VILNIUS UNIVERSITY
BUSINESS SCHOOL

INTERNATIONAL PROJECT MANAGEMENT PROGRAMME

BAYAN ALAMRO

THE FINAL MASTER THESIS

"Projektų Tvarumo Vertinimas Transporto Industrijoje"	**"Assessment of the Projects Sustainability in the Transportation Industry."**

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Supervisor: Dr. Danguolė Oželienė

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SUMMARY

VILNIUS UNIVERSITY BUSINESS SCHOOL
INTERNATIONAL PROJECT MANAGEMENT PROGRAMME
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ASSESSMENT OF THE PROJECT'S SUSTAINABILITY IN THE TRANSPORTATION INDUSTRY

Supervisor – Dr. Danguolė Oželienė
Master's thesis was prepared in Vilnius, in 2024
Scope of Master's thesis – 70 pages.
Number of figures used in the FMT – 22 Figure
Number of Tables used in the FMT – 6 Tables
Number of bibliography and references – 92 references

The FMT described in brief: This master's thesis assesses the sustainability of projects in the transportation industry, focusing on the case study of Copenhagen Cycling Infrastructure. It explores the environmental, economic, and social impacts of this project and analyzes how effective integration of these factors can enhance sustainability while highlighting best practices and recommendations for future initiatives.

Problem, objective, and tasks of the FMT: Transportation projects often fail to leverage sustainable practices, limiting their overall positive impact fully. This thesis uses case studies like Copenhagen Cycling Infrastructure to assess how sustainability can be better integrated into transportation infrastructure.

The **objective** is to explore the drivers of transportation projects' sustainability and assess their impact on project outcomes, providing recommendations for future projects.

Tasks:

1. Define essential sustainability principles in transportation projects
2. Analyze the sustainability practices of selected case study
3. Assess environmental impacts and explore the economic and social benefits linked to the project
4. Identify effective methods for incorporating sustainability into transportation projects
5. Provide recommendations for enhancing sustainability in future transportation projects.

Research methods used in the FMT: The research methods used in this study involved both qualitative and quantitative approaches. The qualitative approach included a comprehensive literature review, while the quantitative approach involved case study analysis using the Multi-Criteria Decision Analysis with the Simple Additive Weighting method to assess sustainability outcomes. Finally, a comparative analysis was conducted to identify best practices and formulate recommendations.

Research and results obtained: This research assessed the sustainability of Copenhagen's cycling infrastructure in terms of the environmental, economic, and social dimensions of sustainability. It reduced GHG gas emissions, improved air quality, and reduced dependency on motor vehicles. It has shown evidence that the venture is viable economically, with cost-cutting, health expenditure reduction, and the creation of new employment. It also showed that accessibility and equity have improved through more inclusive and affordable modes of transport. The study showed, among other MCDA tools, that balanced integration will result in impactful and replicable outcomes that place Copenhagen's cycling infrastructure as a global model for sustainable urban transport.

Conclusions of the FMT: Evaluating sustainability in transportation projects is vital to ensure that infrastructure development fulfills current needs while remaining flexible to future obstacles. Integrating sustainability assessments into the project management framework allows for a thorough analysis of economic, environmental, and social elements, fostering transportation systems that are not only effective but also durable and fair.

SANTRAUKA

VILNIAUS UNIVERSITETAS VERSLO MOKYKLA
TARPTAUTINĖ PROJEKTŲ VALDYMO PROGRAMA
BAYAN ALAMRO
TRANSPORTO INDUSTRIJOS PROJEKTŲ TVARUMO VERTINIMAS

Darbo vadovė – Dr. Danguolė Oželienė
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Bibliografijos ir literatūros sąrašas – 92

BD apibūdinimas trumpai: Šiame magistro darbe vertinamas transporto pramonės projektų tvarumas, daugiausia dėmesio skiriant Kopenhagos dviračių infrastruktūros atvejo analizei. Jame nagrinėjamas šio projekto poveikis aplinkai, ekonominis ir socialinis bei analizuojama, kaip veiksminga šių veiksnių integracija gali padidinti tvarumą, kartu pabrėžiant geriausią praktiką ir rekomendacijas būsimoms iniciatyvoms.

BD problema, tikslas ir uždaviniai Transporto projektai dažnai nesugeba panaudoti tvarios praktikos ir visiškai apriboja bendrą teigiamą jų poveikį. Šiame darbe naudojami atvejai, pvz., Kopenhagos dviračių infrastruktūra, siekiant įvertinti, kaip tvarumą galima geriau integruoti į transporto infrastruktūrą.

Tikslas yra ištirti transporto projektų tvarumą skatinančius veiksnius ir įvertinti jų įtaką projektų rezultatams, teikti rekomendacijas būsimiems projektams.

Uždaviniai:

1. Apibrėžti esminius tvarumo principus transporto projekte.
2. Išanalizuoti tvarumo praktiką pasirinktuose projekte (atvejo analizės),
3. Įvertinti su šiuo projektu susijusią aplinkosauginę, ekonominę ir socialinę naudą
4. Nustatyti veiksmingus tvarumo įtraukimo į transporto projektus metodus.
5. Pateikti rekomendacijas dėl tvarumo didinimo būsimuose transporto projektuose.

BD naudojami tyrimo metodai: šiame tyrime naudojamas kokybinis metodas (atvejo analizė), pradedant išsamia literatūros apžvalga ir atliktomis atvejo analizėmis. Galiausiai buvo atlikta lyginamoji analizė, siekiant nustatyti geriausią praktiką ir suformuluoti rekomendacijas.

Tyrimai ir gauti rezultatai: šiam tyrime metu buvo įvertintas Kopenhagos dviračių infrastruktūros tvarumas aplinkos, ekonominių ir socialinių tvarumo aspektų požiūriu. Tai sumažino išmetamų ŠESD kiekį, pagerino oro kokybę ir sumažino priklausomybę nuo variklinių transporto priemonių. Tai parodė, kad įmonė yra ekonomiškai perspektyvi, nes mažinamos išlaidos, sveikatos išlaidos ir sukuriamos naujos darbo vietos. Tai taip pat parodė, kad pasiekiamumas ir teisingumas pagerėjo dėl įtraukesnių ir įperkamų transporto rūšių. Tyrimas, be kitų MCDA priemonių, parodė, kad subalansuota integracija duos veiksmingų ir pakartojamų rezultatų, dėl kurių Kopenhagos dviračių infrastruktūra taps pasauliniu tvaraus miesto transporto modeliu.

BD išvados: Transporto projektų tvarumo įvertinimas yra gyvybiškai svarbus siekiant užtikrinti, kad infrastruktūros plėtra atitiktų dabartinius poreikius ir liktų lanksti būsimiems barjerams. Tvarumo vertinimų integravimas į projektų valdymo sistemą leidžia atlikti išsamią ekonominių, aplinkosaugos ir socialinių elementų analizę, skatinant transporto sistemas, kurios yra ne tik efektyvios, bet ir patvarios bei sąžiningos.

TABLE OF CONTENTS

List of Figures:

List of Tables:

INTRODUCTION

Relevance: The pressing need to tackle climate change, alleviate traffic congestion, and address social inequalities highlights the importance of sustainability in transportation initiatives. Previous research has examined the incorporation of sustainability into urban planning (Crane et al., 2021), yet there is still a demand to enhance our comprehension of how sustainability metrics can be effectively applied across environmental, social, and economic dimensions in transportation infrastructure.

Smith et al., (2021) proposed a systems-oriented framework that merges sustainability assessment with urban design processes, while (Veloso et al, 2024) explored how smart city initiatives can foster sustainable urban growth. Nevertheless, Gonzalez et al. (2022) discovered that just 18% of transportation initiatives worldwide utilized integrated sustainability assessment tools, revealing obstacles to their broader adoption. Furthermore, Frumkin et al. (2021) highlighted the necessity for transformations at the city level to achieve holistic health and environmental advantages, stressing the interlinked nature of sustainability challenges. On a global level, the International Energy Agency (2021) stated that transportation represented 37% of total CO_2 emissions in 2020, with road transport being the primary contributor. Likewise, the European Investment Bank (2023) pointed out that while 32% of transport financing in 2022 was directed towards green and innovative approaches, a more extensive implementation is still needed. This research adds to the existing conversation by assessing the effectiveness of sustainability assessment tools and their real-world use in transportation projects.

Formulation of the problem: Despite the growing acknowledgment of sustainability's significance in the transportation sector, many projects still struggle to effectively integrate these principles into their design and execution.

With complex transportation systems, decision-making has often caused fragmentation in which environmental, economic, and social dimensions are taken care of separately, not as parts of an interlinked system.

The objective: This thesis seeks to explore the drivers of transportation projects' sustainability and assess their impact on project outcomes, providing recommendations for future projects.

Tasks:

1. Define essential sustainability principles in transportation projects
2. Analyze the sustainability practices of the selected case study.
3. Assess environmental impacts and explore the economic and social benefits linked to the project.
4. Identify effective methods for incorporating sustainability into transportation projects
5. Provide recommendations for enhancing sustainability in future transportation projects.

The structure: the thesis is composed of 3 chapters: the first chapter presents a literature review, outlining a theoretical framework for sustainability in transportation and providing an overview of project assessment tools used to evaluate sustainability outcomes in transportation projects. The second chapter focuses on the research methodology and case study selection, with the application of Multi-Criteria Decision Analysis using Simple Additive Weighting (SAW) method, as the primary evaluation method. The third chapter provides a detailed analysis of the three selected projects and discusses the sustainability outcomes based on the findings, followed by recommendations to address the research objectives.

Difficulties and limitations: This research may encounter some challenges including issues with data availability, particularly in accessing quantitative measures of sustainability across different organizations.

Artificial Intelligence in FTM: ChatGPT was used in generating Figure 11, Table 1, Table 4, Table 5 and Table 6. It was used to help with creation of draft version.

1. Sustainability in Transportation Projects: Theoretical Framework and Tools

1.1.Definition of Sustainability

In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

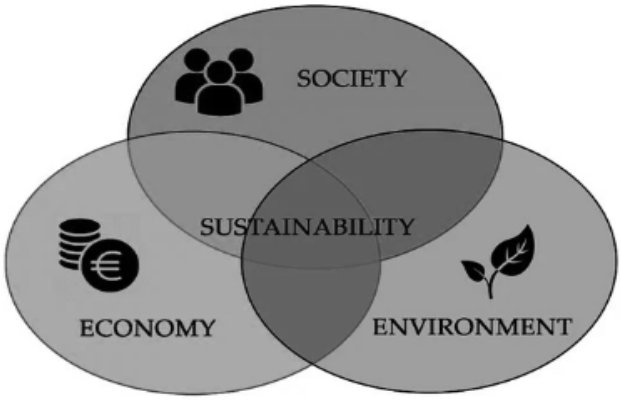
Accordingly, sustainable policies stress the consequence of any given policy or practice on humans, ecosystems, and the wider economy in the future. The concept often corresponds to the belief that "without major changes in respect to the way the planet is run, it will suffer irreparable damage "(Roy, 2021). In an era where man-made climate change, biodiversity loss, and general pollution have become the talk of every home, the world is shifting in the direction of embracing sustainability through the implementation of sustainable practices and increasing green technology investments (Shrivastava et al., 2020).

The concept of sustainability is commonly divided into three intersecting circles or pillars: economic, environmental, and social. Sometimes, it is known as profits, planet, and people (Purvis et al., 2019). In this framework, economic sustainability refers to the maintenance of natural resources, that is also considered crucial inputs into economic activities. These include both renewable and finite resources (Muniz et al., 2023). Although, it is traditionally framed through three core pillars: economic, environmental, and social. However, the concept of a fourth pillar has emerged in recent years, with the primary contender being cultural sustainability.

Cultural sustainability emphasizes the preservation and promotion of cultural identity, heritage, and practices. It recognizes that culture influences how communities perceive and interact with the environment and how they prioritize social and economic values (Sabatini, 2019). Sustainability seeks to balance economic, social, and environmental needs for the present and the future. This three-pillar framework is a good representation of how all elements are connected, that actions and their impacts should be balanced, and acknowledging that no individual, organization, or nation operates in isolation (Mensah, 2019).

Figure 1

The three pillars of sustainability



Source: University of Liverpool, 2023

In 2015, United Nations Member States made a historical leap in implementing the 2030 Agenda for Sustainable Development through an elaborate framework in the interest of ensuring peace and prosperity for all humans in our world and future generations. It was, a very futuristic agenda, which brought into focus 17 all-important SDGs that summed up an appeal for action by each country-developed and developing-to integrate them as one single act of cooperation at a global level. (United Nations).

These SDGs have also reminded us that any effort for the eradication of poverty along with other socio-economic disparities does indeed have to incorporate adequate policy remedies for upgrade in healthcare and education, societal equality, and economic growth that is sustainable. In addition, this flagship initiative underlines the urgent need for unity in the face of challenges thrown up by climate change-underlining the protection of our vital oceans and essential forests as being of the highest importance for the well-being of our whole planet.

Figure 2

The UN 17 Sustainable Development Goals

Source: United Nations, Department of Economic and Social Affairs.

Environmental Sustainability is the foundation of the three sustainability pillars. It focuses on the environment's health, including air quality, clean water, and biodiversity. As climate change shows, environmental sustainability cannot be achieved without social and economic sustainability (United Nations).

At least six United Nations Sustainable Development Goals address environmental sustainability.

Figure 3

The UN 17 Sustainable Development Goals – Environmental icons

Source: United Nations, Department of Economic and Social Affairs.

The main elements of social sustainability are public health, happiness, human rights, equity, and education, which contribute to the community's well-being. One of the three pillars of sustainability is assuring that everyone's fundamental rights and needs are met.

