School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Creating a sustainable mobility index for cities

Raffaele Riverso

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Transport Policy and Planning

SUPERVISOR :
Prof. dr. Evelien POLDERS

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2023
2024

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Preface

This thesis is the culmination of the work put into the creation of a valuable tool that can help in assessing the sustainability performances of cities in their urban mobility. The topic's relevance in the current state of the world can certainly support the development and implementation of policies aimed at reaching more performing results in the sustainability of transport across urban realities. This study examined the available literature to gain and develop a new sustainable urban mobility index, which can support decisions across a global reach of cities.

The work on this thesis allowed me not only to put into practice the vast knowledge acquired during the Master of Transportation Sciences at UHasselt but also furtherly apply practises and knowledge priorly learned during my academic career.

First, I want to sincerely thank and acknowledge Prof. Hermans and Prof. Polders, the promotors of this thesis, for their constant guidance and support; without their constructive, timely, and thoughtful feedback, this thesis would not have been possible. A thank you also goes to the whole teaching staff at UHasselt for the valuable knowledge transferred during the Master's degree.

I need to thank my whole family, and in particular my parents, for their continuous patience, support, and especially love, even when being more than 700 kilometres of distance; I will be eternally grateful to them for giving me this chance to pursue the choice of studying for my Master's degree abroad.

Lastly, to all the friends I made during this amazing experience and to those I can always count on back in Italy: thank you for your friendship and support over all these years, I know I can always rely on you.

Hasselt, 19 June 2024

Summary

The purpose of this thesis is to develop a sustainable index evaluating the performance of different locations worldwide on the topic of urban mobility. This research is carried out to fill the gaps faced by currently existing indexes and create a benchmark of performances across a set of cities.

The objective is to create a tool to support the evaluation of sustainable urban mobility that can bring new insights and data compared to the currently used indexes, such the ones developed by Arcadis and the Institute for Transportation and Development Policy. The research methods comprise assessing the literature available on the topic and analysing a pool of indexes developed on the theme, as well as secondary indicator data collection and analysis. The central framework covers the concept of sustainability and its main dimensions, social, economic and environmental pillars, complemented with current and future mobility trends. This aims to help develop the dimensional structure of a new sustainable mobility index. The process of this implementation starts with the creation of the theoretical indicator framework, based on selecting and adapting relevant indicators from the assessed indexes; moreover, for crucial themes that still need to be evaluated, especially those related to current and future urban mobility trends, new indicators are created. In order to implement the new sustainable index, a pool of cities is selected by assessing a global search based on different determining factors such as the role those cities have on the global level, and the projected megacities that will shape the next decade. Subsequently, the index methodology is discussed and analysed by applying the steps taken: developing a theoretical framework and assessing the variables, data processing, normalisation of the data, weighting, and aggregation. Once the results are calculated, each city obtains a score for all the dimensions of the new sustainable mobility index and a score representing the total overall performance. Based on these scores, the performance ranking as well as results per city are interpreted.

In conclusion, this new sustainable mobility index found how different cities perform across the selected dimensions, where cities from Europe and Asia obtained the top spots. In contrast, the locations in Africa were the ones performing below average. This tool also aims to help the evaluation and assessment of sustainable urban mobility by benchmarking the results to enable lower-performing cities to get insights in measures and policies aimed at the achievement of better results and accomplishments.

Keywords

Sustainability, mobility, index, urban mobility, cities, benchmarking.

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List of Abbreviations

AV = Autonomous Vehicles

BRT = Bus Rapid Transit

EU = European Union

ITDP = Institute for Transportation and Development Policy

MaaS = Mobility as a Service

PT = Public Transport

SDGs = Sustainable Development Goals

UN = United Nations

UITP = Union Internationale des Transports Publics

1. Introduction, Problem Statement and Research Questions

1.1. Introduction

To adapt to the new challenges brought by societal, economic, and environmental changes, cities need to find solutions to integrate, adjust and create policies and services efficiently and in a sustainable way; issues and challenges that characterise urban areas and urbanisation processes, such as congestion and accessibility of public transport to the population, have more profound impacts that span many fields, from health to economy and society (Bouton et al., 2015). The global population surpassed the 8 billion threshold in 2022 (United Nations, 2022), with over 56% living in urban areas (The World Bank, 2023) and the projection for 2050 expects around 68% of the global population to live in cities, adding another 2.5 billion people to urban areas; by 2030, there are already scheduled over 43 megacities with over 10 million inhabitants each, located mainly in currently developing countries (United Nations - Department of Economic and Social Affairs, 2018). The speed and scale of urbanisation bring social, economic, and environmental challenges; understanding and successfully managing the trends governing this growth will help achieve sustainable urbanisation (United Nations - Department of Economic and Social Affairs, 2018).

The impacts of this increasing and forecasted trend in urbanisation will put pressure on the current forms and policies adopted in urban mobility, with consequences, especially in pollutant emissions. Urban areas already produce more than 70% of the total global emissions of CO_2 (International Association of Public Transport, 2020); moreover, in 2021, the overall transport sector accounted for 37% of the total global emission of CO_2 from end-use sectors (Teter, 2023).

This thesis and its content aim to provide a feasible, practical, and supported method to assess urban mobility and its impact on the pillars of sustainability. A tool with the goal of critically and objectively evaluating the sustainability of urban mobility in different contexts worldwide and being aware of both current and new challenges and goals that are driving the field. The development of a new sustainable mobility index for cities can bring new insights and views over the currently used ones, providing an overview and an analysis of the challenges and trends that will characterise and influence the future of urban mobility itself. The connection and relation to previous research is brought by the assessment of used indicators and their methodologies to identify the possible missing links and opportunities over current and future challenges. Academic and practical validation of the methodology chosen, which will also include the dimensions of the analysis itself, will provide the necessary and required support to identify, verify and validate the research questions and develop the solution: the sustainable mobility index for cities.

1.1.1. Sustainability and sustainable urban mobility

The critical factor in achieving this goal is understanding the concept of sustainability, especially related to the transportation field. The idea and construct of sustainability can be described as the interactions and integrations between three pillars: Social, Economic, and Environment (Purvis et al., 2019). Those three concepts must not be considered mutually independent but more with broader areas of analysis and context, which have to work and function in symbiosis to achieve a higher level of sustainability.

Developing policies and actions toward sustainability needs to be intended as an active process and research instead of a passive limitation of human activities, also not exclusive to the mobility and transport field; using technology and procedures, the overall objective of such policies is to preserve, create and distribute wealth, health, resources and an overall better quality of life in the future, continuously and responsibly that accounts for the future generations as well (Vogt & Weber, 2019).

Sustainability in the transportation field can take many forms regarding the different modes and the users involved, both towards people and freight. Initiatives at the international level, such as in the EU, want to provide more affordable, accessible, healthier, and cleaner alternatives to users, mainly regarding lowering the carbon footprint (European Commission, 2023a). Measures and guidelines developed in the last decade work towards an overall more sustainable way of life and towards specific objectives in the transportation field, aiming to reduce pollution and CO_2 emissions. Initiatives comprise alternative fuels, digital technologies, and legislative measures such as the Single European Sky policy or the Fourth Rail Package for passenger rail; the main aim is to create and shift transport and mobility to more sustainable forms (European Commission, 2023b).

1.1.2. Current and future trends and challenges in mobility

The concept of Smart Cities is surfacing, where traditional services are developed and upgraded to be more flexible, more efficient, and sustainable to achieve better operations towards the benefit of its inhabitants; central factors in achieving this goal are the use of infrastructure, data, and technology more responsively and efficiently, to achieve a more sustainable impact of the urban context (Mohanty, 2016).

New players, trends, and challenges, such as Mobility-as-a-Service (MaaS) or micro-mobility options, dominate the current urban context, where problems, such as congestion, deeply affect many urban areas. Those problems can also affect and impact important factors such as infrastructural needs, urban space and its development; the non-appliance and reaction to reduce the consequences of such factors can deeply affect all aspects of sustainability. (International Association of Public Transport, 2020).

Moreover, those current and future opportunities that will characterise the urban mobility context will pass through transformations affecting both the operational and social sides. Findings by McKinsey show that by 2035, the following trends and new technologies will influence and create a shift towards more sustainable options of mobility; repercussions will inevitably have an impact on the different modes of transportation used in urban mobility (Heineke et al., 2023):

- *Autonomous vehicles (AV)*: In North America and Europe, passenger vehicles will have an increase in the level of automation features, providing them with potential use on highways due to self-driving capabilities.

- *Rise of micromobility*: An increase in the micromobility market could more than double the current market value of 180$ billion, reaching over $440 billion by the 2030s.

- *Development of intermodal applications*: use of Mobility-as-a-Service platforms to provide more options and choices to users, integrating different mobility combinations, allowing users to plan their journey more easily.

- *Transition towards shared or pooled zero-emission vehicles*: A rise in the shared mobility segment could reach a market value of $1 trillion in revenues by 2030, providing consumers with more efficient, sustainable, and cost-effective options.

The subsequent impact of those trends on the use of the car as a mode of transport is predicted to lower the passenger miles travelled (PMT) by 15% in the 2030s while at the same time increasing the share of other forms of transport, such as traditional public transports, micromobility options and also new forms of transportation that will be developed (Heineke et al., 2023).

The impact of the mentioned trends on urban mobility, in terms of their sustainability performance, must be investigated; a tool that allows us to analyse and evaluate adequately is the mobility index, a supporting tool that enables the evaluation of the performances of selected locations. This key tool permits to assess how different cities perform in chosen dimensions and factors, with the ability to make comparisons between them to provide useful and practical recommendations in vital areas of mobility.

1.2. Problem statement

A mobility index is a helpful tool to assess the different transport policies and decisions in the urban context. This instrument is composed of indicators representing different variables from different sources and databases, depending on the goal of the index. Each indicator receives a weight, which is based on and justified depending on the overall objectives of the index, then used to calculate an overall score. This score represents the combination of the indicators and the importance given to them by their weight; the objective is obtaining a helpful tool to make comparisons and evaluate performances of determined aspects of mobility. This study will develop a mobility index that can also support the sustainability of different transport policies and urban environment decisions, that might have been undertaken by those cities having high performances.

At present, the need to assess the different transport policies and decisions in the urban context can be met with the help of indexes that evaluate the strengths and weaknesses of mobility systems. Creating a sustainable mobility index aims to provide an effective, efficient, and practical method to help measure those mobility systems, especially with an increasing number of cities working towards the development of sustainable plans for urban mobility. At the same time, the results obtained from indexes can help find and assess areas of improvement in specific contexts or locations.

The topic of a Sustainable urban index has been explored in the academic literature. Still, the indicators used might be both technically difficult to obtain or leave little possible action to be improved, often forgetting about new modes of transport, such as the use of micromobility. Different indicators might also be developed depending on the context, leaving little space for obtaining an objective index that can be used in different geographical locations (Arcadis, 2017). A composite index of different indicators, dimensioned and referencing the sustainability pillars previously mentioned, can be used to assess mobility, evaluate its sustainability, and identify areas for improvement. Interactions and relations between the pillars and the composite indicator define the final objectives and goals of the index, both analytically and logically.

The starting point of the index that will be created are the three pillars of sustainability: social, environmental, and economic. The choice of the cities where the practical application of the index will be tested must be adequately reasoned and supported to give objectively valid results. It also needs to be able to intercept current and future trends, especially regarding the different modes of transport.

Urban mobility can use the concept of sustainability and the three pillars involved to develop policies, solutions, and decisions to address and tackle the challenges previously described, aiming to achieve sustainable forms of mobility in all the concepts and pillars of sustainability. Urban public transport plays a crucial role in achieving this change in mobility; strategies and policies will take advantage of new technological developments and make those currently used more efficient (Bailey & Banister, 2006). The different contexts of urban realities found globally, both in developed and developing countries, can benefit from academic research and experimented indexes, aiming to have objective and inclusive parameters to develop practical actions toward sustainable forms of urban mobility (Canıtez, 2019).

The main objective of this thesis is to provide and create a working index that can assess the sustainability of urban mobility in a context of continuous evolution due to new trends, challenges, and technologies. Within this objective, a comprehensive analysis of the current literature and practical indexes will be conducted to use and assess how the existing materials can be included in this new index. To reflect the contemporary urban context, new indicators need to be evaluated to tackle the current and future challenges and better understand the context of mobility in the modern era.

1.3. Objectives

This thesis and its content aim to offer a feasible, practical, and supported method to assess urban mobility and its impact on the pillars of sustainability. This tool is designed to critically and objectively evaluate the sustainability of urban mobility across various global contexts, while considering both current and new challenges, as well as goals that are driving the field. The creation of a new sustainable mobility index for cities seeks to bring new insights and perspectives beyond the currently used indexes, incorporating challenges and trends that will shape and influence the future of urban mobility itself. This work wants to connect with the previous research on the topic by evaluating the indicators and their methodologies currently used, to identify the potential gaps and opportunities in both current and future challenges. The chosen methodology will be supported by academic and practical validation, ensuring identification, verification, and validation of the research question, culminating with the full development of the new sustainable mobility index.

A more detailed list of objectives can be stated as follows:

- *Objective 1*: Critically analyse and review current mobility indexes to select methodologies to be applied to the new sustainability index.

- *Objective 2*: Critically analyse the dimensions of analysis for the sustainability mobility index to check the possibility of adding a new dimension.

- *Objective 3*: Critically analyse the indicators used inside current indexes as well as new indicators representing current and new challenges, to assess their inclusion in the sustainability index.

- *Objective 4*: Select a number of cities after assessing the feasibility of the data available in each location.

- *Objective 5*: Apply the index to the selection of cities to provide results and conclusions on the sustainability index application.

This set of goals provides a framework for the thesis and the development of its content and insights; the intentions here presented reflect the purposes of the thesis and the specific themes that will be analysed. In the following section, the objectives will be assessed and further developed into the research questions the thesis will assess.

1.4. Research Questions

This chapter provides a clear view of the research questions and sub-questions to develop effective research into the problem statement described in the previous section. The main research question will cover the overall objective of the thesis.

- ***How best to create a sustainable urban mobility index for (international) cities?***

The subsequent sub-questions will help to provide more detailed information on some steps of the index's development.

