful implementation of sustainable urban mobility will depend on coordinated efforts across policy, technology, and societal behavior. By addressing these challenges and leveraging innovative solutions, cities can create more sustainable, livable environments for their residents, contributing significantly to global efforts against climate change and promoting a healthier, more equitable future.

CHAPTER 5

CONCLUSIONS

5.1 Summary and conclusions

In conclusion, this thesis, which highlighted the challenges as well as the role of geopolitics in achieving sustainable mobility, presented specific case studies of cities, in order to investigate which cities' authorities focus on in order to increase the overall sustainability of urban mobility, but also what are the specific practices and policies they follow in order to achieve this. These questions constitute the research questions of the study, and were answered through the review of the case studies. It was found that the specific areas on which the cities' authorities are basically focusing - at least those studied - are: infrastructure, electronic and information systems, alternative transport systems, intelligent transport and traffic management, and pricing, taxation and government initiatives. Any city wishing to enhance its sustainability, as far as mobility and transport are concerned, should target at least one - ideally all - of the above-mentioned areas and implement specific policies and practices, as the study has shown that these practices, for the city's sustainability, should be targeted in at least one - ideally all - of the areas mentioned above, as well as implement specific policies and practices, as the study has shown that these practices, for the city's sustainability, should be targeted in at least one - ideally all - of the above-mentioned areas.

In the infrastructure sector, practices include transport hubs and transfer points, maps of transportation nodes, dynamic information systems for passengers, electric public transportation, battery changing stations and vehicle charging points, reconfiguration of the bus network, reorganization of the main roads and smart and sustainable development of the city from scratch. In the area of electronic and information systems, practices include IoT technologies (real-time weather and other data process, efficient management of traffic of ships, informed decision-making, connected vehicles), online platforms for direct access to networks, information and services, transparency and efficiency of public processes and services and encouragement for the use and processing of public data by citizens. In the field of alternative transport systems υιοθετήθηκαν shared car and bike usage models, transport options for individuals with limited mobility, pedestrian and cycling traffic has been facilitated, walking and cycling have been promoted through various campaigns etc. Various intelligent and transport management models have also been adopted; these include traffic supervision systems, real-time vehicle tracking, smart traffic lights with automatic adaptation to road traffic, smart packing systems with the utilization of sensors displaying available parking spots. Last but not least, various initiatives to tackle the problem of pricing have been promoted, such as fixation on the purchase price of the vehicles, facilitation of the creation of cooperative schemes to limit the price of electricity and creation of favorable frameworks for the setting up of charging stations and charging points.

5.2 Limitations and recommendations

Through the review of the international literature, it became clear that the concept of sustainability in the mobility sector is not fully defined, so that sustainability in this sector means different things in different contexts. The lack of a universal sustainability framework that can be applied in every situation makes achieving sustainability in mobility more challenging. Furthermore, it was found that the issue of geopolitics in the energy transformation of the transport system has not been sufficiently explored. The literature focuses on the energy transition in general and the use of renewable energy sources, and how this transition will shape the future global energy landscape, but without clear references to the mobility sector transition and the specific implications it will have on the geopolitical scene. It is therefore proposed to further explore the concept of sustainability in the mobility sector and the ways in which this can be achieved, and to study the implications of the specific energy transition of global mobility systems on the global geopolitical scene.

It should also be noted that this paper was based solely on a literature review, without using quantitative or qualitative research methods. In this case, it is likely that the lack of original data limits the scope of new insights. This reliance on secondary sources can lead to potential biases if the reviewed literature is not comprehensive or if it predominantly reflects certain viewpoints. It is therefore proposed that a study be carried out which, based on the literature review presented, will apply quantitative or qualitative research methods, for example through the completion of relevant questionnaires by the authorities of the cities in question, and/or through interviews with officials and citizens. These practices will allow for a more in-depth analysis as the data will be obtained directly from the stakeholders and will not rely on secondary sources.

References

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *J. Urban Technol., 22*, 3–21.