In other words, social sustainability helps communities and governments maintain peace and protects individuals from poverty, hunger, illness, violence, and oppression, among other

social challenges. Companies contribute to social sustainability by fostering a positive and diverse culture of inclusion, providing worker safety and fair treatment to keep them safe while paying a living wage. From the sustainable development perspective, nine UN SGD goals, including the first five, are anchored on social sustainability. (Ly et al, 2023)

Figure 4

The UN 17 Sustainable Development Goals – Social icons

Source: United Nations, Department of Economic and Social Affairs.

Social sustainability, focused by the SDGs, is inextricably linked to the protection of basic human rights, meaning that social sustainability can hardly be achieved without having the basic needs of all people met and human rights protected. Also, the sphere of social sustainability is closely connected with environmental preservation and economic security.

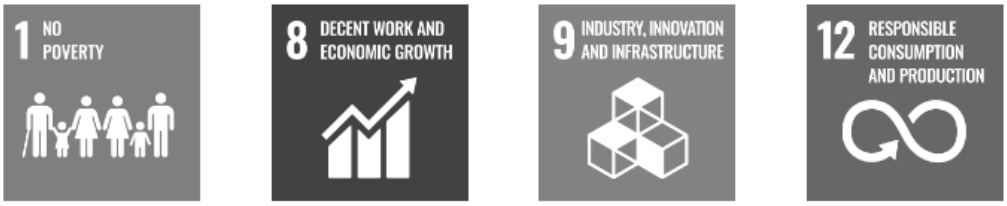
For instance, the adoption of healthier, plant-based dietary patterns not only bolsters public health outcomes but also extends positive impacts on the environment. The recent COVID-19 crisis has clearly demonstrated that prioritizing public health not only curtails healthcare expenditures but also allows individuals to safely engage in economic activities, showcasing the symbiotic relationship between public well-being and economic prosperity (Yang et al., 2021).

Economic sustainability is important to drive economic development, employment generation, remuneration, labor rights, and sustainable livelihoods. As part of the sustainability framework, economic sustainability is a driver of innovation and economic growth with an improved quality of life, indicating the need to reconcile economic enterprise with environmental and social goals. It also plays an important role in community well-being and governmental stability by saving people from the throes of poverty, diseases, malnutrition, and homelessness.

In the corporate domain, the enterprises seek to create an enabling organizational culture that ensures the safety, fair treatment, and living wage payment for their employees. Notably, four specific UN SDGs directly target economic sustainability, emphasizing its critical importance in the broader sustainability discourse (Velenturf et al., 2021).

Figure 5

The UN 17 Sustainable Development Goals – Economic icons



Source: United Nations, Department of Economic and Social Affairs

Like the other pillars, economic sustainability strongly relates to the environment and society. The better the economic conditions, the less resource-constrained the social well-being can become. Increasing wealth usually results in rising consumption, which can harm the environment. (Vogel et al.,2021)

Achieving economic growth and improved living standards without increasing emissions, pollution, or overconsumption of natural resources is challenging. (Okeke et al.,2024)

Each of the pillars of sustainability- environmental, social, and economic- is interrelated and, therefore, needs to be balanced to achieve long-term viability. (Ranjanbari et al.2021) Nature provides important resources: medicines and materials necessary for health and economic sustainability. Environmental sustainability maintains critical life support systems, such as the atmosphere and soil, essential for ecological balance and human life. Social sustainability looks at how economic systems directly affect human well-being and deal with poverty, hunger, and inequality. However, the focus on economic growth and extraction of natural resources without considering the environmental and social consequences led to the climate crisis. Sustainability is a complex and challenging concept; nevertheless, it underlines a holistic approach to all human and environmental well-being (Ahmad et al., 2023).

1.2. Sustainability in Transportation

Public transportation plays a vital role in reaching those goals of environmental sustainability that eliminate all activities in transport which have negative impacts on the environment. This involves not only cutting carbon emissions but even working on energy efficiency and shifting towards renewable sources of energy. An important factor in sustainable transport is the facilitation of public transport and the adoption of active modes of travel such as walking and cycling. Besides, electric cars and other low-emission technologies should be introduced with a view to creating a more environmentally friendly transport system.

In urban planning, the strategies that aim to reduce travel distances are crucial for sustainable mobility. For example, mixed-use neighborhoods that combine residential, commercial, and recreational spaces contribute to shorter commutes and, therefore, a lower carbon footprint. Integrating all the different facets of sustainable transport can enable cities to meet global goals, such as the below 2°C target of the Paris Agreement.

It is also going to be a core component of sustainable transport practices through the transition to renewable energy and electric vehicles. Ahmad et al. (2023) state that recent transport investments have increasingly emphasized environmental, social, and governance considerations. This trend has gradually pushed the industry to give priority to clean energy technologies and invest in innovations that reduce emissions. In the final analysis, sustainable transportation is essential to meeting the goals of international sustainability frameworks for a greener and more environmentally sensitive future of transport systems worldwide.

Further research into urban mobility, shared transportation, and policy-making has identified a number of key lessons that are being used to implement sustainable transport practices. For example, Buehler and Pucher (2021) have noted that cities like Amsterdam and Copenhagen have integrated cycling into their respective urban infrastructures in a way that creates low-carbon-emission transport systems, improves public health by increasing physical activity, and enhances the general sense of community among residents. This emphasis on investment in cycling exemplifies how strategic urban planning can yield multiple benefits beyond transportation.

Furthermore, as Gössling (2021) has pointed out, what makes Copenhagen a "successful cycling city" serves to illustrate how targeted policy measures and significant investments in cycling infrastructure are needed for the bike-friendly urban environment of a city in order to ensure that active transportation modes are embraced. With the right combination of policies and

infrastructure improvements, cities can improve mobility while reducing carbon footprints and contributing to healthier lifestyles for their citizens.

In corroboration with that, shared mobility has cropped up as a likely answer to the search for sustainable urban transport. In this respect, the study conducted by Pan et al. (2020) exemplifies how the emerging concepts of bicycle sharing and hitching rides might reduce car ownership and congestion in the city. This is further reiterated by Marsden and Docherty in 2019, who noted that the future of sustainable transport systems will rely heavily on how well policies are planned and implemented.

As we go further into the concept of sustainable transportation, it is obvious that a multi-modal approach, but with a priority on sustainability, is what will help in nurturing a greener and more effective urban transport atmosphere. This reiterates what Martens said in 2017 about "transport justice," where transportation services are to be fairly provided to all members of the community, especially the most marginalized or oppressed.

Moreover, the social equity in transportation contributes to a fairer society and general sustainability objectives since it reduces environmental and economic burdens. Recent studies have tried to explain the difficult interrelationship of transport options with the welfare of urban households; it was noted that sustainable mobility efforts go beyond simple emission reduction to issues of improving life quality. Most importantly, research by Ali Rani and Verma (2022) stresses that sustainable transportation policies can also play a contributory role toward uplifting public health with social equity in developing economies.

Within an environmental perspective, new technologies need to be incorporated into transportation systems to ensure that the transportation system is sustainable for the long term. The development and implementation of efficient demand-side policies, which foster public transport and discourage travel by private cars, can contribute to the reduction of climate change impacts. These factors align with state-of-the-art analyses, which point to pathways toward global transport decarbonization. The acceptance of innovative solutions and the shifting toward sustainability will be some of the steps in realizing a sustainable and resilient transport sector. Focusing on shared mobility, social equity, and environmental sustainability, an urban area is able to create a pathway to a more harmonious and efficient transportation environment.

The International Energy Agency's "World Energy Outlook 2020" highlights one of the important features: the Net Zero Emissions by 2050 Scenario, which underlines electrification, the

use of low-carbon fuels, and a strong efficiency drive as critical components in pursuing net-zero emissions in the transport sector. Recent research also underlines the importance of policy tools, individual behavior, and institutional frameworks in the way of promoting sustainable mobility initiatives. Reichenbach et al. (2023) precisely develop the complex relations between technological changes and shifting discourses on mobility transition. These have placed formidable challenges before public transport practitioners in effectively implementing sustainable transport policies at grassroots levels.

In other words, the concept of sustainable transportation encompasses a complex set of measures regarding how to minimize ecological footprints, improve the conservation of energy resources, and use new clean forms of energy conversion. This approach champions public transport and active mobility options, along with the mass introduction of electric vehicles, with accessible and efficiency-oriented urban planning strategies. By embedding such sustainable systems in social justice and equity principles, communities can realize optimal benefits and improve their quality of life. While these individual elements are of great importance, integrating them into a workable whole remains one of the biggest challenges to overcome in pursuing sustainable transportation options.

1.3. Integrating Sustainability in Transportation Projects:

Integrating sustainability into project management in the transport sector focuses on making different project objectives align with broader environmental, social, and economic goals. To this end, sound project management provides the best way of integrating the consideration of sustainability at every stage of the project's life cycle, which includes the stages of planning, execution, monitoring, and closure of the project. With greater emphasis on environmentally friendly, socially equitable, and economically efficient approaches, sustainable development may derive enormous benefits from transportation projects. Such initiatives help advance the idea of sustainability and contribute substantially to enhancing the quality of life for all members of society and conserving our environmental resources for future generations.

Effective project management must consider stakeholder engagement, which has been identified as an absolutely essential element. It is critical that stakeholder involvement begins early in the process of defining sustainable solutions that minimize potential risks and ultimately ensure a much smoother project delivery overall (Bernat et al., 2023).

Including stakeholders allows for various perspectives and thus ensures that transport projects address community needs and support long-term sustainability. Governance and institutional policy also play an important role in sustainably managing transportation. As Beyazit et al. (2023) have pointed out, "The sustainable governance of urban mobility systems is critical in shaping sustainable and resilient cities that address today's challenges."

Effectively putting a comprehensive governance framework in place requires regulatory measures with sustainability-driven policies. Based on this fact, the ground for the research is founded on reconfiguring urban mobility governance in ways that bring about justice and inclusivity of transport systems. This infuses movement representation and practical frameworks into governance to develop equitable and sustainable transport solutions.

The other essential and crucial ingredient contributing to the realization of sustainability is the application of contemporary metrics along with advanced evaluation tools. Creutzig et al. (2018) recommend the inclusion of sustainability assessment indicators at the heart of project management systems that will involve several techniques such as life cycle analysis, GHG emission studies, and complete social impact analysis. The indicators incorporated in the projects enhance the performance of sustainability to a great extent.These integrated approaches thus afford managers a number of powers through closely keeping track of actual performance from the very outset, which enables them to monitor performance at its earliest stages; thus, in designing transportation systems, sustainability needs to be at the center and forefront with environmental considerations high on planners' agendas.

Advanced digital management tools have now become crucial for real-time data analysis, hence helping substantially to find any impending challenges on the road to sustainability.This data-based approach allows organizations to take preventive measures far before such issues grow to uncontrollable levels. This proactive strategy minimizes environmental impacts and ensures that the resources are efficiently allocated toward the higher-level objectives of sustainability, as underlined by Abedsoltan et al. (2024). For example, integrating real-time information into the urban transportation system will be instrumental in enhancing operational efficiency, safety, and utilization of available resources (datasmart.hks.harvard.edu). Besides this, digital solutions are generally known to be characteristic data ecosystems that help to maximize visibility across different processes, enhance productivity, and improve decision-making capabilities. Such enhancement can result in improved designs, reduced waste production, or sustainable materials

within the system. Examples of how technology has become actively leading to sustainable transportation projects include that of artificial intelligence in integrated transportation. These integrations highly increase operations by manifold and are opening up a whole new sphere of creating ingenuity in fostering sustainability. In a big way, AI helps optimize resource utilization, which is instrumental in emission reduction—a key ingredient in developing greener transportation infrastructure (Elassy et al., 2024). For example, AI can significantly improve the different dimensions of incident response and prediction. It also can enhance the capabilities of video detection systems so that the possibility of conflicts between pedestrians and vehicles can be reduced to a greater extent. At the same time, it can offer better monitoring and management of assets, indirectly facilitating the infrastructure in a good state of repair and maintenance (Tselentis et al., 2023).

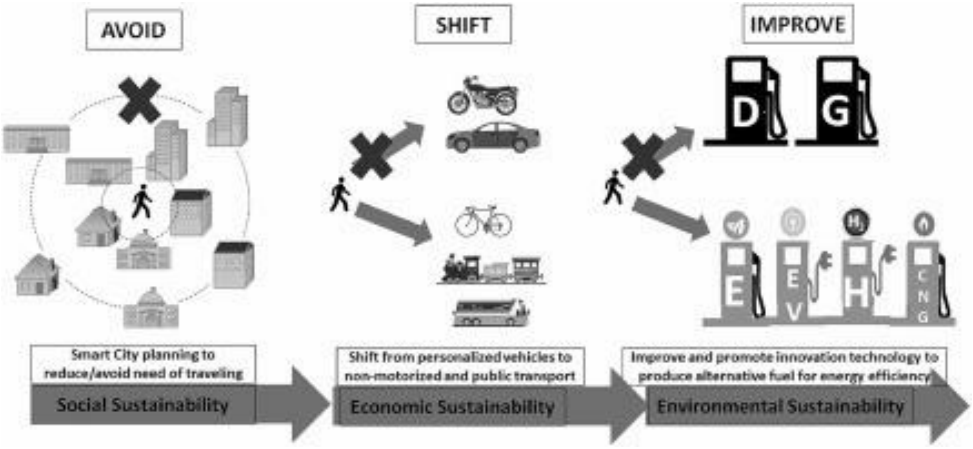
Assessing sustainability within the framework of transportation projects significantly highlights the crucial importance of various technological components that play a vital role in this area. Recent studies undertaken over the past few years have established, through evidence, that the use of project management systems for sustainability will indeed ensure that transport projects meet their mobility purposes while contributing to the larger objectives of sustainability.

These include, but are not limited to, reduction in negative emissions and the facilitation of equal access by everyone, and limited socio-economic impacts on people. (Lawrence, A, 2024)

Incorporating artificial intelligence and advanced smart infrastructure into the management of transportation projects is a must in developing systems designed to be highly efficient but also sustainable, and resilient in the face of challenges.