- *Which literature sources can be referenced for sustainable mobility indicators?*

- *Which methodologies exist to develop a composite indicator for sustainable urban mobility?*

- *What structure will be used for the dimensions of the sustainable mobility index?*

- *What are the criteria for selecting the cities for which the sustainable mobility index score will be computed?*

- *How do different cities perform? How can their ranking be explained?*

- *How can cities improve their performance based on the proposed sustainable mobility index?*

The purpose of the questions mentioned above is to provide a clear path for the development, production and analysis of the overall argument and objectives of the thesis. The following chapters will answer those questions to create a logical, referenced, and supported base for developing the sustainable mobility index.

1.5. Structure of the thesis

In chapter 2, the literature review will be presented, focusing on exploring the concept of sustainability and the current indexes and their methodologies. An assessment of the index's dimensioning will be provided inside chapter 3 to deliver a supported and valid framework for the index. The methodology selection for the sustainable urban mobility index will then be provided in the same chapter, to determine the indicators that will compose the index; this also includes an analysis to select the cities on which the index will be used. Chapter 4 will be focused on the data collection, with the consequent assessment of it. The content of chapter 5 will be the methodology. This methodology consists of 5 steps, which comprise the selection of the dimensional framework and the variables better portraying the concepts and contexts selected for the dimensional structure, the processing of the data collected and subsequent normalisation. The last two steps, the weighting and aggregation of the processed data, enable to calculate and obtain the performances results.

Chapter 6 focuses on the interpretation of the results obtained, and those scores will allow also to provide recommendations to those locations having lower scores, by assessing what can be improved and learned by those cities performing best. A discussion of the developed index, including possible limitations of the research approach are highlighted in chapter 7. Conclusions, with an overall summary of the answers provided to the research questions stated, and points for further research, will close the thesis in chapter 8.

2. Literature Review

In this chapter, an overview of the academic and practical literature will be provided to assess the studies and analysis already present and performed in those two contexts. The main division of the section will be between a first assessment of the concept of sustainability and its pillars, followed by a second part focused on the existing indexes that can be used as a baseline for the creation of the new sustainable mobility index.

2.1. Concept of sustainability

To better assess the sustainable urban mobility index, the concept of sustainability mentioned in the previous chapter needs to be appropriately defined and analysed, focusing on the three pillars described. In the next sections, the three pillars will be analysed individually to assess how each dimension approaches the concept of sustainability.

The current concept of sustainability was defined in 1987 by the United Nations Burtland Commission as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations, n.d.). It comprises three dimensions, as previously mentioned:

- **Environmental:** "*meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them*"(Morelli, 2011).

- **Economic:** "*efficiency, that is non-wastefulness, in the use of scarce resources for achieving […] the satisfaction of the needs and wants of individual humans and justice, including justice between humans of present and future generations and justice towards nature, in the setting of human–nature relationships over the long-term and inherently uncertain future*" (Baumgärtner & Quaas, 2010).

- **Social:** "*achieving social equity and sustainability of communities*" (Dempsey et al., 2011).

Those three dimensions are also defined as pillars and encompass the idea of factors and goals related to the specific dimension. This tripartite division of the concept of sustainability itself is not exclusive, as the different dimensions are highly interconnected and intersected in their goals. The concept and definition of sustainability are constantly reflected upon and challenged both over its pillars; given the nature of being an active process that involves different dimensions covering different topics, the core pillars of sustainability are critically reviewed by discussions at different levels, including ethics, cultural, environmental and economic (Vogt & Weber, 2019).

Overall, the concept of sustainability can be applied in different forms and refer to different uses of it (Salas-Zapata & Ortiz-Muñoz, 2019), in particular:

- *A set of criteria*

- *A goal or a vision*

- *An object*
- *An approach*

Those different possible forms of interpretation of the concept have repercussions on both the theoretical and practical applications: the meaning of sustainability and, therefore, the policies and actions surrounding it. However, the intrinsic multivariate nature and forms of sustainability do not stop the production, development and analysis of the policies and objectives from providing solutions and studies towards the different aspects of sustainability itself (Salas-Zapata & Ortiz-Muñoz, 2019).

In the following section, an analysis of the use of the three pillars as the framework for the mobility index will be provided to assess if a different dimensioning could better reflect the concept of sustainability when related to urban mobility.

The last section of Chapter 2.1 will be dedicated to the assessment of an alternative dimensional framework for the concept of sustainability, using the 5Ps framework. This last dimensioning will be assessed to explore the possibility of overcoming the limitations of the traditional pillars of sustainability and the problem that might occur with the addition with the fourth pillar.

2.1.1. Environmental Sustainability

The first pillar is the environmental one, whose intention is to "The natural resources of the earth […] natural ecosystems must be safeguarded for the benefit of present and future generations through careful planning or management, as appropriate.'' (United Nations, 1973) as defined during the 1972 UN Conference on the Human Environment. Moreover, environmental sustainability can also be recognised as a condition of balance and resilience of the human society's actions and needs of resources and services without exceeding the capacity of the supporting ecosystem or diminishing the biological diversity (Morelli, 2011). On a broader practical scale, environmental sustainability deals with issues such as climate change, water and land pollution comprising the impact on related resources, and the human impact on biodiversity (Ripple et al., 2017).

In the context of mobility, the main issue and impact on this dimension is pollution. As previously stated, around 37% of the total amount of CO_2 emission can be related directly to transportation (Teter, 2023); moreover, urban mobility is strictly connected to the emissions in urban areas, which account for 70% of total CO_2 emissions (International Association of Public Transport, 2020).

2.1.2. Economic Sustainability

The second pillar is the economic one, with the key principle in sustainably driving economic growth, both towards the environmental and social aspects. This is highly related to consuming natural resources and providing primary welfare goals of basic needs, such as water, shelter, food, and health (Kuhlman & Farrington, 2010). It can be noted that the goals and objectives of this dimension are deeply integrated with the other two pillars.

An approach to economic sustainability in mobility, but not exclusively in this sector, can be identified in the circular economy concept: It is a model of production and consumption involving recycling, reusing, leasing, refurbishing, repairing, and sharing products and materials as long as possible. The materials of a product that has reached the end of its life are kept inside the economic cycle to create further value without consuming more resources. This contrasts with the traditional linear economy model, based on products with a "single use" purpose, relying on higher amounts of materials, labour, and energy. Following a circular economic model can have repercussions in many areas of mobility, especially the ones with high needs in terms of materials or energy, as well as limit the waste of highly valuable resources (European Parliament, 2023).

2.1.3. Social Sustainability

The third dimension, social sustainability, was the least researched within the three pillars and gained more attention starting in 2000. Nowadays, it can be regarded both as the interaction of the society itself and the context and environment they live in; this description ties up with the other two dimensions of sustainability previously described (Doğu & Aras, 2019).

Key concepts and goals of this pillar can be explained by actions such as improving education, social justice, and women empowerment, with repercussions such as a better and fairer distribution of wealth, both at a community and geopolitical level, and improving the overall quality of life (Vogt & Weber, 2019).

Transport is then deeply connected to social sustainability through the policies that can be implemented. Due to the far reach of transportation into the social stratus, policy taken in transportation and urban mobility towards its sustainability can impact the society itself that uses it. Therefore, urban sustainability requires actions in urban mobility and transportation that can provide benefits over social sustainability itself (Caulfield et al., 2001).

2.1.4. 5Ps of sustainability

Another approach can be defined through the 5Ps of sustainability (*The UN Agenda 2030 for Sustainable Development*, 2024):

- *People:* Fighting poverty and social exclusion and promoting health and well-being to ensure human capital development.
- *Planet*: Ensuring sustainable management of natural resources, countering biodiversity loss, and protecting environmental and cultural assets.
- *Prosperity:* Affirming sustainable models of production and consumption, guaranteeing decent employment and training.
- *Peace:* Promoting a non-violent and inclusive society without discrimination; fighting illegality.

- *Partnership:* Taking integrated actions in the several areas involved.

Those 5 principles are a further classification over the 17 Sustainable Development Goals (SDGs) assessed by the United Nations, shown below:

Figure 1 Sustainable Development Goals (SDGs) (United Nations - Department of Economic and Social Affairs, 2023)

Those 17 goals were adopted in 2015 by all the United Nations Member States in the 2030 Agenda for Sustainable Development, marking a shared global multinational effort to provide a future of peace and prosperity for the planet and its people. Support, both economic and legislative, in achieving the objectives of the SDGs and dealing with related thematic issues is assigned to the UNDESA, the United Nations Department of Economic and Social Affairs (2023). A critical SDG that needs to be mentioned in more detail regarding the topic of Urban Mobility is Goal 11.

SDG number 11, defined as Sustainable Cities and Communities, can indeed be considered as one with a direct relationship with the concept of Urban Mobility and the pursuit of sustainability in it. Between the targets defined inside this SDG, the following ones can be deemed as heavily impactful in the topic of this thesis:

- Target 11.2: **Affordable and sustainable transport system**, consisting of “provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons." (*Goal 11*, 2024, p. 11)

- Target 11.3: **Inclusive and sustainable urbanisation**, consisting of "enhance inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlement planning and management in all countries." (*Goal 11*, 2024, p. 11)

- Target 11.6**: Reduce the environmental impact of cities**, consisting of "reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management." (*Goal 11*, 2024, p. 11)

- Target 11.8: **Strong national and regional development planning**, consisting of "Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning." (*Goal 11*, 2024, p. 11)

The inclusion of the 17 SDGs into the 5Ps wants to highlight how those different goals are fundamentally intertwined and represent a shared framework, as opposed to one-sided goals. Progress on one of the Ps needs balance on the other ones to achieve and implement overall supported and shared sustainability (Kaysie, Brown & Krista, Rasmussen, 2019).

2.2. Mobility Indexes

The composite index can be a valuable tool in helping and supporting the gap between the policies and plans and the practical implementations of solutions toward sustainable forms of mobility. Given the quantitative results and analytical methodology used to elaborate the scores of the index, it can support and improve communication with stakeholders involved in both the development and the implementation of mobility policies. On the other hand, more theoretical and academic results could give more challenges in being explained to stakeholders; an important goal for researchers is to be able to explain the concepts and results achieved clearly and understandably in order not to have different forms of interpretation of the results and policies (Foltynova et al., 2020). Using sustainable mobility indexes has been proven helpful in developing strategies and enhancing the diffusion of sustainable urban mobility options in different geographical locations, with subsequent differences in economic and cultural contexts (Morfoulaki & Papathanasiou, 2021) & (Miranda, 2012).

At a planning level, indexes and subsequent indicators are used to evaluate different alternatives and policies that policymakers will prioritise at a political level. In the EU context, in 2019, the Sustainable Urban Mobility Plans (SUMPs), first developed in 2009, were updated to create strategies and solutions at a local level following European communal guidelines (Rupprecht Consult, 2019). Those guidelines comprise 12 steps, and the 6th is the set of indicators and targets, an action strictly related to indexes. The use of standard indicators, well-defined and known, has a beneficial impact on the overall policy assessment and development: it permits the benchmark of different cities, as well as comparison to national and international statistics, and helps in communicating with the stakeholders and the general public (Rupprecht Consult, 2019).

Moreover, the use of sustainable mobility indexes is currently in use to benchmark the data collected across different cities, such as the data collection from the SUMPs in the EU. By benchmarking the results, it helps the evaluation of strengths and weaknesses of cities' mobility systems, as well as collecting data to further plan communal policies and plans for both communal networks and regulations (European Commission, 2024).

Three indexes will be presented and explained in more detail in the next sections. Those three indexes represent an overall example by three institutions that are globally involved in the transport and urban mobility field providing experience, policy guidance, and consulting to achieve sustainable objectives and goals all across the globe.

2.2.1. ITDP – Indicators for Sustainable Mobility

This index was developed by the Institute for Transportation & Development Policies (ITDP) (Chestnut & Mason, 2019), a US organisation founded in 1985 to fight climate change while transforming mobility to achieve a better quality of life in cities globally. ITDP works across five continents, with over 100 cities in 40 nations worldwide, to design and implement transport policies and urban development solutions to make cities more liveable, fair, and viable.

The index developed by ITDP has the purpose of helping cities in the choice of transportation policies and developing sustainable solutions. Data and research were conducted in the North American continent in Canada, Mexico, and the USA, focusing on 30 cities, of which 4 were in Canada, 4 in Mexico and 22 in the US. The principal focus in terms of sustainable forms of transport is mainly related to public transport.

The indicators span the following three different main categories:

Access to Transit comprises the following indicators (Chestnut & Mason, 2019):

- **People Near Rapid Transit**: an indicator measuring the percentage of the population located at a 10-minute walk or bike ride from a public transport station of a rapid transit system.
- **Jobs Near Rapid Transit**: It represents a measuring of the percentage of jobs within a 10-minute bike ride or walk of a rapid transit station.
- **Low-income Households Near Rapid Transit**: It measures the percentage of the population making less than $20,000 a year who lives within a 10-minute bike ride or walk of a rapid transit station.
- **People near frequent transit (PNFT)**: The percentage of the population within a 10-minute bike ride or walk of a frequent transit stop.
- **Jobs Near Frequent Transit**: It measures the percentage of all jobs within a 10-minute bike ride or walk of a frequent transit stop.

- **Low-Income Households Near Frequent Transit**: It represents a percentage of households making less than $20,000, located within a 10-minute bike ride or walk of frequent transit.

Rapid transit was defined as any Bus Rapid Transit (BRT) corridor, Light Rail Transit (LRT) corridor, or rail-based transit mode that meets the BRT basics definition in the BRT Standard. Stops are defined as frequent if served by an average of five services an hour, resulting in around 12-minute headway, from 7 a.m. to 9 p.m. on a weekday, and include rapid transit stations. The figure selected for the low-income indicators is related to the federal poverty level for a family of three ($20,780).

The next category is **Accessibility**, which comprises the following indicators (Chestnut & Mason, 2019):

- **Access to Jobs by Sustainable Transit**: It represents a measure of the average number of jobs that can be reached within 30 minutes and 60 minutes by walking, cycling, and public transit, divided by the census tract of the area. This indicator represents a percentage of all the jobs in the city.