Amaya, J., Delgado-Lindeman, M., Arellana, J., & Allen, J. (2021). Urban freight logistics: what do citizens perceive? *Transportation Research Part E: Logistics and Transportation Review*, 152, 102390.

Arroyo, R., Mars, L., & Ruiz, T. (2018). Perceptions of Pedestrian and Cyclist Environments, Travel Behaviors, and Social Networks. *Sustainability, 10*, 3241.

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy, 15*, 73-80.

Banister, D. (2011). The trilogy of distance, speed, and time. *Journal of Transport Geography, 19*, 950-959.

Barteková, E., & Kemp, R. (2016). National strategies for securing a stable supply of rare earths in different world regions. *Resources Policy, 49*, 153-164.

Bazilian, M. D. (2018). The mineral foundation of the energy transition. *The Extractive Industries and Society, 5*(1), 93-97.

Beaudoin, J., & Lawell, C.-Y.C.L. (2018). The effects of public transit supply on the demand for automobile travel. *Journal of Environmental Economics and Management, 88*, 447–467.

Bekiaris, E., Tsami, M., & Panou, M. (2017). A "Greening Mobility" framework towards sustainability. *Transportation Research Procedia*, 24, 131–136.

Benedikt, O. (2016). 'The valuable citizens of smart cities: The case of Songdo City'. *Graduate Journal of Social Science, 12*(1), 17-36.

Berger, G., Feindt, P., Holden, E., & Rubik, F. (2014). Sustainable Mobility—Challenges for a Complex Transition. *Journal of Environmental Policy & Planning*, 16(3), 303-320.

Bielinska-Dusza, E., Hamerska, M., & Zak, A. (2021). Sustainable mobility and the smart city: A vision of the city of the future: The case study of Cracow (Poland). *Energies, 14*, 7936.

Binetti, M., Caggiani, L., Camporeale, R., & Ottomanelli, M. (2019). A Sustainable Crowdsourced Delivery System to Foster Free-Floating Bike-Sharing. *Sustainability, 11*, 2772.

Blondeel, M., Bradshaw, M. J., Bridge, G., & Kuzemko, C. (2021). The geopolitics of energy system transformation: A review. *Geography Compass, 15*(7), e12580.

Caballini, C., Corazza, M. V., & Delponte, I. (2023). Turin, Rome and Genoa: comparison of the level of maturity of three large Italian cities towards Mobility as a Service. *Transportation Research Procedia, 69*, 163-170.

Canzler, W., & Wittowsky, D. (2016). The impact of Germany's Energiewende on the transport sector – Unsolved problems and conflicts. *Utilities Policy, 41*, 246-251.

Capellan-Perez, I., de Castro, C., & Arto, I. (2017). Assessing vulnerabilities and limits in the transition to renewable energies: Land requirements under 100% solar energy scenarios. *Renewable & Sustainable Energy Reviews*, September.

Carattini, S., Kallbekken, S., & Orlov, A. (2019). How to win public support for a global carbon tax. *Nature, 565*, 289–291.

Carvalho, L. (2015). 'Smart cities from scratch? A socio-technical perspective'. *Cambridge Journal of Regions, Economy and Society, 8*(1), 43-60.

Caulfield, B., Furszyfer, D., Stefaniec, S., & Foley, A. (2022). Measuring the equity impacts of government subsidies for electric vehicles. *Energy*, 248, 123588.

Cheng, H., Shapter, J. G., Li, Y., & Gao, G. (2021). Recent progress of advanced anode materials of lithium-ion batteries. *Journal of Energy Chemistry*, 57, 451–468.

Cienski, J., & Hernandez, A. (2020). Why carbon-free Europe will still need North African energy. *ProPolitico*. Available at: https://www.politico.eu/article/why-carbon-free-europe-will-still-need-north-african-energy/

City of Ljubljana. (2023). Sustainable mobility. Available at: https://www.ljubljana.si/en/ljubljana-for-you/transport-in-ljubljana/sustainable-mobility/

D'Acierno, L., & Botte, M. (2020). Optimizing frequency-based railway services with a limited fleet endowment: An energy-efficient perspective. *Energies, 13*, 2403.