Figure 6

Sustainable Transport



Source: Shah et al. 2021

Sustainability in transportation projects is no longer optional but imperative for addressing global challenges. By integrating sustainable infrastructure design, renewable energy, equitable access, and environmental mitigation strategies, transportation systems can contribute significantly to achieving global climate and development goals.

1.4. Project's Sustainability Assessment Tools

In case of guiding transportation initiatives effectively, ensuring that such efforts are in line with essential principles of sustainability, there is a lot of importance attached to sustainability assessment tools. These specialized tools provide structured framework that allows assessing different kinds of impacts—environmental, economic, and social—linked to transportation projects. They offer insights and information of great value to a wide range of stakeholders involved in or affected by these initiatives. With growing focus on key issues such as decarbonization, resource efficiency, and equitable development, the importance of such assessment tools in the transportation sector will only continue to grow (Torres et al., 2018).

Assessment tools are detailed methodologies elaborately designed to determine the potential impacts of various projects, policies, or systems on criteria based on the principles of sustainability (Burchart and Przytula, 2024). In the transport sector, they take a critical look at aspects such as greenhouse gas emissions, patterns of resource use, social equity, economic viability tests, and impacts on public health, among others. Since they incorporate both qualitative and quantitative measures within their frameworks, they permit in-depth analysis of projects and, hence, full compliance with important environmental, economic, and social goals that are very essential in sustainable development.

They have also uncovered trade-offs, used data to give recommendations, and ensured that transportation systems are in line with global sustainability goals like the United Nations Sustainable Development Goals. Their integration in transport planning assures that decisions taken today are well considered for both present and future challenges (Sharifi et al, 2024).

They engage in a wide-ranging stakeholder group, including policy makers, experts, community representatives, and environmental advocates, to guarantee that all assessments under their care are inclusive and equitable. In practices, they help guide the optimization of resource

allocation, the prioritization of investments, and the identification of innovative solutions that enable project managers to compare alternative designs and strategies for improving the sustainability outcomes while lowering the costs (Mauren et al.,2022).

Across the world, there are many sustainability assessment tools specifically developed for transportation and infrastructure projects. Besides these, numerous other tools have been designed to meet the unique needs of certain sectors or geographic regions. In fact, a closer look indicates an existing list featuring over 50 different tools that individually address a comprehensive range encompassing environmental, social, and economic dimensions of sustainable development. From an array of broad, multi-sectoral frameworks such as EIA, to very specialized models like the GreenPave tool that focuses on road pavement assessment, the variety is huge. A wide array of tools is an effective way to bring into light the urgent need to address a diverse range of challenges arising under different contexts and scenarios. Certain tools, such as Life Cycle Assessment (LCA), are developed specifically to focus on the entire lifecycle of a project from its inception to its eventual conclusion, which makes them absolutely indispensable in projects involving significant material and energy use. Unlike other forms of assessment tools, Health Impact Assessment offers insight that is highly focused and pays attention to detail in regard to the various ways that transportation systems can impact public health outcomes, including exacerbating respiratory conditions. This is normally a direct outcome of air pollution, which becomes extremely relevant within a city context, especially within areas with high levels of traffic congestion (Mas Lopez et al. 2023).

There are regional and sectoral differences contributing to the overall heterogeneity of the assessment tools in use across different contexts. For instance, throughout Europe, there has been widespread application of the Strategic Environmental Assessment as a means to ensure that transport policies and programs effectively address sustainability considerations. On the other hand, measures such as Greenroads and GreenPave, which focus on specific infrastructure components, are more widely practiced in North America. Similarly, the tools that have been developed for urban transport systems are quite different from those developed specifically for rural or freight-specific projects in their focus and context of application.

One of the major drivers behind this ongoing development and improvement of these countless tools in the field of transportation planning has to do with the increasing recognition of sustainability as an important and critical priority.

Of course, there are a lot of tools in existence today, some of which have received much wider recognition and are used often. The reason for this could be their comprehensiveness, strong regulatory backing, or their applicability in many contexts of a project. Some of these key tools include:

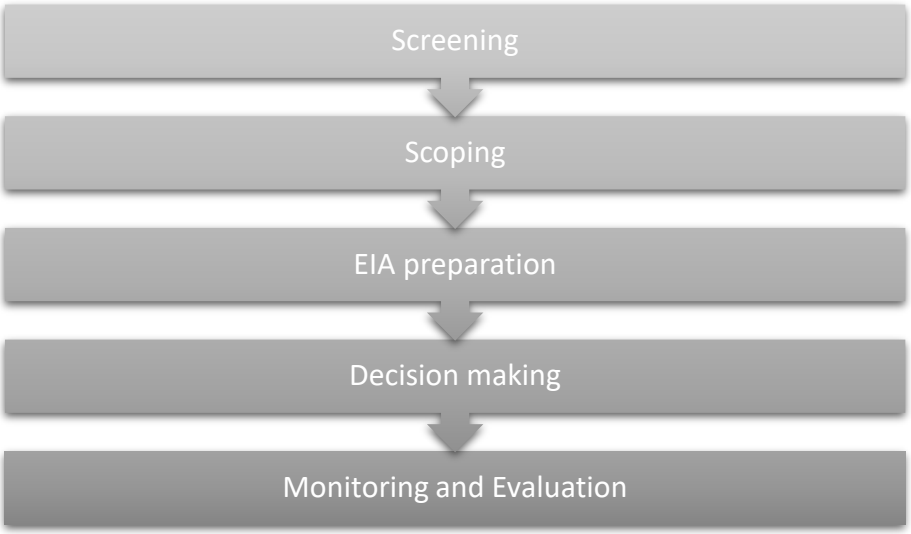
1.4.1. Environmental Impact Assessment

EIA is one of the most widely used sustainability assessment tools globally, often mandated by regulatory authorities. Its primary focus is to evaluate the environmental consequences of transportation projects before their implementation. This includes examining potential impacts on air quality, water resources, soil integrity, noise levels, and biodiversity.

By identifying and mitigating adverse effects, EIA helps ensure that projects align with sustainable development principles. For example, an EIA for a highway construction project would assess risks to local ecosystems and recommend measures such as wildlife crossings to minimize habitat disruption.

Figure 7

The environmental impact assessment (EIA) stages.



Source: European Commission

In Lithuania, the Environmental Impact Assessment (EIA) process is governed by the Law on Environmental Impact Assessment of the Proposed Economic Activity, in line with the EU's

EIA Directive (Directive 2011/92/EU, amended by Directive 2014/52/EU). The EIA system classifies projects based on their potential environmental impact:

- **Annex I**: Projects listed in this annex automatically require a mandatory EIA due to their significant environmental impact. These include large-scale industrial facilities, major infrastructure projects like highways and railways, and waste management installations.
- **Annex II**: Projects not automatically requiring an EIA, but which undergo a screening process. The Environmental Protection Agency assesses these projects to determine if an EIA is necessary, based on factors such as the project's size, location, and potential environmental effects. Examples include smaller industrial developments or urban expansion projects.

The EIA process involves this screening mechanism, where projects in Annex I automatically undergo a detailed assessment, while those in Annex II are evaluated on a case-by-case basis. Public participation is an essential component, enabling stakeholders—including the public and relevant authorities—to engage in the decision-making process. The system also complies with the Espoo Convention, ensuring that neighboring countries are informed and consulted for projects with potential transboundary environmental impacts.

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1.4.2. Life Cycle Assessment (LCA)

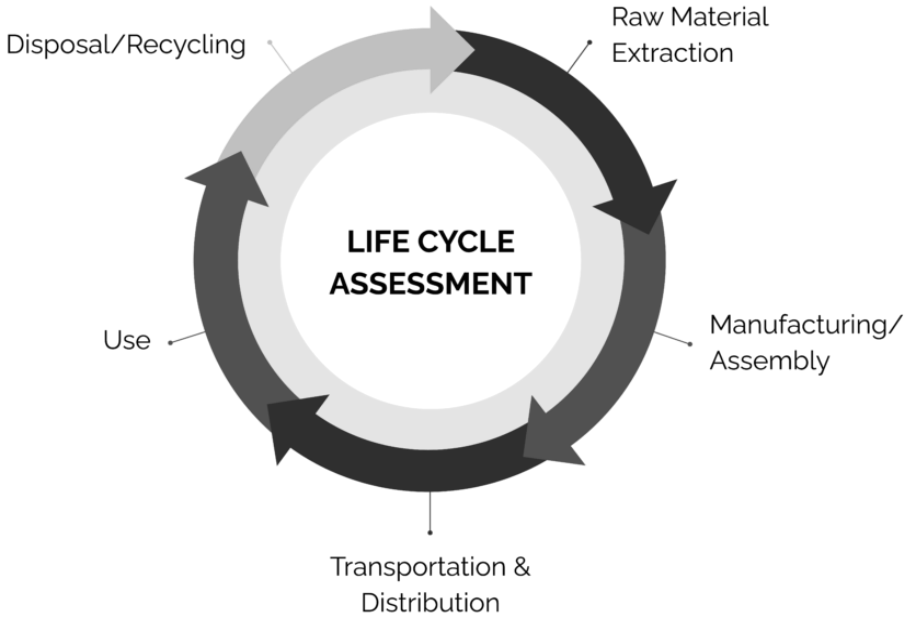
Life Cycle Assessment, LCA, is a broad-spectrum methodology used in determining the environmental impacts of an undertaking through its whole life cycle. The stages included in the assessment go from extraction of raw materials and processes involved in manufacturing to operation, maintenance, and disposal or recycling at the end.

Life Cycle Assessment is an invaluable tool for projects with large-scale, long-term environmental sustainability goals, as it provides precise insights into the specific stages of a project or process that have the greatest environmental impact.

This includes identifying areas of significant carbon emissions, resource consumption, and other ecological effects, enabling targeted strategies to mitigate these impacts effectively.

Figure 8

Life Cycle assessment.



Source: Sustainability tools in cultural heritage.

For example, in rail construction, an LCA might reveal energy consumption during manufacturing as a significant contributor to GHG emissions; it would also provide strategies for reducing the overall environmental footprint, such as using reclaimed or low-impact materials. Quantifying impacts, LCA allows systematic comparison of design alternatives and informs data-driven decision-making for sustainability goals.

1.4.3. Cost-Benefit Analysis (CBA)

Cost-benefit Analysis is a quantitative technique that compares the costs and benefits of a project under different economic, environmental, and social dimensions to assess its feasibility. Its primary purpose is to guide decision-makers in selecting public investments, ensuring that resources are channeled into activities that provide the most outstanding value to society. The components of evaluation in Cost-Benefit Analysis within the transportation domain include construction costs, maintenance costs, and health costs related to emissions. At the same time, it considers all the vast benefits of transport projects: saving time, increasing the safety of citizens, and, most importantly, inducing economic growth.

One of the most important aspects of cost-benefit Analysis is that it can uniquely estimate not only the immediate effects but also the cascading effects that radiate through interconnected systems. For example, when infrastructure is upgraded and optimized, accidents decrease, subsequently lowering associated financial burdens. Similarly, streamlining transportation systems reduces fuel consumption and lowers operational costs, resulting in overall cost savings over time.

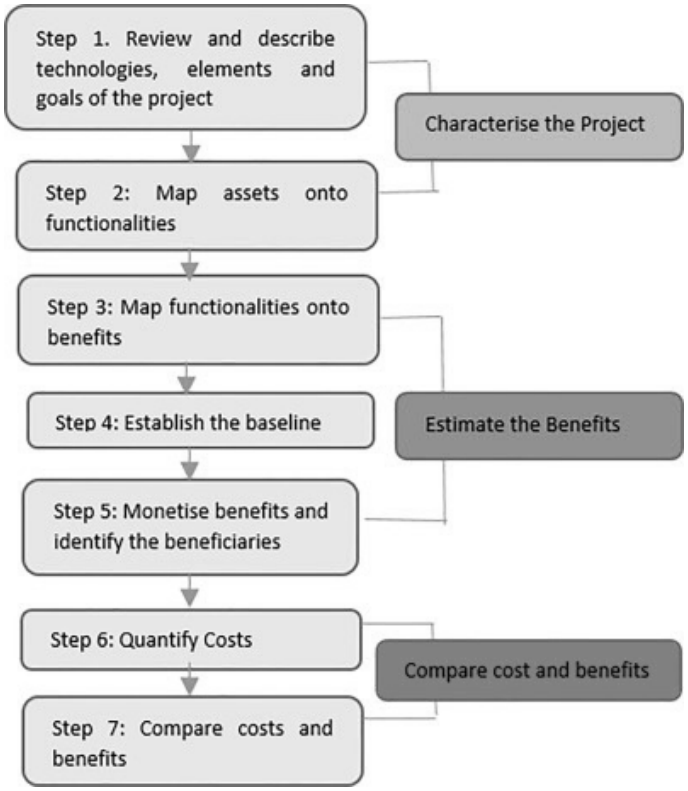
Cost-benefit Analysis embraces many methodologies, from sensitivity analysis to probability analysis and break-even analysis, to mention a few, in estimating costs and benefits. The standard techniques used include Engineering Estimates, Parametric Modeling, Analog Estimation, and the Delphi Method. Each has its strengths, mainly when applied to transportation projects where data-driven models are relied on to make accurate cost and benefit projections.

Authoritative guidelines, such as the European Commission's "Guide to Cost-Benefit Analysis of Investment Projects, " further support the widespread application of cost-benefit Analysis in infrastructure planning. These guidelines are important to ensure that public investments are channeled in a way that allows for sustainable and fair development practices and contributes to broader societal goals. A recent economic analysis delving into the feasibility of smart roadside infrastructure sensors for connected and automated mobility sheds light on the necessity of applying Cost-Benefit Analysis.