- **Access to Low-Skill Jobs by Sustainable Transit**: It measures the average number of jobs requiring less than a high school education that can be reached by walking, cycling, and public transport within 30 and 60 minutes for each census tract in the area.

- **Access to People by Sustainable Transit**: It represents a measure of the average number of people that can be reached within 60 minutes, categorised by each census tract in the area. This indicator was developed as a proxy measure to calculate access to jobs in areas where job data was unavailable.

The third and last category is **City Characteristics**, comprising the following indicators (Chestnut & Mason, 2019)*:*

- **Block Density**: It is a measure of the average number of city blocks per square kilometre of the study area considered. Blocks are defined as developed, surrounded on all sides by publicly accessible pedestrian passages.

- **Weighted Population Density**: It represents the average experienced density of a person in the city. Unlike traditional population density, this measure is weighted by the population of each census tract of the area considered, which provides a more detailed and in-depth understanding of population density.

Those three mains contain easily understandable and replicable indicators that can be tied into policy interventions. The methodology consisted mainly of the development of the indicators, which were obtained primarily with the help of ArcGIS software and its network extension, with General Transit Feed Specifications (GTFS) data collected from TransitFeeds and local transit agencies. Road data was gathered from OpenStreetMap, while social and population data were from national surveys and censuses, namely the US Census American Community Survey 2015 for the population and the

Longitudinal Employer-Household Dynamics 2015 survey for the job data. Subsequently, the results obtained were plotted to be correlated to the benchmark indicator *Sustainable Transport Mode Share*.

The analysis of the city considered in the North American continent helped reach academic results in social and behavioural fields and connections to geographical and operational contexts. Key results can be summarised in the following list (Chestnut & Mason, 2019):

- The population in the proximity of transit systems and the availability of jobs are the main factors influencing the mode share; for the second-mentioned variable, the number of jobs is more impactful in absolute terms rather than a significant share over the total ones.

- Faster trips of 30 minutes can be more significant than longer 60-minute ones for the mode share, making it a possible valuable threshold for measurement.

- Lower-income households tend to have greater access to public transit than the overall population; however, their ability to reach jobs requiring undergraduate and high school education is lower than the average job accessibility of the whole population.

The main limitation of this index is that the analysis focuses mainly on the classical form of urban transport, namely the modes of car, walking, cycling and public transport, without considering other forms of transport, such as shared and e-mobility options. In addition, the analysis and the application of the index were conducted only in the North American continent, therefore achieving results that might be considered only in the nations of application; results in other areas of the world might be different depending on the location of the application, subsequently posing a geographical limit to the results obtained.

2.2.2. Arcadis – Sustainable Cities Mobility Index

The index was developed by Arcadis (Arcadis, 2017), a consultancy and design company that aims to provide sustainability solutions as the core of policies and solutions to maximise the impact of improving the quality of life worldwide. It is present in over 70 countries worldwide, using the power of technology and data to develop, implement and deliver solutions to today's global challenges and trends in a sustainable, efficient, and effective way.

This index uses 23 indicators based and organised in the three pillars of sustainability, called sub-indexes, whose characteristics were previously described and analysed. The indicators are described and categorised in the following tables, one for each of the pillars; more details and information are provided in the table of each sub-index.

- ***People*** measuring the human and social impacts of the city's mobility systems.

Table 1 People sub-index indicators (Arcadis, 2017)

Indicators	Unit	Source	Data Level	Further explanation
Fatalities	Traffic fatalities per 100,000 inhabitants	National Safety Council, Eurostat, WHO, various	Mostly city level (exceptions include China and Australia)	Traffic safety is of utmost importance, and fatalities can be indicative of an under-served or undermaintained system.
Access to Transport Services	Bus and metro stops per km2	European Metropolitan Transport Authorities (EMTA), EPOMM, various	City	Accessibility of transport services heavily impacts how utilised they are by the residents of a city.
Modal Split of Trips Taken	Share of total trips taken by public transport	European Metropolitan Transport Authorities (EMTA), various	City	A higher number of trips taken by public transport recognises utilisation. The higher the utilisation, the better.
Rider Connectivity	Wi-Fi in metro tunnels, stations and on buses, 2g/3g/4g in metro stations and tunnels	Various including local transport provider websites and news publications	City	Wi-Fi and 2/3/4g service within the transport system makes travel easier as well as more enjoyable and productive by allowing residents to use devices seamlessly during their journey.
Upkeep of the Metro System	Year of last major improvement, defined by track expansion or station additions	Various including local transport provider websites and news publications	City	Track and station additions assist in making use of the metro system easier for residents.
Wheelchair Access	Share of buses and metro stations that are wheelchair accessible	Various including local transport provider websites and news publications	City	Transport accessible to all boosts the quality of life for residents.
Uptake of Active Commuting	Share of commuters cycling or walking to work	EMTA, EPOMM, Various	City	The ability to cycle or walk to work is reflected in the number of people who choose to do so each day. Active commuting has many benefits for residents.
Transport Applications and Digital Capabilities	Availability of transport system on Google Maps, an app created by the transportation authority, and the existence of digital ticketing	Various, including the Observatory of Automated Metros	City	The incorporation of digital capabilities into a transport system makes using public transport easier in cities.

Airport Passengers	Annual passenger traffic	ACI Airport Statistics	City	Airport traffic reflects the ability to get in and out of a city via plane.
Hours of Metro Accessibility	How many days a week the metro operates 24 hours	Various including information pages of local transport providers	City	24-hour accessibility in metro systems allows for greater use and flexibility for people. Cities without a metro system are penalised here, as metro systems are quick, easy and efficient. Often, the most sustainable form of public transport currently available to cities.

- ***Planet***, assessing the environmental implications of the urban mobility system.

Table 2 Planet sub-index indicators (Arcadis, 2017)

Indicator	Unit	Source	Data Level	Further explanation
Transport Greenhouse Gas Emissions	Metric tons of CO2 per capita multiplied by CO2 from Transport	CDP Cities	City (Metric tons of CO2 per capita) x National (CO2 from transport)	This includes city data on all sources of emissions adjusted with national data on the share of emissions resulting from transport.
Provision of Green Space	Green space as a share of the city area	Siemens Green City Index, World Cities Culture Forum, European Environment Agency	City	Greater use of public transit relieves the need for roads and parking, which can subsequently be turned into green space. Green space also helps counter the emissions from transport.
Congestion and Delays	Increase in overall travel time	TomTom, Numbeo	City	This measures the average increase in travel time from a free-flow situation to peak hours. Greater congestion leads to greater emissions and pollution.
Bicycle Infrastructure	Bicycles per capita and bicycle sharing schemes	Metrobike	City (sharing schemes); National (bike ownership)	Bicycle-sharing schemes and ownership help alleviate road traffic and congestion.
Air Pollution	PM10 levels (ug/m3) / PM2.5 levels – simple average	WHO Global Urban Ambient Air Pollution Database	City	This includes all sources of pollution. Transport does account for a critical share of pollution.
Efforts to Lower Transport Emissions	The existence of LEZs and their prevalence (Cebr score) and	Various including the European Commission's	City	Low emission zones impact pollution, as do high emission standards. This is

	vehicle emission standards	Urban Access Regulations website		a critical part of city and national policy to ensure environmental sustainability.
Electric Vehicle Incentives	Provision of incentives to produce/ purchase EVs	Various, including government transport department websites	City	Encouraging residents to switch to Electric Vehicles is an essential step in ensuring a lower emissions future.

- ***Profit***, measuring the economic aspect of the city's mobility system.

Table 3 Profit sub-index indicators (Arcadis, 2017)

Indicators	Unit	Source	Data Level	Further explanation
Commuting Travel Time	Average commuting time	Numbeo Traffic Index	City	Additional time spent commuting is less time to contribute to economic activity.
Economic Opportunity	Transport system revenues as a share of expenses	Various including annual reports of transport providers	City	A city's ability to fund transport system needs through revenue is critical to its sustainability.
Public Finance	Share of city budget spent on transport	Eurostat, city budgets	City	Many transit system upgrades are financed through multiple sources of funding, private, federal, state and city budgets. City budgets should still contribute to infrastructure needs and are indicative of its commitment to sustainable mobility.
Efficient of Road Networks	Max city speed limit	AA, Auto Europe	City	The more efficient the road network, the higher the speed limit can be set. There was no correlation between this indicator and the fatalities indicator in the People pillar.
Affordability of Public Transport	Transport spending as a percentage of income	Numbeo, Expatistan	City	Refers to the price of a regular monthly pass for public transport as a proportion of average monthly net earnings in the city. Affordability is a key factor in residents' usage.
Utilisation of the Transport System	The average number of public transport journeys per capita	Land Transport Authority Singapore, American Public Transport Association, various	City	A higher number of trips taken by transport recognises utilisation per capita. Higher usage also allows greater revenue capture from fares for a city.

Results of the analysis of 100 cities worldwide were presented in 2017, providing an overall analysis of the pillars of sustainability and relative indicators and a framework to evaluate the human and social implications of urban transport, its choices, and its policies. The main findings showed that the European region takes the top chart of overall results, but the top spot was reserved for Hong Kong. In the overall results, wealthy and advanced technological regions such as Europe and Asia dominate the higher parts of all three sub-indexes. Those cities and those that made bold, sustainable decisions in their approach towards transport policies were awarded their choice with better placements than others.

The methodology involved consisted of a three-stage averaging process to create a composite score for the three categories of indicators to establish a corresponding ranking for the cities analysed. Key mathematical and analytical processes involved are the statistical analysis of the given dataset, as well as the normalisation of the indicators, to be able to have comparable scores. The subsequent action is the evaluation of the sub-indexes with a weighting system. The weighting system allows to assign to each indicator a nominal value that represents its impact on the overall sub-index's quantitative performance; this value can be assigned depending on different systems of validation, such as academic literature or direct surveys of the population involved. The overall purpose is to be able to evaluate the impacts of the different specific and detailed indicators, which also use different units of measure, to calculate and assess the quantitative performance of a more general and broader objective involving all the single indicators. The categorisation and scale assigning of the weighting system depend, and it's decided, on the objective and goals of the context of the application, such as prioritising the indicators having a more significant impact on urban mobility. An average between the three sub-indexes is then taken to calculate the final overall scores.

The main limitation of this index is an intrinsic characteristic that comes with the number of indicators involved: the availability of data. All the indicators require one or a combination of more databases to extrapolate and produce a score assigned to each city; this also assumes that data in each of the sourcing databases contains values for all the cities considered. Another limitation is the assigned weight system: by considering different scoring to the different indicators of the sub-indexes, the performance of the cities could vary, determining possibly different overall results. Moreover, no attention is paid to some of the new trends in mobility, such as shared mobility options, making it less adherent with the current and future challenges.

2.2.3. WBCSD – Sustainable Urban Mobility

This index was developed by the World Business Council for Sustainable Development (WBCSD) in 2015 under the Sustainable Mobility Project 2.0 (SMP2.0). The analysis was to provide a set of indicators to be used as a benchmark in evaluating the performance of different cities on a global scale in order to be able to intervene and improve the local situation of each different context. WBCSD is an organisation of over 200 global companies with the goal of galvanising the global community to create a sustainable future for business, society, and the environment. Its member companies provide a forum representing over $8.5 trillion of combined revenue and 19 million employees, combined with a network of 70 national and regional business councils.

Six pilot cities were considered for this project: Lisbon, Bangkok, Campinas, Chengdu, Hamburg, and Indore. The results obtained were used to improve further and better define the methodologies of the indicators that will be described, allowing the refinement of all the related aspects by providing additional guidance.

Four dimensions of sustainable mobility were considered to develop the model:

- *Global environment*
- *Quality of life in the city*
- *Economic success*
- *Mobility system performance*

The last dimension was added in order to be able to evaluate the performance of the mobility system inside the city. Those four dimensions mentioned above include 19 indicators described in the following table, providing information on the indicator itself, the parameter of consideration, and the data source; it needs to be noted that some indicators appear in more than one dimension, therefore influencing both the dimensions in which they are listed.