De Vlieger, I. (1997). On-board emission and fuel consumption measurement campaign on petrol-driven passenger cars. *Atmospheric Environment, 31*, 3753–3761.

Delrue, F., Alvarez-Díaz, P. D., Fon-Sing, S., Fleury, G., & Sassi, J. F. (2016). The environmental biorefinery: using microalgae to remediate wastewater, a win-win paradigm. *Energies, 9*, 1–19.

Dincer, I., & Acar, C. (2016). A review on the potential use of hydrogen in aviation applications. *International Journal of Sustainable Aviation, 2*, 74.

European Commission. (2017). An agenda for a socially fair transition towards clean, competitive and connected mobility for all. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017DC0283

European Commission. (2019). The European Green Deal. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691

European Commission. (2021). A fundamental transport transformation: Commission presents its plan for green, smart and affordable mobility. Available at: https://transport.ec.europa.eu/transport-themes/mobility-strategy_en

European Environment Agency. (2017). Ljubljana wins European Green Capital Award for 2016. Available at: https://www.eea.europa.eu/highlights/ljubljana-wins-european-green-capital-2016#:~:text=Slovenian%20capital%20Ljubljana%20has%20been,environmental%20awareness%20amongst%20its%20citizens.

European Union. (2010). Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:207:0001:0013:EN:PDF

Fragkos, P., & Paroussos, L. (2018). Employment creation in the EU related to renewables expansion. *Applied Energy, 230*, 935-945.

Freitas, F. L. M., Sparovek, G., Berndes, G., Persson, U. M., Englund, O., Barretto, A., & Mortberg, U. (2018). Potential increase of legal deforestation in Brazilian Amazon after Forest Act revision. *Nature Sustainability, 1*, 665–670.

Gallo, M., & Marinelli, M. (2020). Sustainable mobility: A review of possible actions and policies. *Sustainability, 12*(18).

Gavalda, J., & Ribera-Fumaz, R. (2012). Barcelona 5.0: from knowledge to smartness? *Economics*, 129526106.

Geels, F. W., & Kemp, R. (2012). The multi-level perspective as a new perspective for studying socio-technical transitions. In Geels, F.W., Kemp, R., Dudley, G., & Lyons, G. (Eds.). *Automobility in Transition? A Socio-Technical Analysis of Sustainable Transport*. New York: Routledge.

Gholz, E., & Hughes, L. (2019). Market structure and economic sanctions: the 2010 rare earth elements episode as a pathway case of market adjustment. *Review of International Political Economy*.

Giffinger, R., & Gudrun, H. (2010). Smart cities ranking: An effective instrument for the positioning of the cities. *ACE Arquitectura Ciudad y Entorno*, 4(12).

Global Commission on the Geopolitics of Energy Transformation. (2019). A New World. The Geopolitics of the Energy Transformation. *IRENA*.

Gomez-Camacho, C. E., & Ruggeri, B. (2019). Energy sustainability analysis (ESA) of energy-producing processes: a case study on distributed H2 production. *Sustainability, 11*, 4911.

Gulley, A. L., McCullough, E. A., & Shedd, K. B. (2019). China's domestic and foreign influence in the global cobalt supply chain. *Resources Policy*, 62, 317–323.

Guo, F., Yang, J., & Lu, J. (2018). The battery charging station location problem: impact of users' range anxiety and distance convenience. *Transportation Research Part E: Logistics and Transportation Review*, 114, 1–18.

Gutierrez, V., & Munoz, L. (2016). SmartSantander: Towards the smart city paradigm. *6th Japan-EU Symposium on ICT Research and Innovation*. Available at: https://www.soumu.go.jp/main_content/000445923.pdf

Habib, S., Kamran, M., & Rashid, U. (2015). Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks – A review. *Journal of Power Sources, 277*, 205-214.

Hache, E., & Palle, A. (2019). Renewable energy source integration into power networks, research trends and policy implications: A bibliometric and research actors survey analysis. *Energy Policy, 124*, 23-35.