According to a study led by Kloeker et al., 2023, this sheds light on the high initial investment in implementing intelligent transportation systems. However, the study has proven that the prodigious benefits accrued over time, like better traffic management and bolstered security, give reason enough to justify the costs incurred. This goes to remind one of the indispensable role that Cost-Benefit Analysis plays in shaping the planning and execution of infrastructure projects, ensuring that the investments yield substantial and long-lasting societal advantages.

Figure 9

The basic Framework of Cost benefit analysis



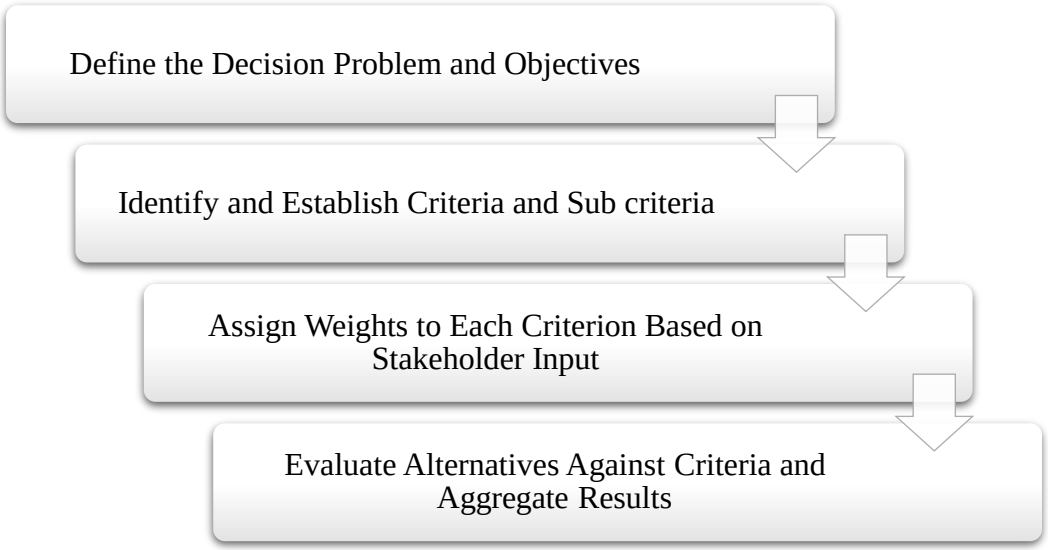
Source: Goel et al, 2022

1.4.4. Multi-Criteria Decision Analysis

MCDA is a very strong and useful tool in decision-making, especially where there is an appraisal of various projects or alternatives against multiple criteria that often involve conflicting interests. This approach becomes indispensable where trade-offs between competing priorities are not only palpable but also inevitable. Such priorities can be from the promotion of economic growth and maintenance of environmental sustainability to the enhancement of social equity and other concerns. With MCDA, stakeholders are able to carry out a thorough assessment and comparison of the various factors underpinning an issue, informed by a structured approach to decision-making that ensures a fair and reasoned conclusion, with diverse implications for each criterion. Making complex decisions clear—at its core—MCDA aims to help people wade through decisions involving multiple criteria at once. This approach is hence very flexible and applicable to a variety of projects in different industries by using both qualitative and quantitative data. The usual MCDA process includes some key steps: defining the decision problem, identifying relevant criteria, determining criterion weights based on the feedback of stakeholders, and evaluation of options against these criteria.

.Figure 10

Multi-Criteria Decision Analysis steps in project management,



Compiled by Author, based on Estevez et al.,2021

While MCDA is an effective tool, it does present several challenges. One of the main issues is establishing suitable weights for each criterion. If the weighting procedure is not managed meticulously, it can produce biased outcomes, particularly if specific stakeholders wield more power in the process. Moreover, the complexity of the methodology may complicate its application in scenarios with numerous criteria or options. Lastly, the subjective nature of the scoring system may result in conflicts among stakeholders concerning how alternatives should be evaluated.

1.4.5. Strategic Environmental Assessment

Strategic Environmental Assessment (SEA) is a methodical approach for assessing the environmental impacts of specific plans and programs, as described by the European Commission. Unlike assessments focused on individual projects, SEA functions at a broader strategic level, emphasizing the incorporation of environmental factors into the development, approval, and execution of policies, plans, and programs. This forward-thinking strategy ensures that sustainability is integrated into extensive decision-making processes, thereby encouraging sustainable development.A significant advantage of SEA is its capacity to evaluate cumulative environmental impacts, which is particularly crucial in areas such as transportation, energy, and

land management. For instance, when expanding a regional rail system, SEA can investigate potential effects on ecosystems, air quality, and public health, allowing policymakers to choose the most sustainable options. By examining these impacts early in the planning process, SEA aids in avoiding environmental harm and supports resource-efficient growth.

The SEA process consists of several vital steps, including scoping, drafting an environmental report that takes into account baseline data and plausible alternatives, public engagement and participation, decision-making, and monitoring.

Figure 11

General Process of Strategic Environmental Assessment

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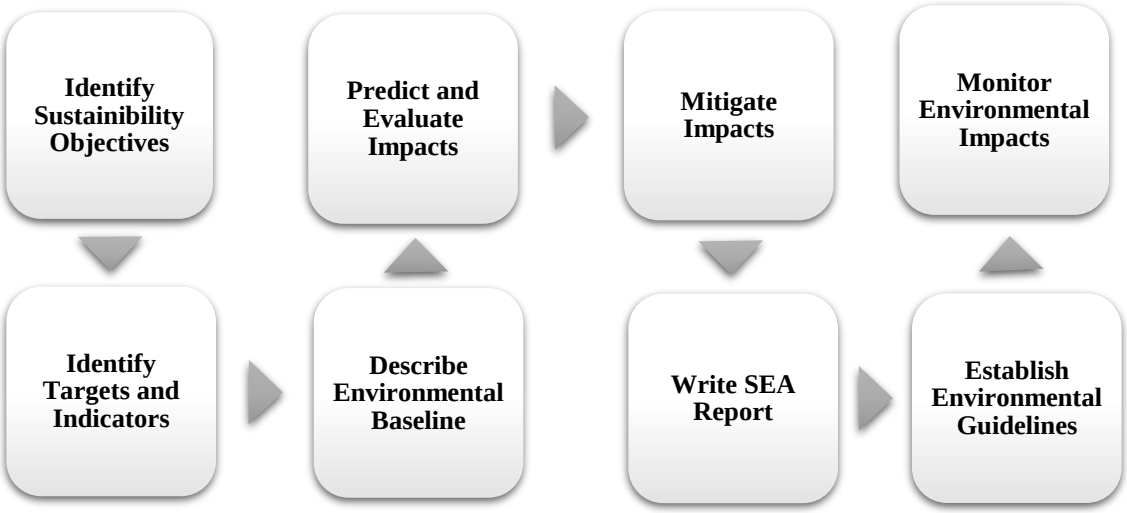


Compiled by Author, based on Souloutzoglou et al. 2020

This organized method promotes coordination across various sectors and ensures that environmental goals are in harmony with economic and social aims. Moreover, by involving stakeholder feedback and public participation, SEA improves transparency and guarantees that a wide range of viewpoints influence strategic decisions, which increases the chances of acceptance and effective implementation. Additionally, SEA contributes to adherence to international sustainability agreements and treaties, such as the United Nations Sustainable Development Goals (SDGs). By incorporating environmental accountability into high-level planning, SEA is instrumental in promoting sustainable development and reducing risks associated with large-scale

policy directives. The European Commission observes that implementing the SEA Directive should result in more sustainable and resource-efficient development by systematically evaluating various options during the planning phase.

In conclusion, SEA is a critical tool for embedding environmental considerations into strategic decision-making, ensuring that plans and programs align with sustainable development objectives. Its thorough methodology enables the early detection and mitigation of potential environmental effects, encouraging more informed and responsible policymaking.

1.4.6. Health Impact Assessment

Health Impact Assessment (HIA) is a structured method for assessing the potential health effects of policies, plans, and projects, particularly in sectors like transportation that greatly affect public health. It is distinguished by its emphasis on health considerations during the decision-making process, ensuring that infrastructure advancements align not only with economic or technical objectives but also to foster healthier communities.

The core advantage of HIA lies in its capacity to tackle health outcomes from a multidisciplinary perspective, linking transportation planning directly with public health. It recognizes both direct effects, such as variations in air quality and noise levels, and indirect effects, such as improved access to healthcare services or increased opportunities for physical activity through enhanced walking and cycling facilities. For example, analyzing a new metro line could reveal its potential to reduce traffic congestion and emissions, thereby decreasing respiratory illness rates while also considering its impact on equitable access to job and healthcare opportunities.

It utilizes a combination of qualitative and quantitative methodologies to provide a comprehensive overview of potential health consequences. It employs baseline health statistics, forecasting models, stakeholder engagement, and public opinion surveys to evaluate current conditions and predict future changes. This diverse approach enables HIA to examine health risks and advantages in depth. For instance, predictive models can illustrate how decreased vehicle emissions may lead to reduced asthma prevalence, while feedback from stakeholders can bring attention to social equity issues.

Health Impact Assessment is a flexible tool that can be applied to both small-scale projects, like adding a bike lane, and larger-scale developments, such as highway or rail construction. It

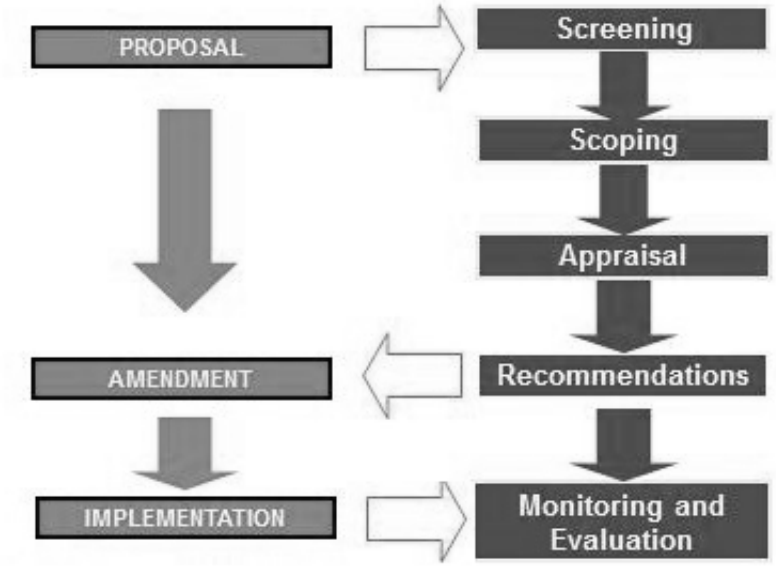
plays a key role in promoting health equity by identifying disproportionate impacts on vulnerable populations, including low-income groups, children, and the elderly.

Collaboration is central to the HIA process, involving public health experts, transportation planners, policymakers, and community members to ensure diverse perspectives are integrated, enhancing the credibility and alignment of outcomes with community interests.

The goal of HIA is to offer recommendations that minimize negative health impacts and maximize positive effects. It focuses on key health determinants, such as living conditions, social networks, and lifestyles, and evaluates how these factors impact public health and disparities. The HIA process involves five stages: screening, scoping (planning), impact assessment, recommendations formulation, and evaluation.

Figure 12

Stages of Health Impact Assessment



Source: The Journal of Community Informatics.

HIA functions not just as an isolated instrument but as an integrated approach that complements other environmental and social assessments, such as Environmental Impact Assessment (EIA) or Social Impact Assessment (SIA). By connecting these fields, HIA guarantees a more comprehensive understanding of the implications of a project. It also supports international initiatives such as the World Health Organization's recommendations on healthy cities and aligns

with Sustainable Development Goals, specifically SDG 3 (Good Health and Well-Being) and SDG 11 (Sustainable Cities and Communities).

Despite the clear advantages of HIA, it confronts challenges such as limited data access, challenges in quantifying specific health outcomes, and potential pushback from stakeholders who may be unfamiliar with its processes. Nevertheless, improvements in data collection technologies, including geospatial analysis and health monitoring systems, are enhancing HIA's accuracy and relevance. Health Impact Assessment is vital in ensuring that transportation initiatives promote public health goals. By systematically recognizing and addressing risks while highlighting health benefits, HIA empowers decision-makers to develop infrastructure that encourages sustainable and inclusive progress. It serves not just as a technical tool but as a strategic framework for designing transportation systems that are just, effective, and conducive to health.

According to the research and evaluation of the sustainability assessment tools and methods referenced, Table 1 below offers a comparative summary of the advantages and disadvantages of each tool in transportation projects.

Table 1

The Advantages and Disadvantages of Sustainability Assessment Method

Assessment Method	Advantages	Disadvantages
Environmental Impact Assessment	- Comprehensive evaluation of environmental impacts. - Identifies direct and indirect environmental consequences. - Helps meet regulatory requirements.	- Often focuses on larger projects, limiting applicability to smaller-scale initiatives. - May not capture all indirect effects. - May overlook social/economic factors
Health Impact Assessment	- Identifies health risks associated with transportation projects. - Promotes public health through mitigation measures. - Addresses health equity issues, particularly for vulnerable groups.	- Data limitations can affect accuracy. - Requires expert input and resources.

Strategic Environmental Assessment	- Assesses environmental implications at the policy, plan, or program level. - Helps incorporate sustainability into long-term planning. - Encourages proactive rather than reactive decision-making. - Supports compliance with international environmental agreements.	- May lack specificity for individual projects. - Broad scope can complicate decision-making. - Time and resource-intensive for large programs.
Multi-Criteria Decision Analysis	- Evaluates a broad range of sustainability criteria. - Useful for complex projects with conflicting objectives. - Flexible and adaptable	- Results can be subjective depending on the weighting of criteria - Requires careful definition of criteria and indicators
Cost-Benefit Analysis	- Quantitative, focusing on financial costs and benefits. - Provides a clear measure of net societal value. - Helps prioritize projects based on economic efficiency.	- Assumptions and predictions can lead to inaccurate results. - Difficult to account for long-term or indirect benefits.
Life Cycle Assessment	- Evaluates across the entire life cycle (raw material to disposal) - identifies environmental hotspots and improvement opportunities. - Facilitates comparisons between different project options.	- Primarily focused on environmental impacts. - Data intensive and requires detailed information.