The indicators are organised into the four dimensions as listed in the subsequent table, followed by table 5 with more details and information about the single indicators:

Table 4 Division of the indicators inside the dimensions of SMP2.0 (World Business Council for Sustainable Development, 2015)

Global Environment	**Quality of life in the city**	**Economic Success**	**Performance of the mobility system**
• Mobility space usage • Emissions of greenhouse gases • Congestion and delays • Energy efficiency • Opportunity for active mobility	• Affordability of public transport for the poorest group • Accessibility for mobility-impaired groups • Air polluting emissions • Noise hindrance • Fatalities • Access to mobility services • Quality of public area • Urban functional diversity • Commuting travel time • Economic opportunities • Comfort and pleasure • Security	• Urban functional diversity • Commuting travel time • Economic opportunity • Net public finance • Mobility space usage	• Affordability of public transport for the poorest group • Accessibility for mobility-impaired groups • Congestion and delays • Energy efficiency • Opportunity for active mobility • Intermodal integration • Comfort and pleasure • Security

Table 5 Indicators of SMP2.0 (World Business Council for Sustainable Development, 2015)

Indicator	Definition	Parameter	Data source
Affordability of public transport for the poorest group	Share of the public transport cost for fulfilling basic activities of the household budget for the poorest quartile of the population	Affordability index of public transport for the poorest population quartile is based on the relation between the cost of 60 relevant public transport trips and the average monthly household income.	City or national databases
Accessibility for mobility-impaired groups	The accessibility for deficiency groups to transport and transport services.	Average reported convenience of city transport for target groups.	Survey
Air polluting emissions	Air polluting emissions of all passenger and freight city transport modes.	Total tailpipe harmful emission harm equivalent per year per capita.	National values, or literature values, if not available
Noise hindrance	Hindrance of the population by noise generated through city transport.	Percentage of population hindered by city transport noise based on hindrance factors for noise level Lden measurements.	Measurements
Fatalities	Fatalities by road and rail transport accidents in the city.	Number of deaths within 30 days after the traffic accident as a corollary of the event per annum caused by urban transport per 100,000 inhabitants.	National, regional, and city data sources, World Bank/UN Global Indicators data.
Access to mobility services	Share of population with appropriate access to mobility services.	Percentage of the population living within walking distance of public transport (stop or station) or shared mobility (car or bike) system.	Spatial data (GIS)
Quality of public area	Presence in the city of attractive areas, such as pedestrian streets or squares, which facilitate social activities and encourage citizen interaction.	Reported social usage of streets and squares and subjective appreciation of the public area quality	Survey
Urban functional diversity	Functional diversity refers to a mix of spatial functions in an area, creating proximity to mutually interrelated activities.	Average presence (value 1) or not (value 0) of out of 10 spatial functions related to daily activities except for work in grids of 1 km x 1 km.	Spatial data (GIS)
Commuting travel time	Duration of commute to and from work or an educational establishment.	The average duration of the combined outward journey and return journey to work or an educational establishment is expressed in minutes per person per day.	Survey
Economic opportunity	Degree of accessibility to the job market and education system.	Citizens' perception of potential difficulties in accessing the job market and education system due to mobility networks.	Survey
Net public finance	Net results of government and other public authorities'	Net government and other public authorities' revenues from transport-	National databases

	revenues and expenditures related to city transport.	related taxes and charges minus operational and other costs per GDP; investments are excluded from the parameter calculation.	
Mobility space usage	Proportion of land use, taken by all city transport modes, including direct and indirect uses.	Square meters of direct and indirect mobility space usage per capita.	Spatial analysis (GIS)
Emissions of greenhouse gases (GHG)	Well-to-wheels GHG emissions by all city passenger and freight transport modes	Tonne CO2 equivalent well-to-wheel emissions by urban transport per annum per capita.	Traffic model calculations
Congestion and delays	Delays in road traffic and in public transport during peak hours compared to free flow travel.	Weighted average per trip of the ratio of peak period travel times to free-flowing travel times with respecting rules in road traffic and travel time adherence of public transport during peak hours on up to 10 major corridors for both transport modes.	Measurements and statistical data from databases
Energy efficiency	Total energy consumed for city transport	Total energy use by urban transport per passenger-km and tonne-km (annual average over all modes)	Traffic model calculations
Opportunity for active mobility	Options and infrastructure for active mobility refer to the use of soft modes, namely walking and cycling.	The length of roads and streets with sidewalks and bike lanes and 30 km/h (20 mph) zones and pedestrian zones are related to the total length of the city road network (excluding motorways).	Spatial analysis (GIS)
Intermodal integration	Availability of intermodal connections and quality of the interchange facilities.	Number and frequency of the connections between the different transport modes and the reported good organisation, information and physical access in the interchange facilities.	Survey
Comfort and pleasure	The physical and mental comfort of citizens while using the urban transports and services.	Average reported satisfaction about the comfort of city transport and of pleasure of moving in the city area.	Survey
Security	Risk of crime in urban transport.	Reported perception about crime-related security in the city transport system (including freight and public transport, public domain, bike lanes and roads for car traffic and other facilities such as car or bike parking)	Survey

In order to obtain a standardised value for all the indicators, a scale from 0 to 10 was used, in combination with the usage of the average score for the different areas considered. The usage of an average score, however, can represent a limitation as it does mask the extreme values that might be relevant when analysing patterns and trends over specific indicators.

In addition to the indicators used, a set of parameters was suggested as influential in understanding city mobility and its development opportunities; some of these parameters were also used in the analytical definitions of the indicators. Those parameters were not considered indicators for the purposes of the index because they do not represent positive or negative data but instead helpful information about both the location selected and its society, as they are highly dependent on the different locations and cities' targets regarding policies and actions. The suggested parameters are (World Business Council for Sustainable Development, 2015):

- ***Occupancy rate***: This parameter represents the average load factor of vehicles, usually defined per mode. Being able to optimise the occupancy rate of private and public vehicles is essential to reach a compromise between energy efficiency, transport costs and comfort. This parameter is related to energy efficiency, affordability, and public finance indicators and impacts the calculation results for emissions, air pollution, and energy efficiency.

- ***Motorization rate***: This parameter is defined as the number of motorised vehicles per 1000 inhabitants. It usually increases with the city's economic development and is a suitable parameter for interpreting some indicator values.

- ***Modal split***: It is defined as the percentage of travellers using a specific transport mode. Modal split is an important parameter to define sustainability targets and balance using the different transport modes.

- ***Smartphone penetration***: The penetration of internet and cloud technologies is an essential parameter for deploying real-time information, smart ticketing/payment technologies, etc. A possible way to evaluate it is to measure the percentage of the population having smartphones.

- ***Vehicle miles travelled per capita***: This parameter measures the vehicle distance travelled per inhabitant. It allows evaluation of the mobility network's efficiency in terms of distance travelled and occupancy rate of the vehicles. It can also provide information on whether urban functions are well distributed over the city area.

- ***Speed in the transport network***: The speed in the transport network influences how much people will move. It is influenced by the speed of the vehicles, the size of the area covered with efficient mobility infrastructures for all modes (including biking and walking), the quality of the interchange between lines, and the frequency of public transport.

- ***Car friendliness of the city centre***: As more and more cities would like to decrease the negative impacts of private cars in the city centre, they evaluate the car friendliness of their city centre. It is related to the number of parking spaces available per square kilometre, parking tariff policy, the existence of pedestrian zones or access restrictions based on the emission standard of the vehicle or related to the period of the day restrictions.

- ***Availability of public transport cards***: This parameter measures the vehicle distance travelled per inhabitant. It is an important parameter as it allows for evaluating the mobility network's efficiency in terms of distance travelled and occupancy rate of the vehicles. It can also provide information on whether urban functions are well distributed over the city area.

Those parameters can be helpful in assessing the necessity for new indicators and dimensions of analysis of urban realities, as they can provide new benchmarks or indicators related to the pillars of sustainability. Academic literature and practical examples research, as well as a check of the availability of data, will be performed in the thesis to assess the feasibility and inclusion of those parameters in the index.

This index was not applied to a pool of cities but is rather provided as a more theoretical framework and assessment to investigate sustainable urban mobility, posing it as a support to collect performances.

Therefore, a main limitation of this index is the nature of being a benchmark to be used for all the single locations rather than being a direct comparison between those. At the same time, it is still a valuable tool in evaluating the performance of a city mobility system. If repeated over time, it makes it possible to evaluate the impact and improvement of new mobility practice implementations, with a focus on the single indicators, thus providing quantitative proof of the benefits of specific measures that could be used by other cities as well.

2.3. Findings

The main findings that can be obtained from the literature review span both the dimensional framework and the indicators themselves.

Regarding the first topic, the literature assessed confirms the progression and evolution of the pillars and dimensions that represent the concept of sustainability, especially related to the traditional three pillars and the more recent SDGs and 5Ps. The creation of the dimensional framework will take into account the key considerations made, in order to provide the new sustainable mobility index with a structure that can represent the concept of sustainability at its fullest extent.

Regarding the mobility indexes assessed, those three indexes provide useful and reliable information within their indicators. Still, a key point in all of them is that they are mainly missing the inclusion of data and values representing the current and future trends of mobility that were also cited in the introduction and problem statement sections. The selection of the indicators will consider this to intercept and evaluate how those trends can impact urban mobility and its sustainability.

3. Framework of the sustainable mobility index

In this chapter, the methodology for the index will be assessed and evaluated. A sustainable urban mobility index requires a dimensional structure and framework that both reflects the concept of sustainability in all its forms and can intercept and relate to the indicators in each category. Therefore, the analysis that is needed and undertaken deals with how effective and critically the main index structure is able to portray the concept of sustainability itself. This will include not only the dimensions in reference to the three pillars of sustainability and the sustainable Ps but also the indicators themselves.

The proposed structure will be used in the framework of the sustainable mobility index and support the categorisation in which the indicators will be developed and calculated.

In the second part, the assessment and analysis of the indicators will be performed. Firstly, the indicators used inside the indexes presented in the literature review will be revised to select and assess their validity inside the index in development. Secondly, a reflection will be performed on which additional indicators to select in order to cover current and future trends in the topic of urban mobility priorly presented.

The overall goal is to provide a structured framework for the sustainable mobility index, both at the dimensional level as well as at indicator level, structurally supported by the literature review assessed and towards the overall obtainment of numerical data-based results.

3.1. Dimensioning

Regarding the dimensions of the index that will be developed, the main discussion and evaluation is on how the structure needs to be dealt with. The dimensions of the index need to be able to support and provide already a categorisation to express the concept of sustainability. This also helps in the division and selection of the indicators within each dimension.

This framework will act as the primary structure of the index, immediately portraying the goals and purposes that the sustainable urban mobility index wants to provide. The choice of dimensioning also requires reflecting the trends and analysis of the concept of sustainability as well as portraying and evaluating the impacts of this latest construct in urban mobility.

3.1.1. Three pillars of sustainability

The main structure that was used as a framework in Arcadis' index considers the three pillars themselves as the dimensions. This leaves the index to be developed inside the three categories that refer back to the concepts of social sustainability, economic sustainability, and environmental sustainability. This dimensioning comes with some disadvantages:

- It is limited to the structural dimensioning of the concept of sustainability, which, as assessed in the literature review chapter, is not fixed and can vary depending on both current trends and critical review.
- Concerning the previous point, if the number of pillars is fixed, it does not allow the inclusion of new dimensions that can still be developed from the concept of sustainability.
- It does not assess the developed SDGs inside the three pillars, therefore not including the possibility of connecting and relating to those purposes and concepts developed by the UN.

On the other hand, the advantages that can support the use of dimensioning related to the pillars of sustainability can be traced down to the ability to use the critical and reviewed literature related to the concept of sustainability. It is a structure that is widely accepted and already used as a framework while recognising the inherent limitations it brings.

3.1.2. Sustainable Development Goals (SDGs) and 5Ps

When considering a possible dimensioning related to the SDGs, the advantages that can be addressed are related to the use of more fixed and detailed concepts developed by an intergovernmental organisation. This permits the identification and pursuit of more precise goals in relation to the dimensions considered. However, this goal was developed for the broader concept of sustainability. Therefore, not all goals can be tracked down and be related to the topic of urban mobility; even when considering the broader impact when relating to the dimensions, some SDGs do not have a direct link possible. This can also have an impact on the overall purpose and results that can be obtained through the sustainable mobility index: with the broad categorisation and the presence of no direct link between some of the goals and the urban mobility topic, the focus of the index can be deceived and lost.

Another disadvantage of a structure entirely based on the SDGs is the different interpretations in which the SDGs are translated to the national and local levels. The concept of each goal was well defined at the UN level. However, the way those goals are achieved and their measurement are up to the different countries and states, which can lead to different indicators and calculation methodologies, as is happening inside some regions of the EU (European Committee of the Regions . Commission for Economic Policy. et al., 2019).

3.1.3. Proposed dimensioning structure

When deciding the dimensioning and structure for the sustainable mobility index, many of the previously mentioned considerations need to be considered. As discussed, all the mentioned structures have intrinsic advantages and disadvantages, with repercussions on how the results can be portrayed. Therefore, the following assessed structure does not want to be the ideal and perfect solution on the matter but rather an assessed and supported option that can intercept the new trends and thoughts while validating the work and literature developed during the years.

Key considerations that play a central role in determining the framework for the dimensioning can be summarised as follows:

- *The structure that the three pillars of sustainability has is often considered outdated, and the discussion and development of the structure posed by 5Ps of sustainability proves this last point.*
- *The broad and vast list of SDGs agreed upon and elaborated by the UN can be deceiving when applied to a specific topic such as urban mobility; as priorly assessed, a number of SDGs are involved with an active impact, and the SDG 11 plays a central role on the overall topic.*

A strategy that permits to connect and relate to these two main structures, the three pillars and the SDGs, is using the 5Ps. This classification using the 5Ps portrays an upper and less vast classification of the blueprint the 17 SDGs provide over the concept of sustainability and its multiple goals. The 5Ps classification can represent a more evident intention in expressing the close relations within the multiple SDGs and their contribution to these 5 vital concepts (Embrace Relief Foundation, 2023). Considering the specific topic that this thesis is aiming to work on, a further consideration that will be addressed is regarding the last two "Ps," namely "Peace" and "Partnership." These two concepts represent both pre-requisites and fundamental dimensions in which pursuing the overall goal of sustainable development, spanning over the other three "Ps". However, their representation with quantitative indicators can be challenging by unifying the two concepts together, the objective of elaborating indicators that can portray those two columns entirely and broadly can be intricate but could represent an added value as well to the sustainable mobility index.

This decision of compressing the last two 'Ps" into one category can be considered as a critical limitation that needs to be highlighted; this can, therefore, limit the full representation that the 5Ps want to pursue. A more exhaustive assessment of this limitation, with also the relation with the results that will be obtained with the application of the sustainable mobility index, will further be developed in the discussion chapter.

Therefore, the structure that will be used for the purposes of the sustainable mobility index can be represented as follows:

- ***People***
- ***Planet***
- ***Prosperity***
- ***Peace & Partnerships***

This framework permits to include both the already used structure of the three pillars of sustainability, combined with the more recently developed concept of the SDGs; the element and consideration of the concept of culture can be included inside the last dimension of 'Peace & Partnerships', providing a further added value when compared to the three pillars. The strong connections and relations between the pillars of sustainability are retained and present also in this framework. A closer classification of the SDGs into the 5Ps can avoid the disadvantage of having different goals and concepts that the overall SDGs portray while still retaining the blueprint of those.

3.2. Indicators selected

When considering the indicators that need to be developed inside the index, a review and assessment of the ones used inside the three examples portrayed in the literature review can be used as a starting point. It needs to be reflected upon and reviewed if those indicators can be included in the new sustainable mobility index, if the information they portray is still valid and valuable for the purposes that the new index aims to bring.

An analysis also needs to be carried out to check if the data used to calculate the indicators is available inside the databases searched. In the description of the indicators, the sources used are provided; a further and more profound assessment of the database and sources used will be carried out in chapter 3.2.1.