He, Z., Qi, G., Lu, L., & Chen, Y. (2019). Network-wide identification of turn-level intersection congestion using only low-frequency probe vehicle data. *Transportation Research Part C: Emerging Technologies, 108*, 320–339.

Hickman, R., Hall, P., & Banister, D. (2013). Planning more for sustainable mobility. *Journal of Transport Geography*, 210-219.

Hirayama, M., Shinozaki, H., Kasai, N., & Otaki, T. (2018). Comparative risk study of hydrogen and gasoline dispensers for vehicles. *International Journal of Hydrogen Energy, 43*, 12584–12594.

Holden, E., & Linnerud, K. (2011). Troublesome leisure travel: the contradictions of three sustainable transport policies. *Urban Studies, 48*(14), 3087-3106.

Hurd, A. J., Kelley, R. L., Eggert, R. G., et al. (2012). Energy-critical elements for sustainable development. *MRS Bulletin, 37*, 405-410.

Intergovernmental Twelfth Regional Environmentally Sustainable Transport (EST) Forum in Asia. (2019). Hanoi, Viet Nam. Available at: https://uncrd.un.org/content/12th-est-forum

International Renewable Energy Agency (IRENA). (2018). *Global energy transformation: a roadmap to 2050.*

Itaoka, K., Saito, A., & Sasaki, K. (2017). Public perception on hydrogen infrastructure in Japan: influence of rollout of commercial fuel cell vehicles. *International Journal of Hydrogen Energy, 42*, 7290–7296.

Jablonska, J. (2019). Europe's largest shipping port wants to be the world's smartest. *IBM*. Available at: https://www.ibm.com/blog/port-of-rotterdam-digitization-energy-transition/

Johansson, B. (2013). Security aspects of future renewable energy systems – A short overview. *Energy, 61*, 598-605.

Kaunda, R. B. (2020). Potential environmental impacts of lithium mining. *Journal of Energy and Natural Resources Law*, 38, 237–244.

Keaney, M., and Pernille J.M. (2015). 'Cities 100 – 100 Solutions for Climate Action in Cities'. London: Sustania. Available at: https://issuu.com/sustainia/docs/ cities100

Kiec, M., Ambros, J., Bak, R., & Gogolín, O. (2019). Evaluation of safety effects of turbo-roundabout lane dividers using floating car data and video observation. *Accident Analysis & Prevention, 125*, 302–310.

Kingsmill, B. (2020). The energy transition – the time is now. Carbon Tracker. Available at: https://carbontracker.org/the-energy-transition-the-time-is-now/

Kumar, B. A., Vanajakshi, L., & Subramanian, S. C. (2017). Bus travel time prediction using a time-space discretization approach. *Transportation Research Part C: Emerging Technologies, 79*, 308–332.

Kurtz, J., Peters, M., Muratori, M., & Gearhart, C. (2018). Renewable Hydrogen-Economically Viable: Integration into the U.S. Transportation Sector. *IEEE Electrification Magazine, 6*, 8–18.

Lacher, W., & Kumetat, D. (2011). The security of energy infrastructure and supply in North Africa: Hydrocarbons and renewable energies in comparative perspective. *Energy Policy, 39*(8), 4466-4478.

Lima, E. G., Chinelli, C. K., Guedes, A. L. A., Vazquez, E. G., Hammad, A. W. A., Haddad, A. N., & Soares, C. A. P. (2020). Smart and Sustainable Cities: The Main Guidelines of City Statute for Increasing the Intelligence of Brazilian Cities. *Sustainability, 12*, 1025.

Litman, T. (2024). Well measured: Developing Indicators for Sustainable and Liveable transport planning. *Victoria Transport Policy Institute*.

Litman, T., & Burwell, D. (2006). Issues in sustainable transportation. *International Journal of Environmental Issues*.