Compiled by author based on the literature provided

Choosing an appropriate sustainability assessment tool should consider several aspects to fit the project goals and context. The basis of choice must always relate to the project's needs, particularly its scope, objectives, and peculiarities. Besides, the type of impacts to be assessed,

such as environmental, social, or economic dimensions, has to be considered since different tools are tailored for various aspects of sustainability.

Finally, resources available regarding time, budget, technical expertise, and data accessibility must also be considered when deciding. By thoroughly evaluating these elements, project stakeholders can make an informed decision and select an assessment tool that effectively supports their sustainability objectives.

2. Methodology and Research Approach

This research aims to evaluate the sustainability of Copenhagen's Cycling Infrastructure. The study investigates sustainability across three dimensions, environmental, economic, and social, to identify critical sustainability factors and evaluate their impact on project outcomes. By employing both qualitative data collection and quantitative analysis, this research seeks to answer the following questions:

- What are the critical sustainability dimensions influencing transportation projects?
- How can these dimensions be quantitatively and qualitatively evaluated to compare the sustainability of this project?
- What insights can be derived for future transportation infrastructure planning?

This research relies on secondary data collected from project reports, sustainability assessments, academic studies, government reports, and other publicly available sources. The methodology is grounded in existing academic literature and emphasizes the integration of secondary data with quantitative analysis. While the data collection process follows a qualitative approach through case study analysis, the sustainability assessment itself is quantitative, utilizing Multi-Criteria Decision Analysis with the Simple Additive Weighting method.

These methods will be integrated through a triangulation approach, combining multiple data sources and analysis techniques to ensure the results are robust and reliable.

- Qualitative Methodology: Qualitative methods will be employed to explore the contextual factors, stakeholder perspectives, and operational strategies that contribute to sustainability in the case studies.

Quantitative Methodology: Quantitative methods will be used to assess each project's sustainability outcomes in terms of measurable variables. A Multi-Criteria Decision Analysis approach will be applied to quantify sustainability performance. Criteria in all three dimensions of sustainability will be assessed for each project using available data.

The **SAW method** will be applied to assess the sustainability of the transportation infrastructure, specifically Copenhagen's Cycling Infrastructure. The sustainability criteria across environmental, economic, and social dimensions will be identified based on existing literature and secondary data. Data for each criterion will be normalized for comparability. Each criterion will then be assigned a weight based on its relative importance, derived from sustainability frameworks

and previous studies. The normalized values will be multiplied by their respective weights to obtain weighted scores, which will then be summed to give an overall sustainability score for each project. This method is used for its capacity to manage various, frequently conflicting, criteria and consolidate them into a single evaluation score. it is especially beneficial in sustainability assessments, where it is essential to evaluate projects based on several factors. By employing SAW, this research provides a distinct and quantifiable method to compare projects across different sustainability dimensions.

For this research, the sustainability factors will be categorized according to the three main dimensions: environmental, economic, and social.

1. Environmental Factors:

- Carbon emissions: The amount of greenhouse gas emissions produced by the transportation infrastructure, which impacts climate change
- Energy consumption: The overall energy required to operate the transportation project, including construction and long-term operations
- Resource utilization: Efficiency in the use of materials and resources, which affects the long-term sustainability of the project

2. Economic Factors:

- Project cost: The total capital investment required for the construction and operation of the infrastructure).
- Return on investment (ROI): The financial returns the project is expected to generate over time, including revenue generation and economic benefits
- Long-term maintenance costs: Ongoing costs associated with maintaining the transportation infrastructure, which can significantly impact the project's long-term financial sustainability

3. Social Factors:

- Accessibility metrics: The degree to which the transportation infrastructure improves access to essential services, such as healthcare, education, and employment
- Public health impacts: Improvements in air quality, noise reduction, and overall public health outcomes that can result from sustainable transportation initiatives.
- Equity in stakeholder benefits: Ensuring that all stakeholders, especially vulnerable communities, derive equal benefits from the project

Case studies represent the most appropriate approach for this research due to their capability to deliver comprehensive insights into intricate, real-life circumstances, particularly when there is a scarcity of prior research or established evaluation frameworks. As noted by Yin (2018), case study research is especially relevant when the research questions are centered on "how" and "why" certain phenomena manifest in a given context, which corresponds with the aims of this study to assess the sustainability of large-scale transportation initiatives. Case studies prove to be particularly useful for examining current issues that are challenging to analyze through other methods such as surveys or experiments.

Furthermore, case studies enable the exploration of contextual factors that quantitative methods alone may overlook. They allow for a deeper understanding of the social, political, and environmental conditions that influence the sustainability outcomes of transportation projects

In the context of this research, focusing on Copenhagen's cycling infrastructure allows for a detailed examination of how the city's sustainable transportation efforts are influenced by a range of factors. By evaluating the environmental, economic, and social dimensions of the project, this case study reveals the complexity of achieving sustainability in urban mobility. Copenhagen's cycling infrastructure serves as a model for how cities can integrate sustainable transportation solutions, demonstrating the impact of policies, design choices, and public engagement on the long-term success and sustainability of such projects.

This research combines qualitative case study analysis with quantitative Multi-Criteria Decision Analysis utilizing the Simple Additive Weighting method to evaluate the sustainability of the transportation infrastructure initiatives. Sustainability is assessed through environmental, economic, and social lenses, relying on secondary data to measure the comparative performance of each initiative.

By employing the SAW method, this study systematically analyzes the sustainability results of the chosen initiatives, with the goal of pinpointing the most sustainable option and providing practical recommendations for enhancing future infrastructure development.

The final section will present a comparative analysis by evaluating and comparing the cycling infrastructure projects pursued by Copenhagen and Amsterdam, paying attention to performance within the dimensions of sustainability.

3. Real-Life Example of Sustainability Integration and Its Assessment

To thoroughly grasp the practical implementation of sustainability frameworks in the transportation sector, particularly regarding urban mobility, it is essential to analyze real-life case studies that illustrate how various aspects of sustainability—economic, environmental, and social—are interconnected within large-scale development projects. An illustrative example is the cycling infrastructure of Copenhagen, which significantly contributes to the city's transportation network. Although cycling may appear as a separate mode of transport, it is a crucial component of the urban mobility system, providing an environmentally friendly alternative to more conventional transportation options, like cars and buses.

Copenhagen's cycling infrastructure has emerged as a benchmark for sustainable urban mobility, effectively tackling issues such as traffic congestion, air pollution, and public health, while also fostering economic sustainability. As cities globally seek to achieve sustainability goals, the enhancement of cycling infrastructure presents a viable method to lessen dependence on fossil fuels, reduce carbon emissions, and enhance overall quality of life. This case study will examine the effects of Copenhagen's cycling infrastructure within the wider framework of sustainable urban transportation, emphasizing its social, environmental, and economic advantages.

3.1. The Copenhagen Cycling Infrastructure

The city has cultivated a cyclist-first culture through decades of consistent investment in infrastructure, innovative urban planning, and community engagement. The network spans over 390 kilometers of dedicated bike lanes, designed to prioritize safety and efficiency for cyclists.

The transformation began in the 1970s when Copenhagen faced rising car traffic and environmental challenges. Responding with a shift towards cycling, the city set long-term goals, culminating in its aim to achieve carbon neutrality by 2025. By 2022, over 40% of Copenhagen's residents commuted by bike daily, underscoring the success of the project in reducing reliance on motor vehicles. (Institute for Transportation and Development Policy, 2024)

Copenhagen is home to approximately 675,000 bicycles compared to just 120,000 cars, meaning bicycles outnumber cars by more than five to one. In 2016, the number of bicycles crossing the city surpassed cars for the first time since record-keeping began in 1970—marking a significant milestone in urban mobility. (World Economic Forum)

Cycling accounts for 29% of all journeys in Copenhagen, with 41% of commutes to work or study completed by bike. Among residents who both live and work or study in the city, the

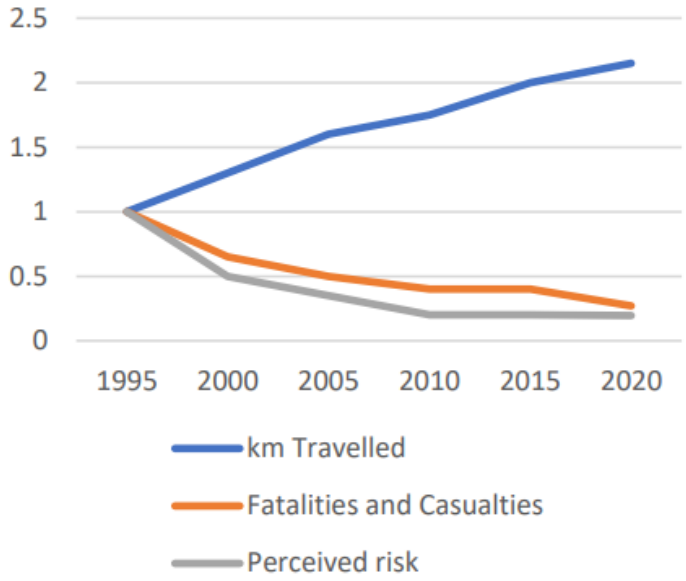
proportion rises to an impressive 62%. In 2016, Copenhagen's cyclists collectively traveled a remarkable 1.4 million kilometers each day, a 22% increase since 2006. (Cycling Embassy of Denmark)

Denmark's extensive network of cycling paths, including innovative bridges and cycling superhighways, plays a pivotal role in the widespread popularity of cycling. This infrastructure is a cornerstone of why Copenhagen is considered one of the safest cities for cyclists.(Emanuel, 2024)

Between 2006 and 2016, the perceived safety among cyclists in Copenhagen rose significantly, from 53% to 76%.

Figure 13

Trend in Relative Cycling Risk in Copenhagen



Source: Bicycle Account Report 2020

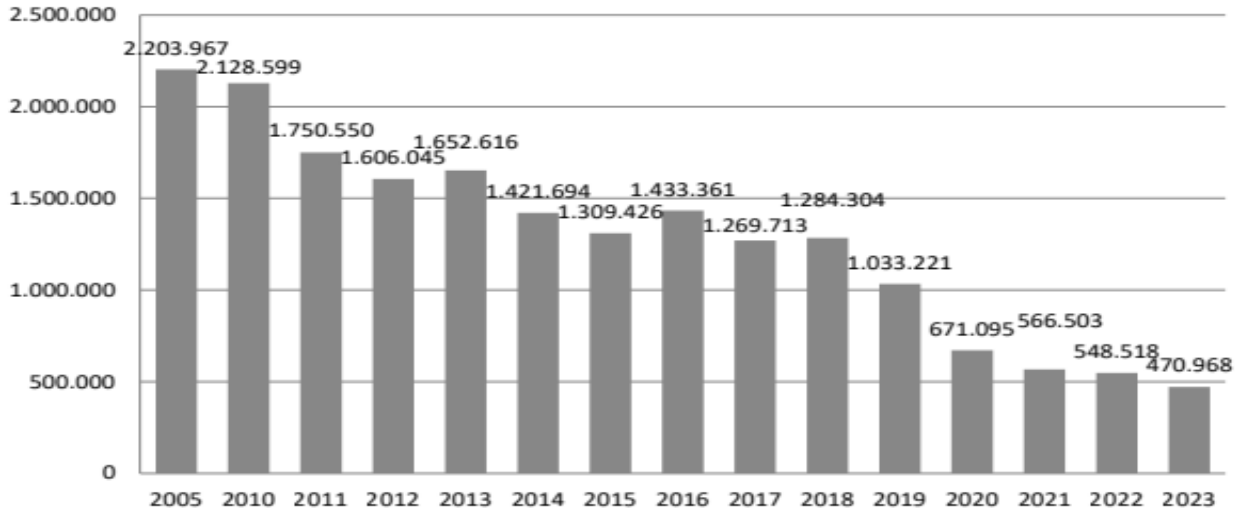
The city council aims to further increase this figure to 90% by 2025, aligning with its goal of achieving carbon neutrality. The CPH 2025 Climate Plan reflects Copenhagen's commitment to addressing climate change while promoting growth, development, and improved quality of life. The plan focuses on four pillars:

- **Energy Consumption**, emphasizing efficiency and reductions.
- **Energy Production**, prioritizing renewable sources
- **Mobility with Reduced Emissions**, advancing sustainable transport.

- **City Administration Initiatives**, showcasing municipal leadership in achieving carbon neutrality by 2025.

Figure 14

CO2 accounting for the Municipality of Copenhagen 2023.



Source: City of Copenhagen 2019

This strategy integrates sustainability with urban progress, setting a model for climate-responsive development. A key component is the Cycle Superhighways—high-capacity cycling routes that connect suburban areas to the city center, enabling seamless, longer-distance commuting. These superhighways are equipped with modern amenities such as traffic light synchronization for cyclists, solar-powered lights, and air pumps to enhance the cycling experience.

A cycle superhighway is a dedicated cycling route designed to prioritize commuters' needs, ensuring a smooth, uninterrupted ride with enhanced safety features. Its primary goal is to improve conditions for cyclists and connect key areas such as workplaces, educational institutions, and residential zones. This makes it more convenient for commuters to choose cycling over driving. Additionally, the superhighways are strategically planned to run near bus and train stations, encouraging seamless integration between cycling and public transportation. (Hallberg et al, 2021).