3.2.1. Existing Indicators

The indicators portrayed in the literature review chapter can help to identify the ones that will enter the new sustainable mobility index. Some of the variables and themes expressed by those indicators are central in calculating the performance of the sustainability of urban mobility. Therefore, the criterion chosen to assess their inclusion in the new sustainable mobility index will be represented by their relevance to the new sustainability index and especially in relation to its dimensional framework discussed in the previous section. This criterion takes also into account how the indicators contained in the priorly assessed index can be deemed beneficial in answering the research questions posed, as well as in pursuing the objectives stated.

Sources for this indicator were indicated inside their original indexes, but data was not always available as opensource. Therefore, a brief indication of the source used will be provided inside this section, while a more detailed assessment of the data collection will be discussed in the chapter 4.

The assessment of indicators will be done using the proposed dimensional structure identified in the previous section. This will allow us to analyse the adherence and ability to portray the Ps of sustainability and their concepts.

- **People**

Inside this dimension, the focus is on society and the sustainable development impacted by it. Therefore, the indicators inside this category should represent the social and human impact on urban mobility.

- ***Airport passengers*** from the Arcadis index.

  It represents the number of passengers at all the city's airports (an airport is considered in the same city system based on the ICAO airport code). Airport traffic reflects the ability to move and travel from a certain city, boosting social connection on both local, international, and global levels. Sources used reflect the one of the original index: statistical reports and documentation from the airport’s websites and companies.

  Units of measure: passengers/year.

  Type of variable: continuous.

- ***Share of accessible metro stations*** from the Arcadis index.

  This indicator measures the percentage of metro stations that are accessible to wheelchairs over the total of the metro network. This indicator supports the concept of accessibility for all people, boosting their quality of life. The sources used reflects the one in the original index: official local operators’ websites, reports or maps.

  Unit of measure: percentage.

  Type of variable: continuous.

- ***Share of accessible bus network*** from the Arcadis index.

  It represents the percentage of the bus stops and vehicles used that are accessible to wheelchairs. Also, in this case, the indicator supports the concept of accessibility for all people, boosting their quality of life. The notion and definition of an accessible bus, however, varies from one operator to the other; some consider accessible vehicles as full accessibility, while others also include the related infrastructure of the stops. Sources used are reflects the one in the original index: transport operators or tourism websites, providing information on the accessibility of the transit network.

  Unit of measure: percentage.

  Type of variable: continuous.

- ***Hours of metro operation*** from the Arcadis index.

  It represents the continuous number of hours on an average weekday when the metro transit system is open and in service. A greater number of hours in which the metro system is open allows for greater flexibility in the choice of travel for the users. Data sources used were the transit operators, official schedules, and tourism information and guides.

  Unit of measure: number of hours.

Type of variables: continuous.

- ***Population density*** from the IDTP index.

  It represents the population density of the selected cities. Urban areas with a balanced population density can support the city's sustainable growth. The value doesn't have to be the highest; it falls within a range that facilitates sustainable development (Salem, 2023). The main sources used were Statista and WorldPopulationReview; these sources, when compared to the ones of the original index, contains data on a more global level, opposed to the local scope of the indicator in the original index.

  Unit of measure: people/square kilometres.

  Type of variable: continuous.

- ***Customer satisfaction*** from the WBCSD index.

  It represents the satisfaction of the users of public transport; a higher value contributes to the general quality of life in urban areas. Elements that are recurring in the satisfaction factor portrayed in the different sources are service (more operation-related factors: headway, frequencies, opening hours), customer service, security, and accessibility. Calculations for customer satisfaction vary within each of the operators, but the overall aim previously described remains the same across all the findings. Compared to the original index, which used surveys as sources, the source used are mainly the documentation and reports available on local operators and transit agencies websites.

  Unit of measure: percentage.

  Type of variable: continuous.

- **<u>Planet</u>**

Inside this dimension, the focus is on the environmental impact and how sustainable development impacts it. Therefore, the indicators inside this category should represent the impact that urban mobility has on the overall environmental context.

- ***Congestion (increase in the overall time)*** from the Arcadis index.

  It is an estimation of dissatisfaction due to long commute times that assumes that dissatisfaction with commute times increases exponentially with each minute after a one-way commute time is longer than 25 minutes. An increase in the overall time spent in congestion has impacts on the overall sustainability of the travel itself, such as pollutant and noise emissions. The source used was the Numbeo Traffic (City) Index of 2023, using the same database source as the original index.

Unit of measure: combination between dissatisfaction and the increased travel time.

Type of variable: continuous.

- ***Air pollution related to traffic*** from the Arcadis index.

  Using as a source the Numbeo Traffic (City) Index of 2023, the following description is given: "*is an estimation of CO2 consumption due to traffic time.*" The degree of CO_2 emissions contributes to the environmental impact of urban mobility. Compared to the original index, the source used is a different database, which was based on values in the CDP Cities database.

  Unit of measure: grams of CO_2 emitted per return trip.

  Type of variable: continuous.

- ***Presence of Low Emission Zone (LEZ)*** from the Arcadis index.

  It is a binary indicator expressing the presence of Low-Emission-Zones (LEZ) in the selected locations. The presence of a LEZ impacts the pollution in terms of vehicle emissions. The main source to check the presence of LEZs is the UrbanAccessRegulation website, as well as local government websites; those sources are also the ones used in the original index.

  Unit of measure: 1 if LEZ is present, 0 else.

  Type of variable: binary.

- ***Modal split public transport (PT)*** from the Arcadis index.

  It represents the share of public transport in the modal repartition of trips in the selected locations. The use of PT when commuting and taking trips in urban areas can help in lowering the environmental impact compared to the use of more impacting modes such as the use of private cars. This parameter was also suggested as a possible indicator inside the WBCSD Index (World Business Council for Sustainable Development, 2015). The source used is different database from the original index, namely Numbeo, when compared to the EMTA database use inside the Arcadis index.

  Unit of measure: percentage.

  Type of variable: continuous.

- *Modal split cycling and walking* from the Arcadis index.

  It represents the sum of the percentages of the cycling and walking modes of transport in the selected locations. Those two modes represent the less impacting ones in terms of emissions in the modal split of a location. This parameter was also suggested as a possible indicator inside the WBCSD Index (World Business Council for Sustainable Development, 2015). The source used is different database from the original index, namely Numbeo, when compared to the EMTA database use inside the Arcadis index.

  Unit of measure: percentage.

  Type of variable: continuous.

- **Prosperity**

Inside this dimension, the focus is more on the economic and technological aspects and how sustainable development is impacted by those themes. Therefore, the indicators inside this category should represent urban mobility relations on those topics.

- ***Commuting travel time*** from the Arcadis index.

  Variable using as source the Numbeo database, with the following description: "Represents the average one-way transportation time required in minutes. It provides an indication of the time it takes to travel from one place to another within a city or region". The inclusion in the Prosperity dimensions resides in the idea that additional commuting time is less time to contribute to economic activity. The source database is the same one used inside the original index.

  Unit of measure: minutes.

  Type of variable: continuous.

- ***Average city expenditure on mobility*** from the Arcadis index.

  The variable indicates the share of the city budget spent on transport. Using the average value of 2% of the city budget used for transport on mobility investment, the value is calculated given the yearly budget of the city in 2023. The sources used are the yearly budget documents and reports from the local government. Those sources reflect also the one used in the original index.

  Unit of measure: euro.

  Type of variable: continuous.

- ***Price for monthly PT pass*** from the Arcadis index.

  The variable represents the average price for a monthly PT pass at the selected location. It refers to the price of regular monthly passes for public transport as a proportion of the average GDP of the city, with affordability being a key factor in resident's usage. The lower this proportion is, the more affordable it is to buy the pass, while higher values result in more finances required to acquire it. The source used was the Numbeo database., which was also the database used in the original index.

  Unit of measure: euro/average income*1000.

  Type of variable: continuous.

- ***Utilization of the transit system*** from the Arcadis index.

  This indicator wanted to represent the journeys by the inhabitants in the selected locations. A higher number of trips taken by transport recognises utilisation per capita. Higher usage also allows greater revenue capture from fares for a city. The sources used, local transport websites and documentation, reflects also the ones used in the original index.

  Unit of measure: journeys/million inhabitants.

  Type of variable: continuous.

3.2.2. Current mobility trends and new indicators.

Urban mobility is an ever-changing topic, heavily influenced by improvements in technologies, new social and economic policies, as well as cultural heritage. When looking into the impacts of pursuing sustainability, those can influence the indicators and their ability to portray current and future trends in the field. Some of those themes were already discussed and presented in the introduction to the thesis, as well as considered as a main limitation of the indexes portrayed in the literature review chapter.

The following points can represent some themes that are not entirely included inside the indicators previously described and assessed, therefore posing a possibility of including new indicators inside the dimensions of the sustainable mobility index; it includes a proposed indicator and its methodological details.

- *Autonomous vehicles (AV):* exploiting autonomous vehicles in transit lines provides different benefits to the overall concept of sustainability. In the case of automated metros, those benefits span the mobility system itself and its capacity, availability, and flexibility, as well as increased safety and better employability for the operators. Investment in this form of automation can bring long-term operational cost benefits compared to the conventional lines, as opposed to higher infrastructural and system costs (International Association of Public Transport, 2019).

- ***Presence of highest grade of automation transit system***

  This indicator is a binary variable indicating the presence of GoA4 (the highest level of automation) transit systems, respectively, using as the main source the 2018 report (latest available) of automated transit systems of the UITP. Supplementary information is also found on the websites of the technology suppliers (Alstom, Siemens, Hitachi Rail).

  Unit of measure: 1 if present, 0 if else.

  Type of variable: binary.

- ***Investment in highest grade of automation transit system***

  This indicator is a binary variable, indicating the investment into GoA4 (the highest level of automation) transit systems, respectively, using as the main source the 2018 report (latest available) of automated transit systems of the UITP. Supplementary information is also found on the websites of the technology suppliers (Alstom, Siemens, Hitachi Rail). The criteria consider new lines or upgrading existing ones, not the extensions of GoA4 systems already in operation.

  Unit of measure: 1 if present, 0 else.

  Type of variable: binary.

Both indicators described above will reside in the ***Prosperity*** dimension, taking as a central point in implementing automated systems the long-term benefits in operational costs.

- *Rise of micromobility*: this theme includes the use and availability of different forms of vehicles, such as bikes, scooters, and mopeds, also in their electrically powered version, in order to answer topics such as congestion, reducing greenhouse gas emissions and the last-mile transportation problem. Integrating this form of transportation with urban public transportation can help in tackling those issues, providing a sustainable alternative and making it a central element of support of a sustainable approach to urban mobility (Lang et al., 2022).

  - ***Availability of bike sharing***

    It's a variable representing the presence of zero, one or more bike-sharing services at the selected locations. The source used was BikeSharingWorldMap.

    Unit of measure: 0 if none, 1 if one service is present, and 2 if more than one service is present.

    Type of variable: multinominal.

- *Availability of electric scooters sharing*

  The variable indicates the presence of zero, one or more scooter services providing electric vehicles in the selected locations. The source used are the websites of the providers and companies active in the sharing scooter market, such as Lime and Scoot.

  Unit of measure: 0 if none, 1 if one service is present, and 2 if more than one service is present.

  Type of variable: multinominal.

Both indicators will reside inside the ***Planet*** dimension, given their overall contribution to the environmental impact of urban mobility.

- <u>*Development of intermodal applications*</u>: this theme effectively takes into account the evolving role that Mobility-as-a-Service (MaaS) can pose in supporting the achievement of sustainable goals (Vitetta, 2022), as well as the integration of different modes of transport to support inhabitants of urban areas and their mobility (Poliak et al., 2017).

  - ***City available on transport apps***

    This indicator, a binary variable, represents the presence of the transit system of the selected location in the Moovit app, a MaaS app that contains one of the largest pools of locations, as well as in Ciytymapper, another MaaS application active globally.

    Unit of measure: 0 if none, 1 if one service is present, and 2 if more than one service is present.

    Type of variable: multinominal.

  - ***City/regional comprehensive transport plan***

    Binary variable that expresses the presence of a comprehensive transport plan implementation for the transit system. The main sources were the local transport agencies.

    Unit of measure: 1 if present, 0 else.

    Type of variable: binary.

  - ***City/regional comprehensive transport tariff zone***

    Binary variable that expresses the presence of a comprehensive tariff zone for the transit system. The main sources were the local transport agencies.

    Unit of measure: 1 if present, 0 else.

Type of variable: binary.

Those indicators are effectively connected to the **Peace & Partnership** dimension, expressing especially the concept of both collaboration towards sustainable goals and integration of urban mobility with current technological trends.

- *Transition towards shared or pooled zero-emission vehicles*: this theme has a direct impact on the emissions related to vehicles. The use of shared and pooled services can help in reducing the overall impact of private car emissions (Amatuni et al., 2020), and the use of zero-emissions vehicles can further aid in achieving this goal.

    - ***Availability of electric vehicles (cars) in car sharing***

      It's a variable representing the availability of zero, one or more car-sharing providers using electric vehicles. The use of electric vehicles in car-sharing services has a direct impact on the emissions of pollutants in urban areas compared to the use of conventional vehicles. Sources used are the websites of car-sharing companies or local government websites that provide an overview of the service providers.

      Unit of measure: 0 if none, 1 if one service is present, and 2 if more than one service is present.

      Type of variable: multinominal.

Given the direct relation to emissions and environmental impact, this indicator will belong to the **Planet** dimension.

3.3. Dimensional framework selected

Inside this chapter, a comprehensive graphic and schematic representation of the dimensions and the included indicators will be provided, posing both the dimensional structure and the detailed framework that characterises the new sustainable mobility index.