Mandra, J.O. (2018), In Depth: Complete Transformation of How Ports Operate Imminent. World Maritime News. Available at:

https://www.offshore-energy.biz/interview-complete-transformation-of-how-ports-operate-imminent/

Mansson, A. (2015). A resource curse for renewables? Conflict and cooperation in the renewable energy sector. *Energy Research & Social Science, 10*, 1-9.

Marsden, G., Kimble, M., Nellthorp, J., & Kelly, C. (2010). Sustainability Assessment: The Definition Deficit. *International Journal of Sustainable Transportation*, 189-211.

Martinez-Harms, M. J., Gelcich, S., Krug, R. M., Maseyk, F. J. F., Moersberger, H., Rastogi, A., Wambugu, G., Krug, C. B., Spehn, E. M., & Pascual, U. (2018). Framing natural assets for advancing sustainability research: Translating different perspectives into actions. *Sustainability Science, 13*, 1519-1531.

Martiskainen, M., Sovacool, B. K., Lacey-Barnacle, M., Hopkins, D., Jenkins, K. E. H., Simcock, N., Mattioli, G., & Bouzarovski, S. (2021). New dimension of vulnerability to energy and transport poverty. *Joule*, 5(1), 3-7.

Meijaard, E., & Sheil, D. (2019). The moral minefield of ethical oil palm and sustainable development. *Frontiers in Forests and Global Change, 2*.

Moore-O'Leary, K. A., Hernandez, R. R., Johnston, D. S., Abella, S. R., Tanner, K. E., Swanson, A. C., Kreitler, J., & Lovich, J. E. (2017). Sustainability of utility-scale solar energy – critical ecological concepts. *Frontiers in Ecology and the Environment, 15*(7), 385-394.

Mora, L., Bolici, R., & Deakin, M. (2017). The First Two Decades of Smart-City Research: A Bibliometric Analysis. *J. Urban Technol., 24*, 3–27.

Observatory of Public Sector Innovation. (2009). Urbana single city card system. Available at: https://oecd-opsi.org/innovations/urbana-single-city-card-system/

OECD (2000). Report on the OECD Conference Environmentally Sustainable Transport (EST). Vienna: OECD.

Ogunkunbi, G. A., Al-Zibaree, H. K. Y., & Meszaros, F. (2022). Modeling and evaluation of market incentives for battery electric vehicles. *Sustainability*, 14, 4234.

Overland, I. (2019). The Geopolitics of Renewable Energy: Debunking Four Emerging Myths. *Energy Research and Social Science, 49*, 36-40.

Overland, I., Bazilian, M., Ilimbek Uulu, T., Vakulchuk, R., & Westphal, K. (2019). The GeGaLo index: Geopolitical gains and losses after energy transition. *Energy Strategy Reviews, 26*, 100406.

Papagni, E., Lepore, A., Felice, E., Baraldi, A. L., & Alfano, M. R. (2020). Public investment and growth: Lessons learned from 60-years experience in Southern Italy. *Journal of Policy Modeling*, in press.

Panagiotopoulou, M., & Stratigea, A. (2014). Smart' Cities as a New Paradigm for Serving Urban Sustainability Objectives – A View in the Mediterranean Experience. Conference: International Conference on Socio-economic sustainability, Regional Development and Spatial Planning: European and International Dimensions and Perspectives.

Pascual, C., & Zampetakis, E. (2008). The geopolitics of energy: from security to survival.

Pavel, C. C., Lacal-Arántegui, R., Marmier, A., Schüler, D., Tzimas, E., Buchert, M., Jenseit, W., & Blagoeva, D. (2017). Substitution strategies for reducing the use of rare earths in wind turbines. *Resources Policy, 52*, 349-357.

Peters, A., & Dütschke, E. (2014). How do consumers perceive electric vehicles? A comparison of German consumer groups. *Journal of Environmental Policy & Planning, 16*(3), 359-377.

Phadke, R. (2018). Green energy futures: Responsible mining on Minnesota's Iron Range. *Energy Research & Social Science, 35*, 163-173.