To qualify as a 'cycle superhighway,' a route must meet specific quality standards. These include amenities like air pumps, footrests, safer intersections, green waves, and traffic lights optimized for cycling speeds. The routes are marked with distinctive road signs and orange markings on the asphalt, making navigation simple and intuitive for cyclists, even at night—just follow the orange "C." (Region Hovedstaden, 2019) To be more specific, Sekretariatet for Supercykelstier (2019) has identified four quality features that define a cycle superhighway:

• Accessibility: Cycle superhighways should link major locations for work, education, and residential areas, as well as public transport. They should also establish an interconnected network that spans all municipalities and be easily identifiable for commuters.

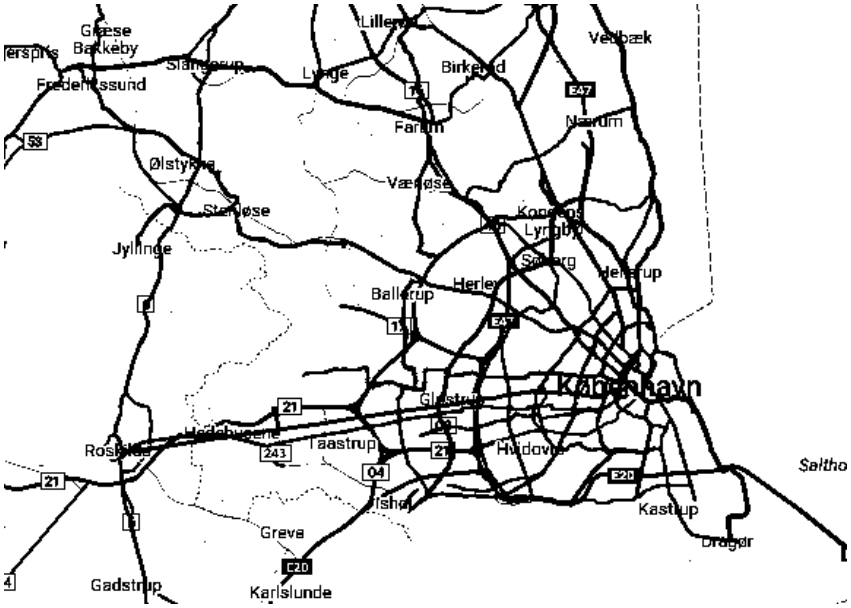
• Passability: Cycle superhighways are designed to provide the quickest route between home and work for commuters, minimizing obstacles and stops while allowing riders to travel at their preferred speed.

• Comfort: Cycle superhighways should ensure an enjoyable biking experience. This involves a high level of maintenance, quality paving, and additional services.

• Safety: Cycle superhighways must enhance safety and provide conditions that reduce the likelihood of bicycle accidents.

Figure 15

Copenhagen Cycling Highway Route Map



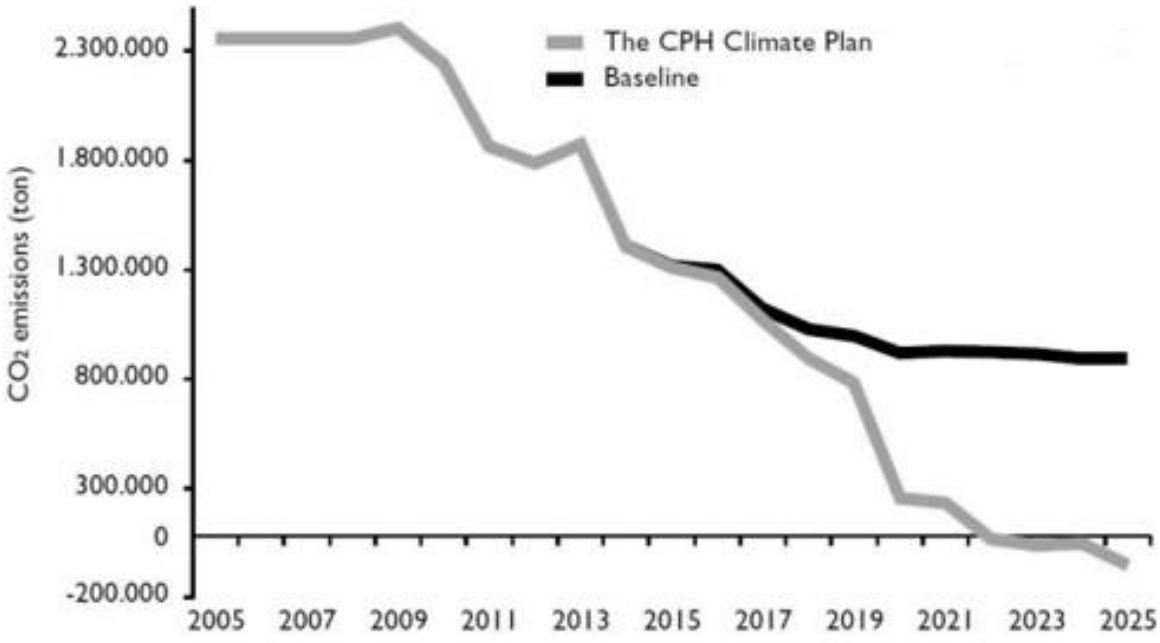
Source: supercykelstier.dk

Copenhagen has invested heavily in developing a comprehensive and interconnected cycling network that promotes cycling as the primary mode of transportation. This initiative encompasses not just the Cycle Superhighways but also designated bike lanes, green wave systems that enables cyclists to experience uninterrupted green signals when they keep a steady pace, and dedicated cycling bridges. (De Angelis et al., 2019).

One of the most significant environmental effects of Copenhagen's cycling infrastructure is the reduction in greenhouse gas emissions. The city has substantially reduced carbon dioxide (CO_2) emissions by encouraging residents to cycle instead of driving cars. Cycling in Copenhagen saves approximately 20,000 tons of CO_2 annually, equivalent to the yearly emissions of around 4,000 cars. This aligns directly with the city's ambitious CPH 2025 Climate Plan.

Figure 16

Copenhagen City CO2 Emissions between 2005-2025.



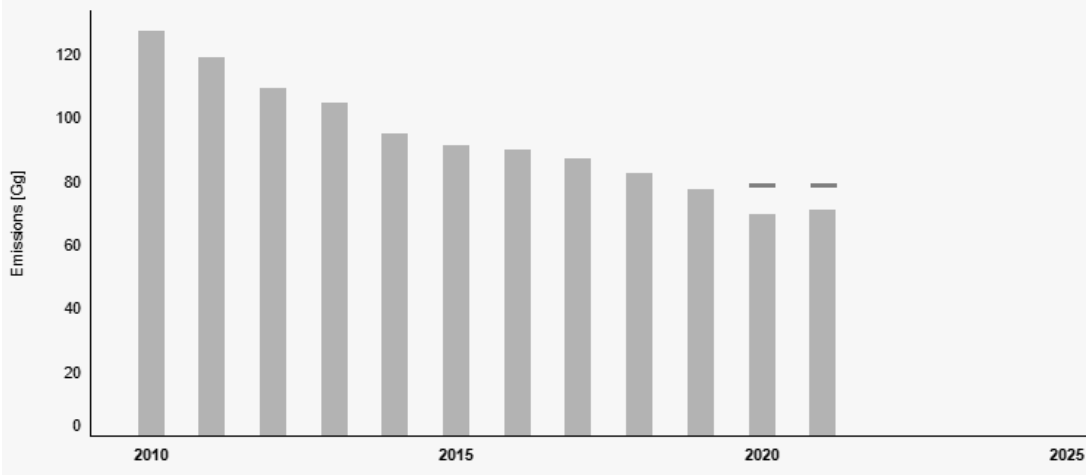
Source: Municipality of Copenhagen, 2020.

The shift from car-dependent transportation to cycling has led to a significant drop in air pollution levels across Copenhagen. Motor vehicles are a major source of air pollutants like

nitrogen oxides (NOx) and particulate matter (PM2.5), which pose serious health risks. By replacing car trips with cycling, Copenhagen has improved air quality, reducing both traffic-related emissions and associated health burdens.

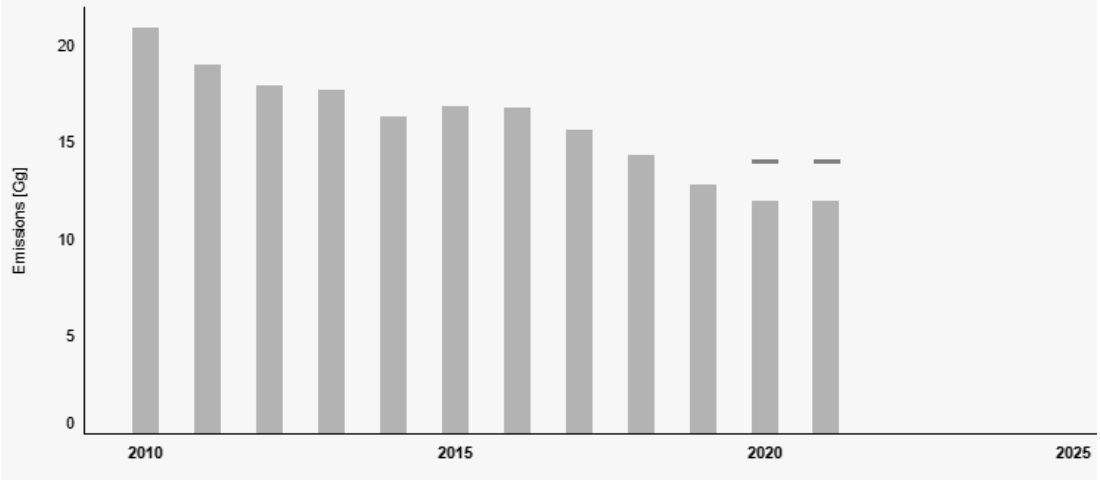
Figure 17

Denmark NOx-Reduction Commitments



Source: European Environment Agency, 2021

Denmark $PM_{2.5}$-Reduction Commitments



Source: European Environment Agency, 2021

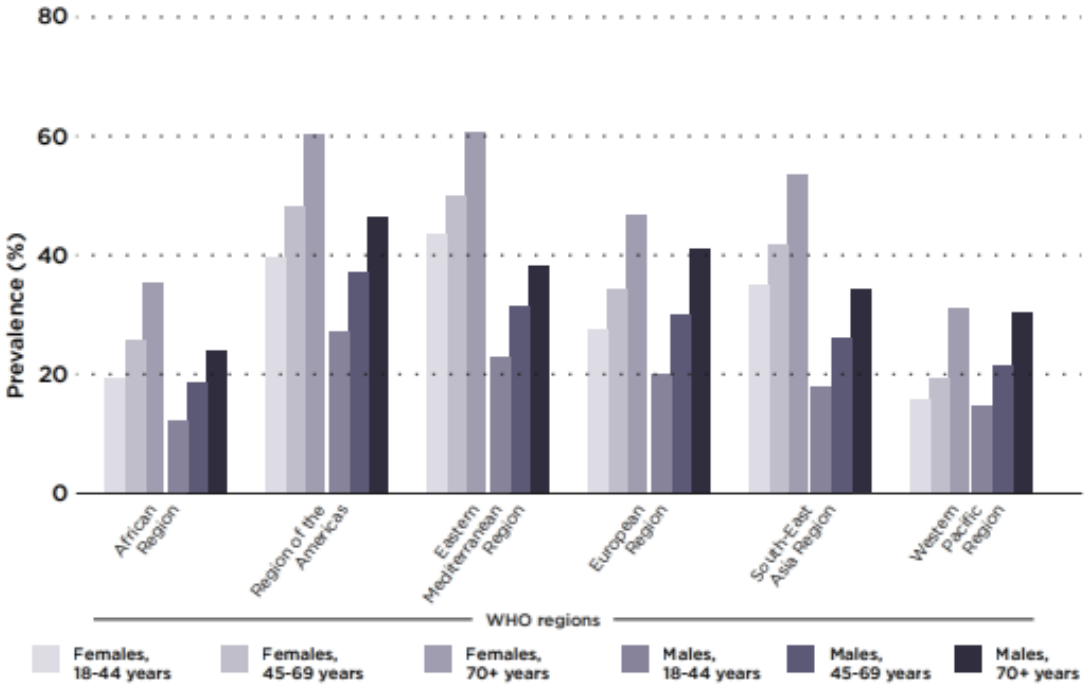
Engaging in cycling benefits not just individual health but also plays a crucial role in enhancing the social sustainability of communities. By facilitating fair access to transportation, encouraging social inclusion, and upgrading public spaces, cycling promotes individual well-being and fortifies social bonds. It serves as a potent means to foster healthier, more interconnected, and just societies. (Logan Et al.,2023)

A vital component of social sustainability is the availability of affordable and dependable transportation. Unlike automobiles, bicycles are economical and accessible to individuals across various income brackets, thereby minimizing transportation disparities. This is especially significant for low-income families and individuals, who may encounter difficulties accessing employment, education, and vital services. Investing in cycling infrastructure guarantees mobility for everyone, irrespective of their economic background. (Papadakis et al.,2024)

According to Denmark's national health profile (Danskernes Sundhed—Den Nationale Sundhedsprofil 2019) Health data collected from over 180,000 Danes highlights this trend. Based on the report a significant portion of the adult population does not meet the World Health Organization's guideline of at least 150 minutes of physical activity per week.

Figure 18

Prevalence of adults aged 18+ years not meeting WHO physical activity guidelines



Source: World Health Organization, Global status report on physical activity 2022

From the physiological standpoint, cycling offers health benefits similar to other forms of physical activity by way of intensity, duration, and frequency. It has positive effects on cardiovascular health and general fitness (Shaker et al. 2021). On the negative side, there are also risks such as an increased danger of traffic accidents, falling, or air pollution exposure. Local barriers may make cycling less appealing, for example, due to poor weather, discomfort, or physical exertion. (Ayad et al.2024)

Even though cycling offers numerous advantages, various obstacles continue to impede its widespread acceptance. At the societal level, policymakers and urban designers frequently show reluctance due to the substantial initial investment required for cycling infrastructure and fears regarding traffic safety. Buehler and Pucher (2021) indicate that the preliminary costs associated with establishing bike lanes and public bike-sharing programs can dissuade decision-makers, particularly in cities that prioritize car travel. On an individual level, many individuals shy away from cycling because of concerns about safety, the physical effort required, and adverse weather.