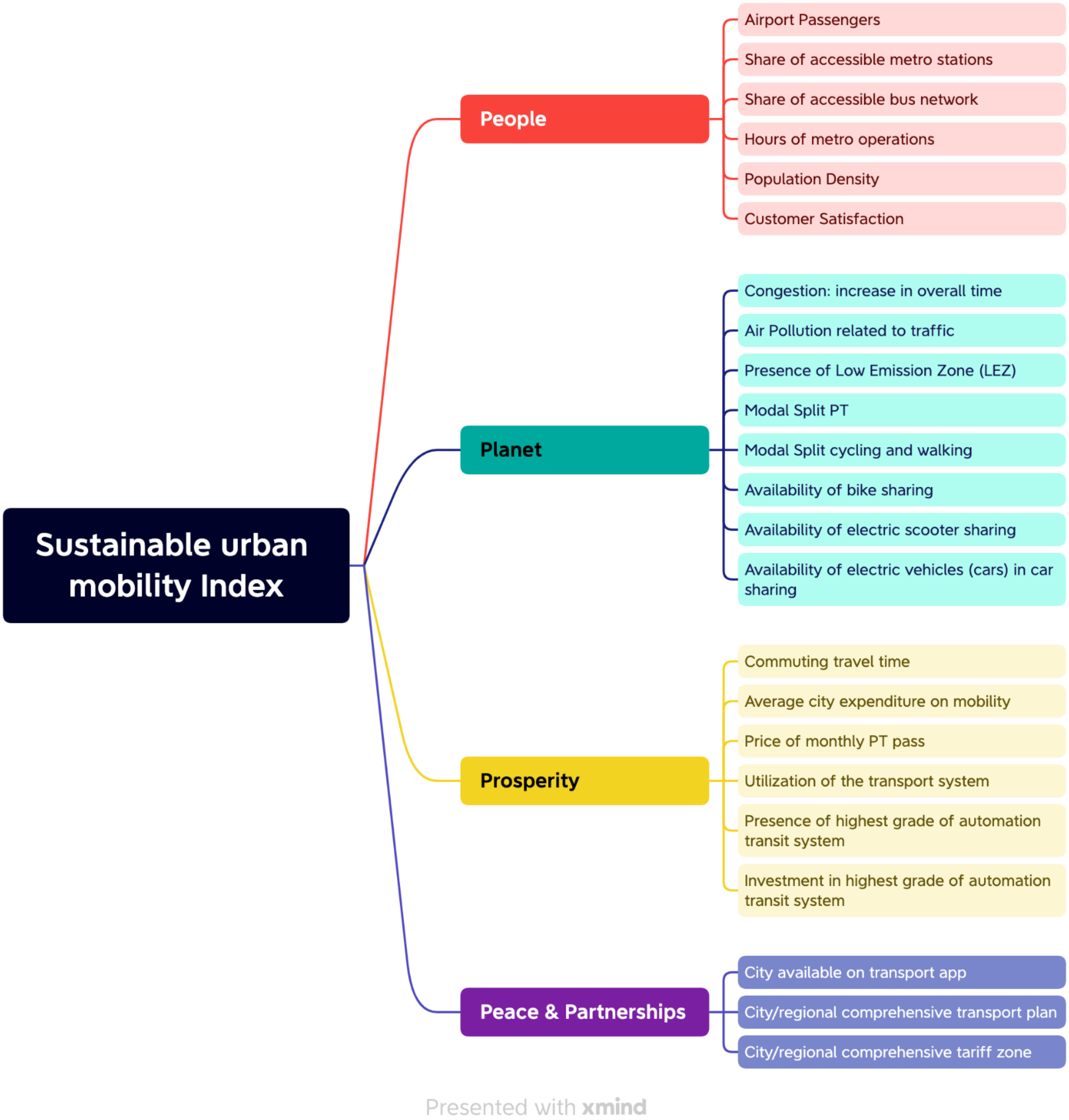

Figure 2 Schematic representation of the Index (own elaboration)

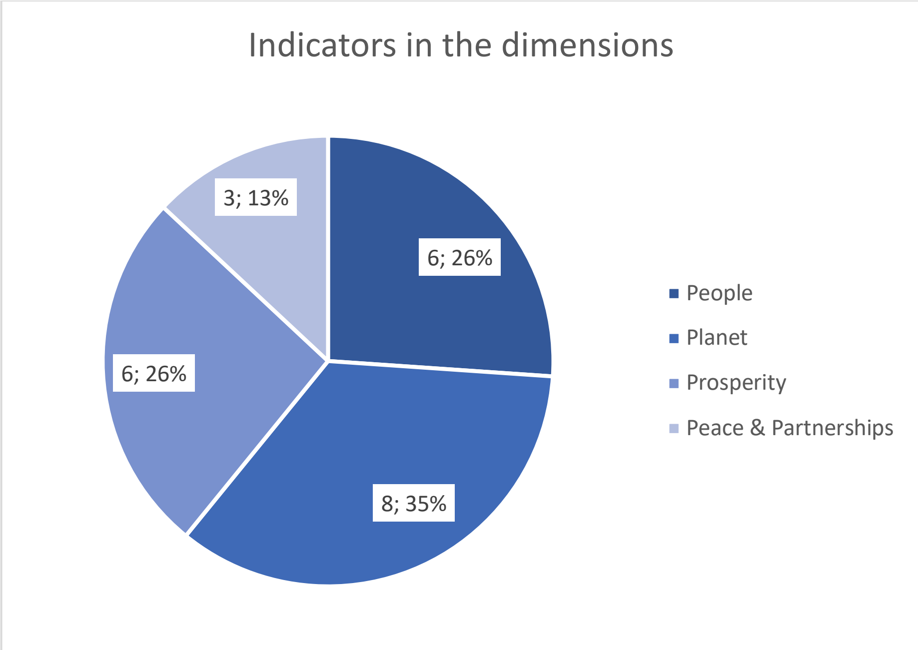

Figure 3 Share of the indicators in the dimensional framework (own elaboration)

Figure 3 shows both the absolute number of indicators inside the dimensional framework, as well as the share that each dimension has over the total set of indicators for the sustainable mobility index. The main observation that can be deducted is the relatively small number of indicators considered in the **Peace & Partnerships** dimensions, representing 13% of the total set of indicators. In comparison, the **Planet** dimension gathers around 35% of the total indicators, which, compared to the 26% of the **People** dimension, contributes to more than half the selected pool of variables.

3.3.1. Categorization of the indicators

Given the nature of the indicators described in the previous part of the chapters, as also mentioned in the description of the indicators, the following categories can be deducted and provided in order to proceed further with the analysis.

- *Binary*
- *Multinominal*
- *Continuous*

The following descriptive analysis can be deducted from the distribution of the categories in the indicators and inside the dimensional framework of the index.

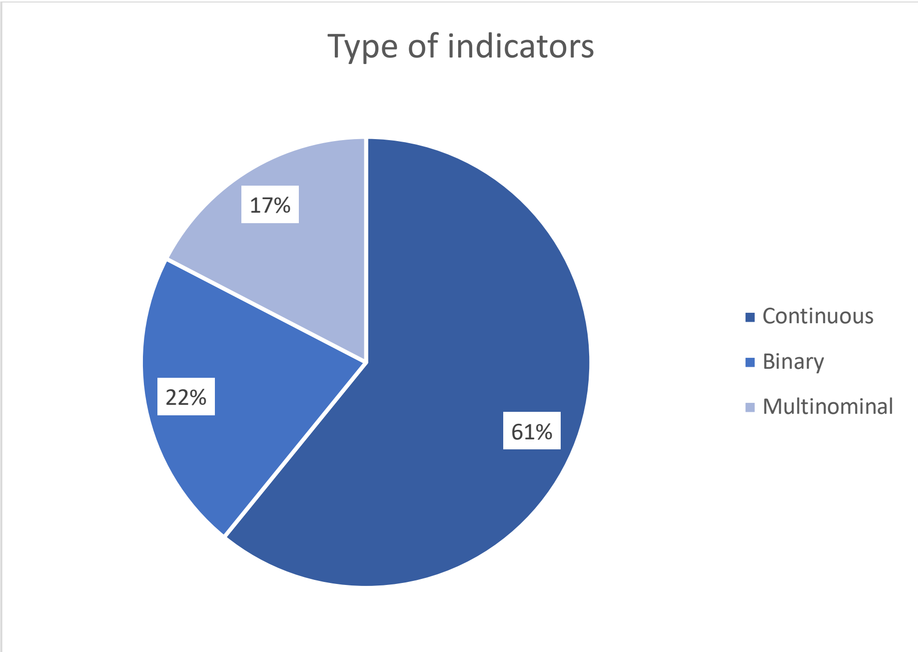

Figure 4 Type of indicators (own elaboration)

More than half of the indicators, 61% of the total set, are of the non-binary type, being expressed in various units of measurement; the rest of the indicator's type is split into 22% of the binary type and 17% of the multinominal type. A more detailed division of the types of indicators inside the dimensional framework can be visualised in the following graph:

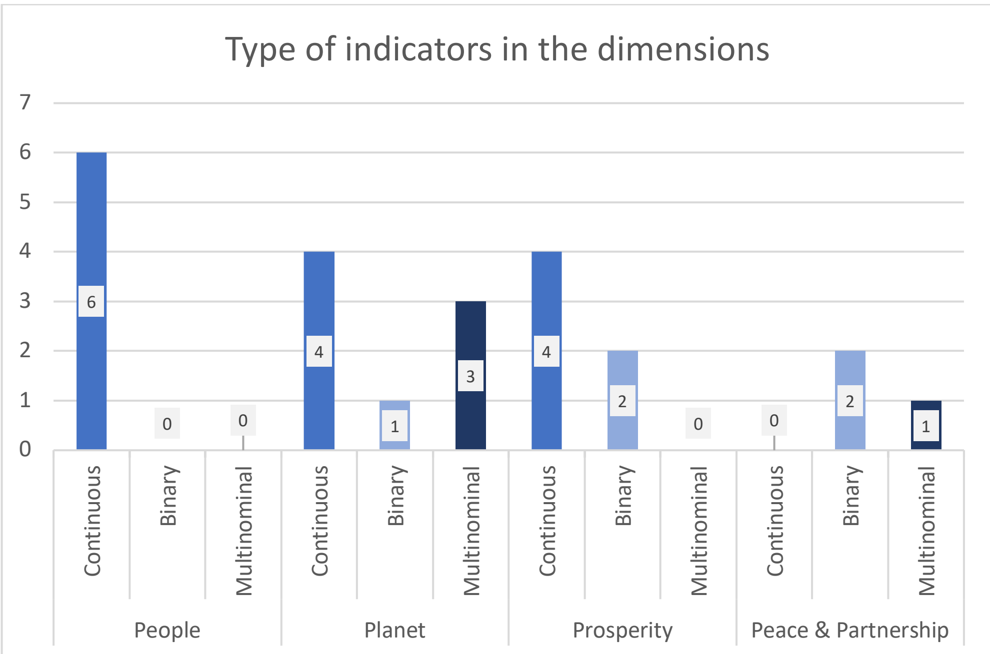

Figure 5 Type of indicators in the dimensions (own elaboration)

As represented, the distribution of the type of indicators is very different depending on the dimensions being considered:

- The **People** dimension is only formed by indicators of the *non-binary* type.
- The **Planet** dimension comprises all the indicator types.
- The **Prosperity** is composed of *non-binary* and *binary* indicators.
- The **Peace & Partnerships** indicators belong to the *binary* and *multinominal* types.

3.4. Analysis and selection of the cities

The purpose of this chapter is to provide an assessment and analysis of the selection of the cities in which the sustainable mobility index will be applied, and the results calculated.

The choice of the cities will also determine the results that will be obtained, in which recommendations in terms of suggestions will be provided to those locations that could improve their performance over the four dimensions and on an overall level.

3.4.1. Assessment and methodology for the choice

Choosing the pool of cities to which the new sustainable mobility index will be applied needs to follow a methodology based on factors that provide a solid backbone and reasoning in regard as well to the results that will be obtained and analysed.

The selection of the cities will be, therefore, based on the importance those cities have in certain fields and factors that permit to determine a suitable set of locations. In order to distinguish and differentiate the list of cities in the selected factors, the methodology chosen will be the following: if a city belongs to more than one field, it will be considered in the pool of the selected cities. There is no restriction in terms of geographical location for selecting the cities, therefore putting the scale of selection on the global level.

The following factors are the ones that will determine the set of selected cities.

- **Touristic Destination**: represents the attractiveness that the city poses on the international scenery, both for business and leisure. The connection between tourism and mobility is intrinsic, with the touristic transportation providing an unavoidable impact on all dimensions of sustainability. Tourism can be considered a driver in changing urban mobility towards more sustainable forms, promoting alternative ways to live in the city (La Rocca, 2015). The following table represents the top 20 cities of Euromonitor’s Top 100 City Destination Index, an annual index reporting the top global cities based on the dimensions of tourism, sustainability, and economic performance (Euromonitor, 2023).

Table 6 Top 20s of Euromonitor's Top 100 CDI (Euromonitor, 2023)

Position	**City**	**Country**	**Position**	**City**	**Country**
1	Paris	*France*	11	Singapore	*Singapore*
2	Dubai	*UAE*	12	Munich	*Germany*
3	Madrid	*Spain*	13	Milan	*Italy*
4	Tokyo	*Japan*	14	Seoul	*South Korea*
5	Amsterdam	*The Netherlands*	15	Dublin	*Ireland*
6	Berlin	*Germany*	16	Osaka	*Japan*
7	Rome	*Italy*	17	Hong Kong	*Hong Kong SAR*
8	New York	*USA*	18	Vienna	*Austria*
9	Barcelona	*Spain*	19	Los Angeles	*USA*
10	London	*United Kingdom*	20	Lisbon	*Portugal*

- **Influence on the national and international level**: the ability of a city to compete in attracting people, capital, and enterprises in a world scenario, thereby boosting the need for robust and sustainable forms of transport and urban mobility (Yamato et al., 2023). The Global Power City Index (GPCI) provides a list of 48 cities that are deemed as significant attractors on a worldwide dimension (Yamato et al., 2023); a comprehensive list and ranking of those cities is included in Appendix 1.

  As an additional source, providing a different interpretation of the concept of global cities, focusing on the relations and connectivity in a worldwide context (*GaWC - What We Are About: Mission Statements*, n.d.); the comprehensive list of the alpha cities, the highest category, is included in Appendix 2.