Port of Rotterdam. (2020). Energy transition: Towards a CO2 neutral port. Available at: https://www.portofrotterdam.com/en/port-future/energy-transition

Qiao, Q., Zhao, F., Liu, Z., Jiang, S., & Hao, H. (2017). Comparative study on life cycle CO2 emissions from the production of electric and conventional vehicles in China. *Energy Procedia*, 105, 3584–3595.

Ramesh, C., Murugesan, A., & Vijayakumar, C. (2019). Reducing environmental pollution from diesel engines fueled with eco-friendly biodiesel blends. *Bulletin of Scientific Research, 1*, 35–44.

Remme, D., Sareem S., & Haarstad, H. (2022). Who benefits from sustainable mobility transitions? Social inclusion, populist resistance and elite capture in Bergen, Norway. *Journal of Transport Geography, 105*.

Renner, S., & Wellmer, F. W. (2020). Volatility drivers on the metal market and exposure of producing countries. *Mineral Economics, 33*(3), 311-340.

Reuters. (2022). Global renewable power prices soar on heavy demand, chaotic supply chain. Available at: https://www.jpost.com/business-and-innovation/energy-and-infrastructure/article-704017

Rohde, R.A. and Muller, R.A. (2014). Air Pollution in China: Mapping of concentrations and sources. PLoS ONE, 10(8).

Sandaka, B. P., & Kumar, J. (2023). Alternative vehicular fuels for environmental decarbonization: A critical review of challenges in using electricity, hydrogen, and biofuels as a sustainable vehicular fuel. *Chemical Engineering Journal Advances, 14*.

Schaffers, H., Komninos, N., Pallot, M., et al. (2012). Smart cities as innovation ecosystems sustained by the future internet. Technical Report.

Schipper, F. (1996). Rationality and the Philosophy of Organization. *Organization*, 267-289.

Scholten, D., Bazilian, M., Overland, I., & Westphal, K. (2020). The geopolitics of renewables: New board, new game. *Energy Policy, 138*, 111059.

Sioshansi, F., & Webb, J. (2019). Transitioning from conventional to electric vehicles: the effect of cost and environmental drivers on peak oil demand. *Economic Analysis and Policy*, 67, 7–15.

Stergiou, A. (2023). Eastern Mediterranean energy geopolitics revisited: green economy instead of conflict. *Journal of Balkan and Near Eastern Studies*, 25(4), 604-625.

Stubinger, J., & Schneider, L. (2020). Understanding Smart City—A Data-Driven Literature Review. *Sustainability, 12*, 8460.

Van Mierlo, J., Maggetto, G., Van De Burgwal, E., & Gense, R. (2004). Driving style and traffic measures—Influence on vehicle emissions and fuel consumption. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 218*, 43–50.

Wang, Y., & Boggio-Marzet, A. (2018). Evaluation of Eco-Driving Training for Fuel Efficiency and Emissions Reduction According to Road Type. *Sustainability, 10*, 3891.

Wasgaether, K., Remme, D., Haarstad, H., & Sareen, S. (2022). The justice pitfalls of a sustainable transport transition. *Environment and Planning F, 1*(2-4), 187-206.

World Commission on Environment and Development (1987). *Our Common Future*. Oxford: Oxford University Press.

Xu, P., Tan, D. H. S., & Chen, Z. (2021). Emerging trends in sustainable battery chemistries. *Trends in Chemistry, 3*, 620–630.

Zetter, K. (2016). Inside the cunning, unprecedented hack of Ukraine's Power Grid. *Wired*. Available at: https://www.wired.com/2016/03/inside-cunning-unprecedented-hack-ukraines-power-grid/

Zhao, Z., & Zhang, Y. (2020). Impact of Smart City Planning and Construction on Economic and Social Benefits Based on Big Data Analysis. *Complexity, 2020*, 8879132.

Ziemann, S., Müller, D. B., Schebek, L., & Weil, M. (2018). Modeling the potential impact of lithium recycling from EV batteries on lithium demand: A dynamic MFA approach. *Resources, Conservation and Recycling, 133*, 76-85.