Nevertheless, research consistently demonstrates that the health advantages of cycling significantly outweigh these dangers. Engaging in regular cycling lowers the likelihood of developing cardiovascular diseases and diabetes, with studies like Lorenzo et al. (2020) revealing notable reductions in mortality rates related to heart disease and stroke. Moreover, cycling enhances mental health, as Ruening Ye et al. (2019) established that physical activities such as cycling can alleviate anxiety and stress while promoting a connection with nature.

In cities such as Copenhagen, cycling has played a crucial role in enhancing public health. The city’s cycling-friendly culture, bolstered by comprehensive infrastructure, has led to a decline in chronic disease rates and fostered social well-being. Research by Schäfer et al. (2020) indicates that cycling in Copenhagen results in improved health outcomes, including reduced healthcare expenses and a better quality of life.

To summarize, despite the challenges, the health and social advantages of cycling position it as a vital approach for enhancing public health, especially in urban areas with well-established cycling infrastructure.

The huge investment in cycling infrastructure in Copenhagen has brought enormous economic benefits, reinforcing its commitment to sustainability and strengthening its overall

economic health. From 2009 to 2020, the Danish government allocated around DKK 1.1 billion in national subsidies for municipal cycling projects (Ministry of Finance, 2021). Starting in 2021, the government plans to invest DKK 2 billion in subsidies for the development of cycling and bicycle infrastructure through the Bicycle Subsidy Scheme, which will continue until 2035 (Transportministeriet, 2021).

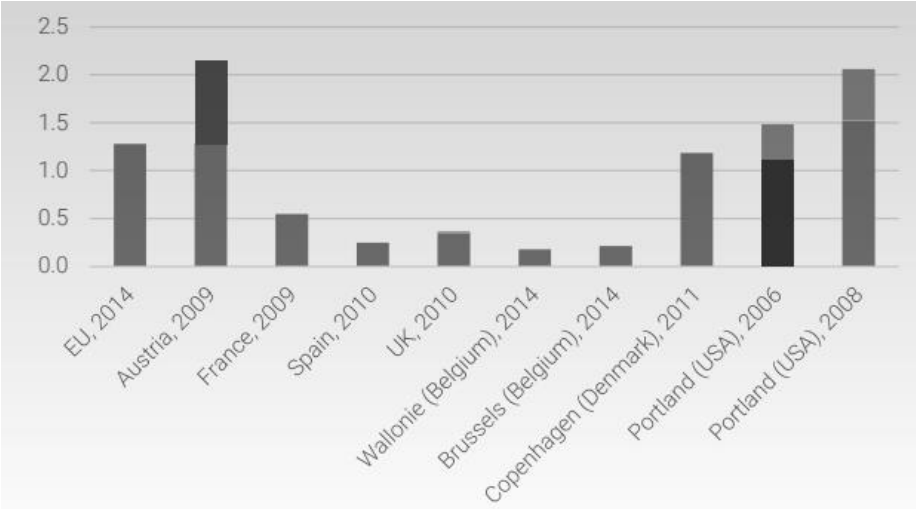
According the the cycling Embassy of Denmark, The economic benefit of cycling is DKK 4.79 (€0.64) per kilometre when all valued effects such as driving costs, time costs and recreational value are considered. This makes cycling much cheaper than car transport, in particular when a car carries fewer than two passengers. Society gains at least DKK 10 (€1.34) per kilometer if people cycle instead of driving, calculated by subtracting DKK 4.79 (€0.64) per kilometer cycled from the DKK 5.29 (€0.71) per kilometer driven by car. Shifting from car trips to cycling is thus a very cost-effective investment. Savings will be even higher in urban areas where cars normally travel at lower speeds, particularly during peak hours. Besides, searching time for parking and time to walk from parking spaces further add to the economic advantages of promoting cycling.

Society saves approximately €0.23 in healthcare costs for every kilometer cycled. This translates to millions saved annually due to reduced incidences of lifestyle diseases (Shwarz et al.,2024). In addition, A healthier population leads to fewer sick days. A report by the European Cyclists' Federation (ECF) estimated that cycling contributes to a 10% reduction in absenteeism. In Copenhagen, this equates to saving businesses millions in lost productivity annually.

Creation and maintenance of the great cycling infrastructure in Copenhagen has been a booster for job opportunities in many sectors. Bike path construction and maintenance, cycling bridges, and superhighways are extremely labor-intensive and require a high level of skill. According to UNECE, for every €1 million invested in cycling infrastructure, 11-15 jobs are created. The higher demand for bicycles has increased the development of Denmark's bicycle industry-manufacturing, sales, and repairs. It has helped to generate revenue from the local bike shops and international brands and, therefore, created long-term employment opportunities.

Figure 19

Cycling jobs per 1,000 people



Source: UNECE

As a global leader in bike-friendly cities, Copenhagen attracts tourists interested in experiencing its innovative infrastructure. Cycling tourism in Denmark generates significant economic impact, with estimates suggesting that cycle tourists contribute approximately DKK 7.8 billion annually to This figure is based on data from 2017, reflecting the turnover from around 1.7 million cycling tourists (Cycling Embassy of Denmark, 2019).

3.2. Multiple Criteria Assessment of Copenhagen Cycling Project

In this part of the research, I will use the Multi-Criteria Decision Analysis for an in-depth sustainability analysis of Copenhagen's cycling infrastructure, focusing on the Simple Additive Weighting approach. The method presented will make it possible to assess the economic, environmental, and social sustainability of the cycling infrastructure in Copenhagen concerning specific indicators provided. It evaluates several alternatives by a set of previously established criteria, giving weight to each one depending on its importance and normalizing the data to be comparable.

The criteria that form the basis of this assessment were chosen to align with the sustainability objectives set by the city, using data from various government and academic reports regarding project performance. In this analysis, we identified nine key criteria

Table 2

Criterions chosen for the assessment

Sustainability Dimension	Indicator (Criterion)
Environmental Factors	Carbon emissions (CO_2)
	Energy consumption
	Resource utilization
Economic Factors	Project cost
	ROI
	Long-term maintenance costs
Social Factors	Accessibility metrics
	Public health impacts
	Equity in stakeholder benefits

Compiled by Author

Normalization has to be done in order to compare the nine criteria equitably. Normalization rescales raw data for each criterion within a standard scale from 0 to 1 so that each criterion has an equal influence on the total score, regardless of its original scale or unit of measurement. In this example, we use the linear method with the formula below.

$$x_{norm} = \frac{x - x_{min}}{x_{max} - x_{min}}$$

Where x_{norm} - normalized score, x - raw score, x_{min}- minimum value of criterion, x_{max} - maximum value of criterion.

In this case, the raw data for the Carbon Emissions (CO_2) criterion could range from high to low emissions. However, running the formula would result in a higher normalized score for lower emissions because that is considered a positive performance in this category.

Table 3

Normalized values for each of the nine criteria

Sustainability Dimension	Indicator (Criterion)	Normalized Value
Environmental Factors	Carbon emissions (CO_2)	0.67
	Energy consumption	0.30
	Resource utilization	0.85
Economic Factors	Project cost	0.87
	ROI	0.60

	Long-term maintenance costs	0.84
Social Factors	Accessibility metrics	0.88
	Public health impacts	0.66
	Equity in stakeholder benefits	0.78

Compiled by author

Each criterion is assigned a weight based on its importance in evaluating the sustainability of Copenhagen's cycling infrastructure.

- Carbon Emissions (CO_2) (kg): 0.15
- Energy Consumption (kWh): 0.10
- Resource Utilization (%): 0.10
- Project Cost (millions $): 0.10
- ROI (%): 0.10
- Long-Term Maintenance Costs: 0.10
- Accessibility Metrics: 0.10
- Public Health Impacts: 0.15
- Equity in Stakeholder Benefits: 0.10

To reach the final result, we apply the Simple Additive Weight formula, which calculates the overall score by multiplying the normalized values of each criterion by their respective weights.

$$S_i = \sum_{j=1}^{n} w_j \cdot x_{ij}$$

Where: S_i= Final score for alternative i, w_j= Weight of criterion j, x_{ij} = Normalized score, n=Total number of criteria

The following table shows the normalized data for each criterion and alternative, along with the final SAW score for Copenhagen's cycling infrastructure.

Table 4

Final SAW score for Copenhagen's cycling infrastructure

Sustainability Dimension	Criterion	Weight	Normalized Score	Weighted Score
Environmental Factors	Carbon emissions (CO_2)	0.15	0.67	0.67 × 0.15 = 0.101
	Energy consumption	0.10	0.30	0.30 × 0.10 = 0.030
	Resource utilization	0.10	0.85	0.85 × 0.10 = 0.085
Economic Factors	Project cost	0.10	0.87	0.87 × 0.10 = 0.087
	ROI	0.10	0.60	0.60 × 0.10 = 0.060
	Long-term maintenance costs	0.10	0.84	0.84 × 0.10 = 0.084
Social Factors	Accessibility metrics	0.10	0.88	0.88 × 0.10 = 0.088
	Public health impacts	0.15	0.66	0.66 × 0.15 = 0.099
	Equity in stakeholder benefits	0.10	0.78	0.78 × 0.10 = 0.078

Compiled by author

The final score is calculated as the sum of the weighted scores for each criterion. Based on the table, the calculation is:

Total Score=0.101+0.030+0.085+0.087+0.060+0.084+0.088+0.099+0.078=0.732

To scale the final score to 0-100, Copenhagen's cycling infrastructure achieves a score of 73.2 out of 100. This score indicates a powerful performance by the city in terms of various key sustainability criteria, including environmental, economic, and social. The infrastructure in Copenhagen is excellent in several key areas: it reduces harmful carbon emissions from vehicles, decreases energy consumption, and increases the health of the citizens through exercise. Moreover, the project becomes economically viable through reasonable project costs, coupled with a high return on investment to indicate profitability. Additionally, the social benefits from increased access and equity only serve to further enhance the tremendous desirability of this project for the population and, in doing so, cater to the needs of a considerable number of people.

\ By strongly emphasizing cycling as a primary mode of transportation through the careful creation of dedicated superhighways specifically designed for cyclists and safe routes that prioritize their safety, the city has experienced a significant and notable increase in the overall number of individuals choosing to cycle. This positive shift in transportation habits has resulted in considerable improvements in the population's public health, a marked reduction in traffic congestion throughout the city streets, and a substantial decrease in carbon emissions, all contributing to a healthier urban environment. This shift towards cycling has positively influenced local businesses, giving them a much-needed boost as more people opt for biking over driving. The city's steadfast commitment to sustainability.

In conclusion, the substantial investment that Copenhagen has made in developing its cycling infrastructure has not only improved its residents' overall quality of life but also serves as a highly valuable example of effective and sustainable urban development practices that other cities might aspire to replicate.

3.3. Comparative Analysis: Copenhagen vs Amsterdam Cycling Infrastructure

Cycling has become the cornerstone of urban mobility in many countries worldwide, which strive for sustainability, eco-friendliness, and a living environment. Among such cities pioneering the change, Copenhagen and Amsterdam enter the fray as Global Exemplars. These two European towns have framed their progressive cycling policies with comprehensive cycling networks, environmental benefits, and positive public health outcomes. In this chapter we are comparing cycling infrastructure, environmental impact, and socio-economic benefits in Copenhagen and Amsterdam to show how this focus on cycling has contributed to the country’s sustainability.

3.3.1. Investment in Cycling Infrastructure

Copenhagen and Amsterdam have shown dedication to cycling through significant investments in their infrastructure. Over the past ten years, Copenhagen has spent more than $200 million on cycling infrastructure (City of Copenhagen, 2020). This involves the development of bike superhighways, dedicated lanes, and enhanced amenities for cyclists.

Additionally, the city has committed to further enhancements, including $64 million in 2022 aimed at improving bike lanes and networks, according to the Danish Ministry of Transport (2022). This is not the first investment made, nor will it be the last, as Copenhagen pursues its

ambitious goal to become the most bike-friendly city globally, aiming to increase the cycling modal share to 50% by 2025 (City of Copenhagen, 2021).

On the other hand, Amsterdam continuously spends about €100 million yearly on cycling infrastructure development. The city has over 500 kilometers of bike lanes and paths, where most of its citizens have the opportunity to be in safe and efficient traffic flow. Amsterdam is also trying to make cycling infrastructures more convenient, safer for cyclists, with improvements like: an increase in the number of bike parks; better traffic light signaling; safer routes (City of Amsterdam, 2020).

Figure 20

Cycling Route Maps in Copenhagen and Amsterdam Cities

Copenhagen Bike Map, Source: Danish Design Review

Amsterdam Bike Map, Source: The Dutch Cycling Union

3.3.2. Cycling Modal Share

With its well-developed cycling infrastructure, Copenhagen has better public health through the promotion of physical activity and reduction in traffic-related air pollution. The city has recorded a decrease in cardiovascular diseases and other diseases related to a sedentary lifestyle, which is mainly due to cycling (City of Copenhagen, 2020). The designed, thoughtful layout of the bike lanes, combined with a strong cycling culture that permeates the city, has resulted in significantly enhanced mental and physical health outcomes for its residents. Furthermore, Amsterdam has experienced numerous benefits from its emphasis on cycling, which has contributed to lower health-related expenses and an overall improvement in the well-being of its population. This has played a crucial role in helping individuals maintain an active lifestyle while alleviating the healthcare costs often associated with diseases linked to lifestyle choices and habits (City of Amsterdam, 2020). However, considering the fact that Copenhagen has a more extensive and much-developed cycle infrastructure and a more significant modal share of cycling, the health benefits resulting from cycling in this city would likely be even more impressive and very substantial.