- **Projected megacities**: a critical factor in achieving sustainable development of the urban context passes through its mobility. When considering the critical role megacities will have in the foreseeable and long future, urban mobility will be a central element in pursuing those goals (Pojani & Stead, 2015). The following table represents a 2016 projection for the top 10 megacities in 2030:

Table 7 Top 10 megacities in 2030 (UNDESA, 2016)

Position	**City**	**Country**	**Position**	**City**	**Country**
1	Tokyo	*Japan*	6	Dhaka	*Bangladesh*
2	Delhi	*India*	7	Karachi	*Pakistan*
3	Shanghai	*China*	8	Cairo	*Egypt*
4	Mumbai	*India*	9	Lagos	*Nigeria*
5	Beijing	*China*	10	Mexico City	*Mexico*

3.4.2. Chosen cities

A total number of 41 cities were chosen given the variables and factors assessed in the previous section and are reported in the following table.

Table 8 Cities chosen from variables (own elaboration)

Paris	Barcelona	Hong Kong	Zurich	Istanbul	Buenos Aires
Dubai	London	Los Angeles	Frankfurt	Moscow	Jakarta
Madrid	Singapore	Lisbon	Toronto	Taipei	Johannesburg
Tokyo	Munich	Melbourne	Brussels	Bangkok	Cairo
Amsterdam	Milan	Sydney	Chicago	Sao Paulo	Mumbai
Berlin	Dublin	Shanghai	San Francisco	Kuala Lumpur	Seoul
New York	Osaka	Stockholm	Boston	Mexico City	

In Appendix 3 a table is provided with the full list of cities analysed, the dimensions considered and the belonging of each location on the factors previously assessed.

The following descriptive data can be deducted in terms of the geographical distribution of the cities chosen based on the previous considerations:

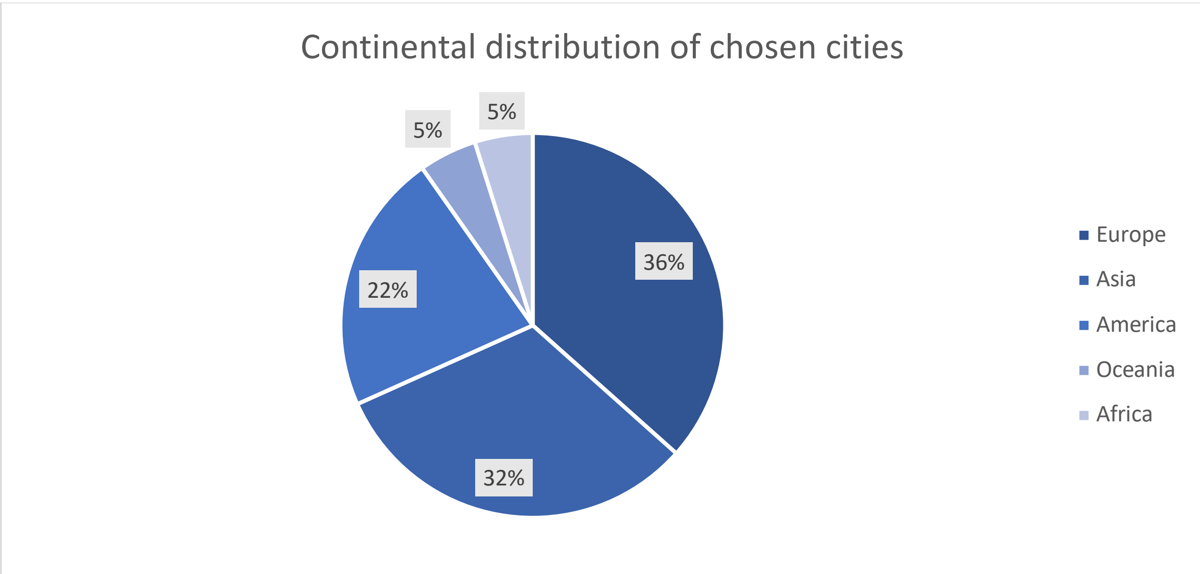

Figure 6 Continental distribution of chosen cities I (own elaboration)

As shown in Figure 6, the majority of the cities are located in Europe and Asia, with the two continents accounting for around 68% of the total selected cities; only a minority of the locations, around 10% in total, is associated with the continents of Oceania and Africa. Subsequently, considering these numbers just assessed, four more cities were added to the pool of the selected ones:

- **Perth** and **Auckland** for the *Oceanian* continent. Those cities represent respectively the fourth and the seventh biggest cities of the Oceanian continent, with Auckland being the first non-Australian city in the ranking (World Population Review, 2024).

- **Lagos** and **Nairobi** for the *African* continent. Lagos appears in the set of cities of one of the variables considered; the city of Nairobi in Kenya is also considered to be a projected megacity in the future (Statista, 2023).

The complete list of cities chosen for the indicators sum up to **45**, here listed below and followed by a graphical representation of the final distribution around the continents.

Table 9 Pool of cities chosen for the Index (own elaboration)

Amsterdam	Chicago	Lagos	Mumbai	Seoul
Auckland	Dubai	Lisbon	Munich	Shanghai
Bangkok	Dublin	London	Nairobi	Singapore
Barcelona	Frankfurt	Los Angeles	New York	Stockholm
Berlin	Hong Kong	Madrid	Osaka	Sydney
Boston	Istanbul	Melbourne	Paris	Taipei
Brussels	Jakarta	Mexico City	Perth	Tokyo
Buenos Aires	Johannesburg	Milan	San Francisco	Toronto
Cairo	Kuala Lumpur	Moscow	Sao Paulo	Zurich

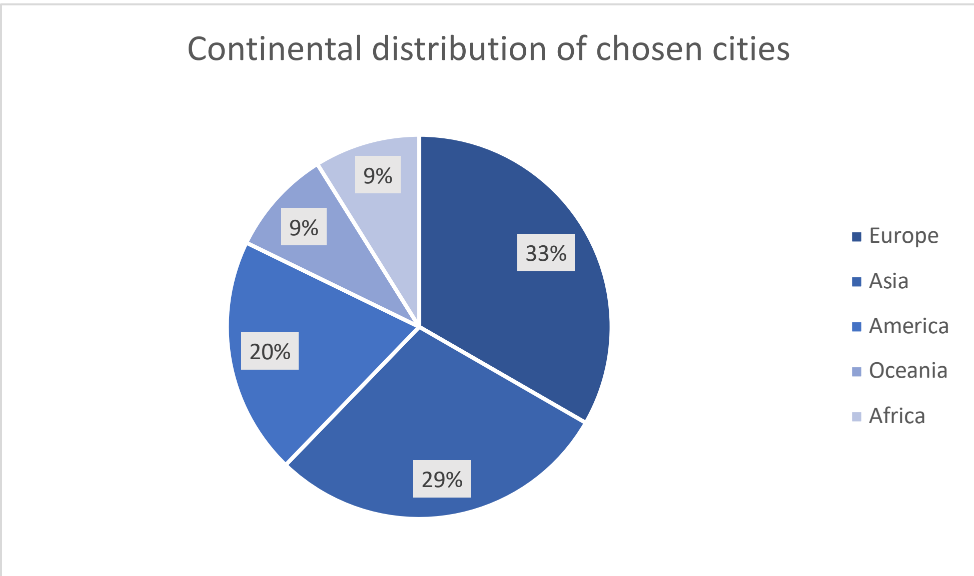

Figure 7 Continental distribution of chosen cities II (own elaboration)

4. Data collection

This chapter will focus on the methodology and assessment of the data collection for the indicators. Those steps are necessary in order to further proceed toward obtaining an overall comprehensive index which will represent the sustainability of urban mobility of the selected cities, using the dimensional framework and indicators previously assessed.

Moreover, at the end of the data collection, further evaluation and consequent actions could be taken prior to the calculation of the performance in light of possible findings during the data collection step.

4.1. Database sources

The values and information to which the indicators are related can be found across different types of sources, such as open data portals, specialised thematic reports and publications, or inside websites and documentation of the authorities responsible for monitoring those variables and theme.

In order to attribute a score to each city for each indicator, different sources and databases need to be consulted. For each dimension the sources used for each indicator are assessed, with also a focus on eventual missing data.

4.1.1. People

- **Airport Passengers**

  The main sources used are the annual and monthly reports, the latest providing the cumulative aggregated data of the whole year, shared by airport companies. The data used refers to the year 2023. In the case of *Nairobi* and *Lagos* airports, the latest available date is 2022; therefore, the values for those two locations are from that year. Data was available for **42** out of 45 selected locations, with missing data for the cities of *Shanghai*, *Toronto* and *Moscow*.

- **Share of accessible metro stations**

  The main sources used are the CityTransitData database of the UITP, as well as the official websites of the transit operators of each location. Some of the selected locations for the index do not possess a metro network, namely *Melbourne*, *Zurich*, *Dublin*, *Johannesburg*, *Auckland*, *Perth*, *Lagos* and *Nairobi*; the lack of data for those cities is therefore not considered for this indicator, as a missing value. Data was available for **33** out of 37 locations possessing a metro network, with missing data from only the Asian cities of *Bangkok*, *Kuala Lumpur*, *Taipei,* and *Seoul*.

- **Share of accessible bus network**

  The main sources are the local transit operators' websites and reports, as well as related governmental and local authorities' websites. Data was available for only **27** of the selected 45 locations.

- **Hours of metro operations**

  The main sources are the local transit operators' websites, which indicate either the time of operations or the official timetables, as well as related governmental and local authorities' websites, inside tourist information pages. Some of the selected locations for the index do not possess a metro network, namely *Melbourne*, *Zurich*, *Dublin*, *Johannesburg*, *Auckland*, *Perth*, *Lagos* and *Nairobi*; the lack of data for those cities is therefore not considered for this indicator, as a missing value. Data was available for all **37** of the selected 37 locations possessing a metro network.

- **Population density**

  The main sources are the databases of *Statista* and *WorldPopulationReview*; in some cases, more precise local sources were used for those locations not included in the mentioned databases. Data was available for all **45** of the selected cities.

- **Customer Satisfaction**

  The main sources used are the reports and reviews from either the local transit agencies or the responsible local authorities' departments. Data was available for **33** of the 45 selected cities.

4.1.2. Planet

- **Congestion: increase in the overall travel time**

  The source used is the *Numbeo Traffic City Index 2023* of the Numbeo database portal. Data was available for **44** out of the 45 selected locations, with only the value from the city of *Osaka* missing.

- **Air pollution related to traffic**

  The source used is the *Numbeo Traffic City Index 2023* of the Numbeo database portal. Data was available for **44** out of the 45 selected locations, with only the value from the city of *Osaka* missing.

- **Presence of Low Emission Zone (LEZ)**

  The sources used are the portal of *UrbanAccessRegulation*, as well as more precise information contained in the pertinent pages of local authorities' departments responsible for the topic. Information was available for **43** out of the 45 pools of cities, with data not found for the locations of *Shanghai* and *Taipei*.

- **Modal split PT**

  The source used is the *Numbeo* database, containing information related to the local modal split of transport for the locations. All **45** cities had data available.

- **Modal split cycling and walking**

  The source used is the *Numbeo* database, containing information related to the local modal split of transport for the locations. All **45** cities had data available.

- **Availability of bike sharing**

  The source used is the portal *BikeSharingWorldMap*, containing open data on bike-sharing services across the globe. Data was available for all **45** locations.

- **Availability of electric scooter sharing**

  The sources used are the different providers and company websites, such as *CityScoot*, *Lift*, *Lime,* and *Bolt*, in which the list of the cities and locations is provided. Data was available for all **45** cities.

- **Availability of electric vehicles in car-sharing**

  The sources used are the different providers and company websites, such as *ShareNow*, *Ubeeqo*, *Free2Move* and *Zipcar*, in which the list of the cities and locations is provided. In certain locations, an overview of the sharing operators providing electric vehicles is given from the municipality's or local authorities' websites. Data was available for **44** out of 45 cities, with the only missing data being from *Moscow*.

4.1.3. Prosperity

- **Commuting travel time**

The source used is the *Numbeo* database, containing information related to the average time of transportation trips for the locations. All **45** cities had data available.

- **Average city expenditure on mobility**

The sources used are the local reports and publications in terms of budgeting and financing of the city budget and expenses. Data was found for **38** out of the 45 selected cities.

- **Price of monthly PT pass**

The source used is the *Numbeo* database, containing information related to the prices of public transport monthly passes for the locations. All **45** cities had data available.

- **Utilization of transportation systems**

The sources used are the portal of the CityTransitData of the UITP, as well as annual reports of the local transit operators containing the pertinent data. Values were found for **35** out of the 45 selected cities.

- **Presence of highest grade of automation transit system**

The sources used are the websites of the companies responsible and implementing the automation technology, such as Alstom, Siemens, Hitachi, and Thales, while also referring to the UITP website section on automated metro. Values were found for **45** out of the 45 selected cities.

- **Investment in highest grade of automation transit system**

The sources used are the websites of the companies responsible and implementing the automation technology, such as Alstom, Siemens, Hitachi, and Thales, while also referring to the UITP website section on automated metro. Values were found for **45** out of the 45 selected cities.

4.1.4. Peace & Partnership

- **City available on transportation apps**

The sources used are the websites of the two applications considered for the indicators, Moovit and Citymapper, which contain the list of cities and regions in which their services are available. Data was available for all **45** selected locations.

- **City/regional comprehensive transport plan**

The sources used are the local and municipal authorities and their respective departments responsible for the topic in question. Data was available for **42** out of the 45 cities, with missing information for the locations of *Bangkok*, *Cairo*, and *Seoul*.

- **City/regional comprehensive transport tariff zone**

The sources used are the local and municipal authorities and their respective departments responsible for the topic in question. Data was available for **43** out of the 45 cities, with missing information for the locations of *Bangkok* and *Sao Paulo*.

4.2. Descriptive statistics

In terms of available data, a distinction can be made between the values available for the locations and the values available for the indicators themselves.

For the locations, all **45** cities have more than 75% of the data available across all 23 selected indicators. Moreover, **36** locations have more than 90% of the data available, of which **22** cities possess the full set of information across all indicators. In summary, **20%** of the cities possess more than 75% of the data across the chosen indicators, **31%** of the cities possess more than 90% of the data, and the remaining **49%** possess all the data across the selected indicators. Therefore, the following graph can summarise the considerations on the availability of data for the selected pool of cities.