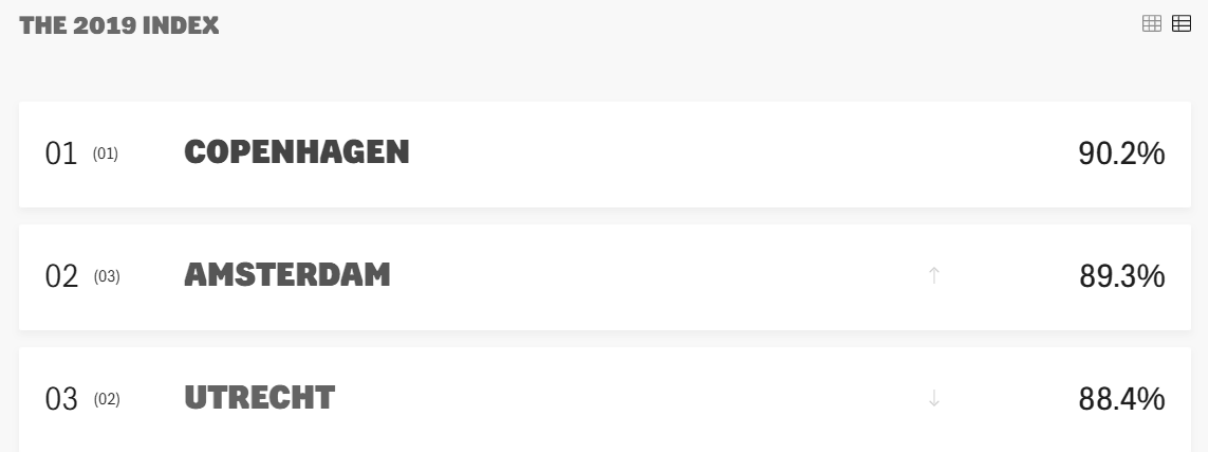
According to the findings presented in the Copenhagenize Index for the year 2019, which is recognized as "the most comprehensive and holistic ranking of bicycle-friendly cities on planet

earth," it is notable that the rankings for both of the cities in question achieved impressive standings, specifically securing the first and second places.

In this assessment, it is important to highlight that Copenhagen has taken the lead, showcasing its superiority in promoting and facilitating cycling as a primary mode of transportation.

Figure 21

Ranking of Most Cycling Friendly Cities



Source: The Copenhagenize Index, 2019

The Copenhagenize Index ranking is a comprehensive evaluation that meticulously assesses cities based on13 key parameters thoughtfully categorized into three main aspects: Streetscape, Culture, and Ambition. Within each of these categories, cities are rated on a scale of 0 to 4 points, reflecting the depth of their performance in various essential facets related to cycling infrastructure and inclusivity.

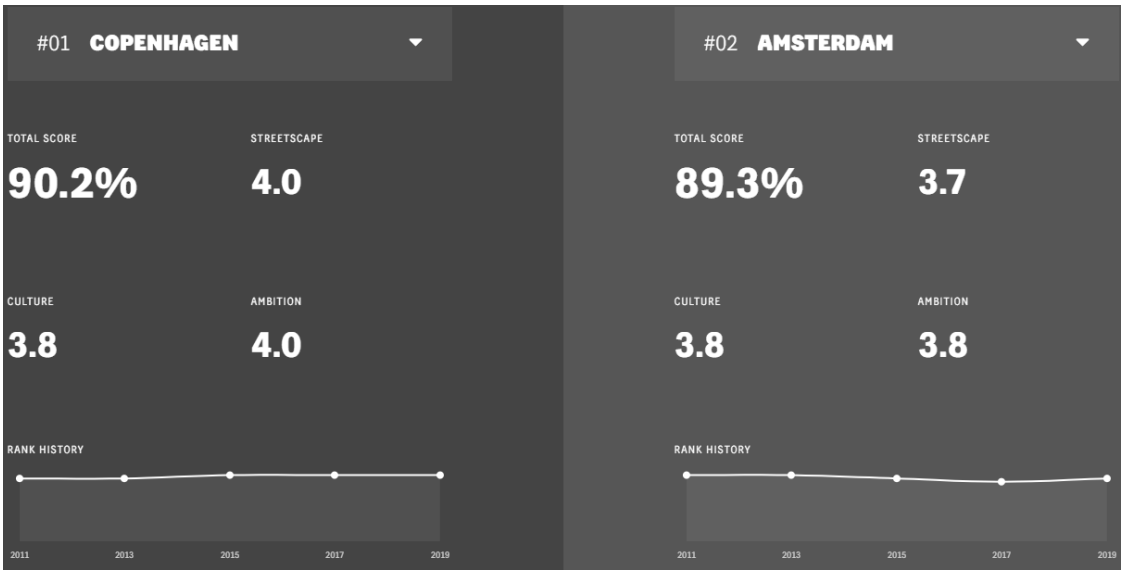
In the Streetscape component, cities are analyzed based on the quality and extent of their bicycle infrastructure, the availability and accessibility of cycling facilities, and the effectiveness of traffic calming measures and urban planning strategies in promoting safe and convenient cycling routes for residents. In the Culture category, significant attention is given to aspects such as gender equality in cycling participation, the overall modal share of cycling as a mode of transportation, and the perceptual attitudes of the public towards bikes as a sustainable urban mobility option.

In The ambition segment, the focus shifts towards evaluating the cities' dedication to enhancing cycling culture and infrastructure through active advocacy efforts, strong political support for cycling-related initiatives, and the successful implementation of bike-sharing programs to encourage broader public engagement with cycling as a viable transportation choice.

Eventually, by adding these individual category scores, the Copenhagenize Index produces a comprehensive ranking that effectively recognizes and rewards cities that excel in fostering a cycling-friendly environment. Higher rankings are granted to those demonstrating exceptional performance across all evaluated parameters.

Figure 22

Comparing Score from Both Cities



Source: The Copenhagenize Index, 2019

Copenhagen took the title of the world's most bicycle-friendly city from Amsterdam in 2015 and has maintained that position through 2019. However, the competition is incredibly tight this time around.

3.3.3. Environmental Impact

Copenhagen's cycling infrastructure helps cut down around 90,000 tons of CO_2 each year, which is vital for the city's goal of achieving carbon neutrality by 2025 (Danish Cyclists' Federation, State of Green). The emphasis on cycling is part of a more significant effort to promote

sustainable transportation and significantly lower the city's carbon footprint. Cycling is a key element of Copenhagen's approach to tackling climate change and improving urban livability.

Amsterdam's cycling infrastructure, on the other hand, helps reduce CO_2 emissions by 40,000 metric tons annually, translating to an economic benefit of €9.2 million (Urban Land Institute, 2019). Although this amount is somewhat lower than Copenhagen's, it highlights Amsterdam's dedication to sustainable transportation and environmental conservation.

3.3.4. Public Health Benefits

Amsterdam's cycling culture greatly enhances public health by promoting physical activity and reducing healthcare costs associated with lifestyle diseases. Regular cyclists in Amsterdam take approximately 50,000 fewer sick days annually, yielding an economic benefit of around €15.3 million.

Handshake Cycling

Additionally, due to their cycling practices, Amsterdam cyclists collectively gain an extra 120 years of lifespan each year, contributing to increased life expectancy. Handshake Cycling.

In comparison, Copenhagen's cycling infrastructure and higher modal share suggest that its health benefits are likely even more prominent. Residents who cycle regularly in Copenhagen report 1.1 million fewer sick days annually. (Ministry of Foreign Affairs of Denmark)

This indicates that the city's investment in cycling infrastructure promotes physical activity and significantly reduces healthcare burdens related to lifestyle diseases.

3.3.5. Economic Impact

Copenhagen's cycling network has significantly contributed to local economic growth by generating savings in transportation and alleviating traffic congestion. Studies show that businesses in Copenhagen experience increased foot traffic and cyclist visits, which enhance local commerce. Cycling has also reduced residents' transport costs as a result of less reliance on cars and public transportation. Tourists have visited the town, and this has enabled them to have cycling tours of the city, among other things. State of Green, 2020. The city is equipped with biking infrastructure that lures tourists and new businesses as the city cements its position as a global leader in green urban transportation.

In return, Amsterdam reaps economic benefits through cycling, as the extensive network of bike lanes brings in business for the locals and even attracts tourists. Cycling not only lowers transportation costs for residents but also brings in visitors from around the world due to its famous culture. This has made Amsterdam a popular spot for cycling tours, which further boosts its economy (Urban Land Institute, 2019).

Table 5

Economic impact of the Cycling industry

	Copenhagen	**Amsterdam**
Bicycle Enterprises	309	300
Jobs in bicycle enterprises	600	900
Annual turnover	€170 million	€100 million

Compiled by author based on Danish Embassy of Cycling

Copenhagen and Amsterdam are well-known for their excellent cycling infrastructure, showcasing the advantages of prioritizing cycling in urban planning. Both cities have invested significantly in their cycling systems, resulting in better public health, enhanced environmental sustainability, and economic growth. The following comparison highlights key metrics concerning their cycling infrastructure, environmental impacts, health outcomes, and economic contributions.

Table 6

Sustainability Factor Comparison between Copenhagen and Amsterdam

Factor	**Copenhagen**	**Amsterdam**
Investment in Cycling Infrastructure	DKK 520 million ($82 million)	€100 million annually
Cycling Modal Share	44% of all trips	38% of all trips
Environmental Impact (CO_2 Reduction)	Reduces around 90,000 tons of CO_2 annually	Reduces approximately 40,000 tons of CO_2 annually

Public Health Benefits	1.1 million fewer sick days annually	50,000 fewer sick days annually
Economic Impact	€170 million annual turnover	€100 million annual turnover

Compiled by author

to conclude this part of the research, Both Copenhagen and Amsterdam are examples that highlight how well-structured cycling infrastructure can change the face of city living. The two cities demonstrate, rather convincingly, a wide array of advantages of prioritizing cycling as a principal form of transport. The current state of Copenhagen has really embraced the cycling culture-think major financial commitments and high-reaching goals such as a 50% cycling modal share by 2025. In fact, it has some amazing results: lowering CO_2 emissions, improving public health, and boosting economic growth. For Copenhagen, much of this was part of a key underlying goal: reaching carbon neutrality by focusing on sustainable transportation. Furthermore, city cycling infrastructure stands in support of local businesses by boosting tourism and creating jobs that pertain directly to the industry of cycling.

Similarly, Amsterdam made huge investments in cycling infrastructure, building a strong culture of cycling. A nearly 36% proportion of the total trips are made by bicycle. The focus on cycling has resulted in some real dividends, including the easing of traffic congestion, the reduction in transportation costs, and dramatic improvements in public health. Although Copenhagen has an extensive cycling network and, consequently, a larger modal share for this mode and therefore more obvious overall impact, Amsterdam remains powerful in its moves toward sustainable urban mobility.

In other words, in one way or another, both cities showcase very well how prioritizing cycling will lead to some positive economic and environmental impacts with outcomes in public health while being able to give valuable inputs and inspiration toward livable sustainability of other cities worldwide.

Conclusions and Recommendations

This research has answered the objectives of the introduction: to provide a comprehensive assessment of sustainability in transport projects through the case of Copenhagen's cycling infrastructure. It has established the principles of environmental, economic, and social critical foundations for developing resilient, efficient, and inclusive transportation systems. Therefore, the case of Copenhagen will demonstrate how these principles can be applied in practice by this city's stated aims of reducing emissions, ensuring equitable access, and creating long-term economic benefits.

This review of the sustainability practices undertaken by Copenhagen makes the city creative in incorporating sustainability into its transportation infrastructure. Heavy investments in cycling infrastructure, such as the Cycle Super Highways with synchronized traffic systems, elaborate on how an active mobile achievement can be conducted in essential environmental, economic, and social areas. It is a practice to meet global sustainability goals, from which important lessons are drawn into other cities.

More evidence of the success of the cycling infrastructure in Copenhagen is proven through an evaluation of its environmental, economic, and social impacts. It has contributed to environmental sustainability by reducing greenhouse gas emissions, improving air quality, and promoting public health. At the same time, it has been economically viable, offering cost savings and employment opportunities. In the social dimension, accessibility and equitable benefits for various stakeholders have been improved.

The same research identified how sustainability is effectively embedded into transport projects. Robust stakeholder engagement and sustainability assessment tools like Multi-Criteria Decision Analysis and Life Cycle Assessment, leveraging innovative technologies that have come forward as key enablers in realizing sustainability. These insights consequently provide a road map for future transportation initiatives, with emphasis on the need for a systematic and inclusive approach at both the planning and execution levels.

This therefore puts the imperative on integration of sustainability into transportation infrastructure to actuate such pressing challenges as climate change, urban congestion, and social inequities. The Copenhagen case indicates that integration can be made possible and transformative for a model city worldwide can scale up. With a holistic perspective on linking

local action to global goals, transportation projects should contribute value toward creating sustainable, equitable, and prosperous urban environments.

Based on the research findings the following recommendations were concluded:

- Implement Active Mobility Policies: Invest primarily in cycling and walking infrastructure that reduces emissions while promoting public health.
- Mandate Sustainability Assessment: Implement the use of MCDA and LCA tools in transportation project planning.
- Establish Stakeholder Frameworks: Provide appropriate mechanisms to ensure early and ongoing stakeholder engagement.
- Standardization of Sustainability Metrics: Use uniform standards for measuring environmental, economic, and social impacts.
- Integrate Technology Solutions: Applying AI and digital tools to further enhance project efficiencies and sustainability outcomes.
- Scale Up Proven Models: Replicate effective practices from Copenhagen within other similar urban contexts worldwide.

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