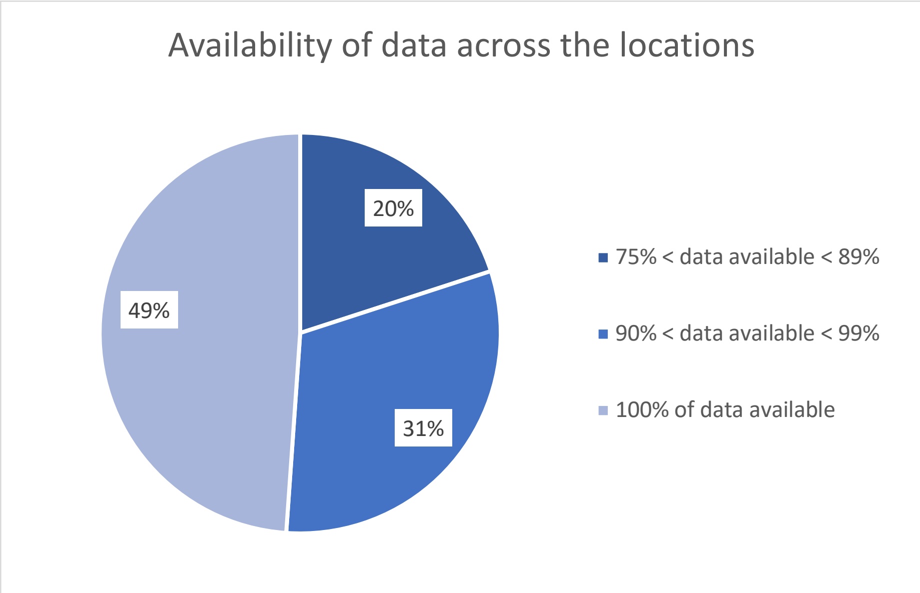

Figure 8 Availability of data across the locations (own elaboration)

For the indicators, the situation after the data collection is the following:

- 2 indicators possess less than 75% of the data available; those indicators are the *Share of Accessible bus network and Customer Satisfaction*, both belonging to the *People* dimension.
- 2 indicators possess more than 75% but less than 90% of the data available: those indicators being the *Average city expenditure on mobility* and the *Utilization of public transport*, both belonging to the *Prosperity* dimension.
- The remaining 19 indicators all possess more than 90% of the data available, 14 of which possess the full set of data across all the selected locations.

The information just assessed can then be visualised in the following graph.

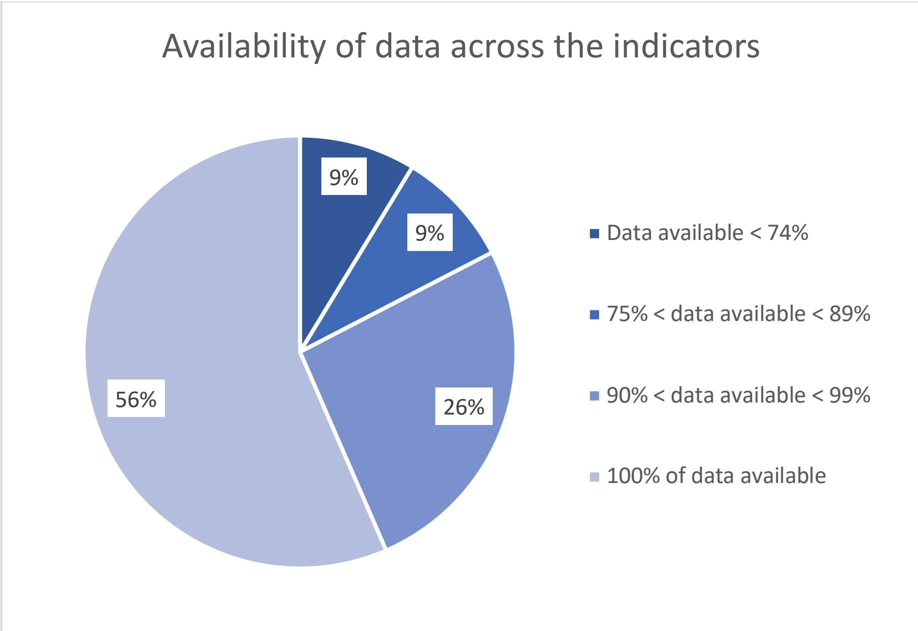

Figure 9 Availability of data across the indicators (own elaboration)

4.3. Assessment of the data collection

Given the considerations just mentioned in the previous chapter, the following consequences can be assessed:

- Overall, the data collection was able to cover most of the values for each indicator in each city. Most of the missing data, in terms of geographical distribution, comes mostly from Asian and African cities.
- Four indicators possess less than 90% of the data available, impacting less than 20% of the total sum of the indicators chosen. Those indicators are the *Share of Accessible bus network* and *Customer Satisfaction* of the People dimensions, the *Average city expenditure on mobility* and the *Utilization of public transport*, both belonging to the *Prosperity* dimension.

In terms of calculation for the performance, following these considerations, the four indicators described will not be used for the calculation of the performance of the sustainability mobility index. The set of the cities will remain the same, given the availability of more than three quarters of data across all the selected locations. The indicators not used in the analysis will be included in a further assessment of the limitations and impact of the calculated performances in order to analyse their contribution in case of their inclusion.

5. Methodology and Application

In this chapter, the methodology used to construct and calculate the scores for the selected cities is provided and assessed. A first layover of the intended objectives in terms of calculations is provided, followed by a deeper and more detailed assessment of the methodology used and analytical steps followed.

As previously assessed, the realization of a composite index can help support the gap between the policies and plans for the application of practical implementations of sustainable mobility. The use of this tool has been supporting the development of strategies and the diffusion of sustainable urban mobility options in different contexts, both on the geographical, economic, and cultural differences and factors (Morfoulaki & Papathanasiou, 2021 and Miranda, 2012). Indexes have been chosen as the best method also in supranational institution such as the EU, in order to create the strategies and solution for local policies: the use of indicators can permit to benchmark different cities and comparing the performances obtained, to help to communicate with both stakeholders and general public (Rupprecht Consult, 2019).

In regard of this thesis, the main objectives in terms of numerical results are the obtainment of two sets of scores for each city:

- First, a ***dimensional score*** for each of the four dimensions used in the index. A total of four scores will be computed for each of the cities, which will represent the overall performance obtained by the cities in the dimensional framework of the index.

- An ***overall score*** that represents the overall performance of each city over the concept of sustainable mobility based on the dimensional framework that composes it.

Those scores will allow to both assess and interpret the results obtained and provide more precise recommendations to those cities that want to improve the score in certain dimensions. The possibility to benchmark cities with each other will enable to highlight the best-in-class performing cities, to whom the worst performing locations can learn in order to improve their sustainability.

Nardo et al. (2008), in the **Handbook in Constructing Composite Indicators**, provide an extensive overview and analysis of the steps to follow to construct a composite indicator or index (Nardo et al., 2008). This handbook is used as a reference for the methodological steps taken to build a composite index in other academic works such as (Hermans et al., 2009 and Gan et al., 2017). Using this handbook as a reference, the different steps and recommendations will be included in the following assessment of the index methodology. Precise and more step-related support is provided in order to further expand the analysis regarding the construction of the index.

In the next sections the precise methodology used will be explained and provided.

5.1. Step 1: Developing a theoretical framework and selecting the variables

This first step consists of the development and assessment of the concept of the composite index, as well as the determination of the sub-groups that should be represented by individual indicators; it also includes the selection criteria for the indicators themselves that should be included in the index. Moreover, it also has the objective to check the quality of the available indicators and the data contained in them (Nardo et al., 2008).

In this step, the main objective is to check the quality of the available indicators and the data contained in them. Indicators in transport sustainability related indexes, and the variables used inside those, should follow the following principles (Litman, 2007):

- *Comprehensiveness*: reflecting both the different dimensions of sustainability and the transport activities.
- *Data quality*: ensuring accurate and consistent information.
- *Comparable*: clearly defined indicators to perform comparison along different dimensions and factors.
- *Easiness to understand*: affect the usefulness for support and validate decision-making processes and communication to the general public.
- *Accessibility and transparency*: all details should be available to all stakeholders.

This also includes the assessment of strengths and weaknesses that each indicator can bring into the index and making sure that the variables used match and contribute to the intended composite indicator. Engagement and involvement of experts and stakeholders can support the evaluation of the indicators in the context of application. Moreover, eventual proxy variables can be used in case the data available is scarce (Nardo et al., 2008).

5.1.1. Application

This step was covered in Chapter 3 of the thesis, where the dimensional framework and potential indicators from a theoretical perspective are discussed. This included existing indicators as well as new ones reflecting current mobility trends. The key findings from that chapter are briefly presented here.

When looking at the literature available, the main findings concerning the dimensional framework were that a dimensioning based on the 5Ps of sustainability can adequately support and overcome the limitations of the three pillars of sustainability and result in a more manageable structural framework. In order to better handle the quantitative nature of the index, the dimensional framework selected is set to 4 dimensions, by unifying two of the Ps of sustainability. Regarding the indexes analysed, the main limitation found was the lack of indicators related to current and future trends with respect to urban mobility. The actions taken to deal with this consideration was the proper inclusion of multiple indicators across all dimensions in order to have available results to evaluate the performances of the selected locations also on these themes.

5.2. Step 2: Data processing

The data needs to be analysed and assessed in order to construct the composite indicator, and this step helps in processing and providing an understanding of the subsequent implications in methodological choices in the further construction of the index (Munda & Nardo, 2005). It consists of performing preliminary analysis of the data obtained, focusing on the singular indicators as well as across the different indicators. ***Descriptive statistics*** can help in performing this preliminary analysis in the context of the singular indicators, while the ***correlation*** between the indicators can be performed to check if it is statistically significant, using the ANOVA test (Abeyasekera, 2003). Inside the application section of the methodology, the results of the correlation analysis are provided.

When data is collected, not always all the sources provide a full set of values and information for all indicators involved. Some data might be missing from the dataset considered; there are three types of missing data, here summarized (Nardo et al., 2008):

- *Missing completely at random* (**MCAR**): missing values do not depend on the variable of interest or any other observed variable in the dataset.
- *Missing at random* (**MAR**): missing values do not depend on the variable of interest, but they are conditional on other variables in the data set.
- *Not missing at random* (**NMAR**): missing values depend on the values themselves.

After the categorization of the missing data, different methods can be used to input and complete the dataset. Those methods include (Nardo et al., 2008):

- *Case deletion*: consists of omitting the missing data from the analysis.
- *Single imputation*: uses statistical methods such as the use of average/median/mode substitution, regression imputation, etc., to estimate the missing values.
- *Multiple imputations:* uses statistical methods such as the *Markov Chain Monte Carlo* algorithm to estimate the missing values.

It is important to notice that in the case of imputation, the assumptions used to support the imputation, including using the existing data, can influence the input results.

5.2.1. Application

Regarding data collection, most of the data was available for all indicators and cities selected, although some missing data was present, especially in geographical locations situated in Africa and Asia. In terms of available data, only 4 indicators possess less than 90% of the data available. Those indicators are:

- *Share of Accessible bus network* (People dimension)
- *Customer Satisfaction* (People dimension)
- *Average city expenditure on mobility* (Prosperity dimension)
- *Utilization of public transport* (Prosperity dimension)

Those four indicators are not considered in the calculation of the index for the selected locations.

In the following table, a summary of descriptive statistical variables is reported for the indicators of the *continuous* variable type.

Table 10 Descriptive statistics of the indicators data (own elaboration)

Indicator	Unit of measurement	Average	Std. Deviation	MIN	MAX
Share of accessible metro stations	Percentage (on 1)	0.8	0.26679	0.106	1
Airport Passengers	passengers/year	46240665	27392747	6526034	144,200,000
Hours of Metro Operation	number of hours per day	19.27027	1.51833	17	24
Population density	people/square kilometres	8856.776	10943.57	295.5	73000
Congestion: increase in the overall travel time	combination between dissatisfaction and the increased travel time	3942.493	5021.058	26.1	28003.2
Air Pollution related to traffic	grams of CO2 emitted per return trip	5430.643	3112.748	1089.3	15336.4
Modal split PT	Percentage (on 1)	0.30982	0.15120	0.01	0.634
Modal split cycling and walking	percentage (on 1)	0.21122	0.11484	0.01	0.596
Commuting travel time	Minutes	42.75711	9.04680	24.37	67.42
Price of monthly PT pass	euro/avg. income * 1000	1.07925	0.85835	0.278404	4.566

Next, a correlation analysis among the indicators is assessed to determine whether there is a significant positive or negative linear relationship between them. The results are shown in table 11, with the subsequent level of the p-value obtained through the ANOVA test of the regression analysis on the indicators involved.

Table 11 Correlation analysis (own elaboration)

Indicators		Correlation	p-value
Air Pollution related to traffic	Congestion: increase in the overall travel time	0.565	*6.24E-05*
Presence of Low-Emission-Zone (LEZ)	Air Pollution related to traffic	-0.657	*2.25E-06*
Modal split PT	Air Pollution related to traffic	-0.750	*4.62E-09*
Modal split cycling and walking	Air Pollution related to traffic	-0.728	*2.06E-08*
Modal split cycling and walking	Presence of Low-Emission-Zone (LEZ)	0.539	*1.88E-04*
Availability of bike sharing	Modal split cycling and walking	0.545	*1.07E-04*
Availability of electric vehicles in car sharing	Air Pollution related to traffic	-0.575	*5.49E-05*
Availability of electric vehicles in car sharing	Presence of Low-Emission-Zone (LEZ)	0.642	*4.58E-06*
Availability of electric vehicles in car sharing	Modal split cycling and walking	0.577	*4.08E-05*
Availability of electric vehicles in car sharing	Availability of electric scooter sharing	0.555	*9.10E-05*
Commuting travel time	Congestion: increase in the overall travel time	0.822	*7.60E-12*
Commuting travel time	Air Pollution related to traffic	0.630	*4.56E-06*
Commuting travel time	Presence of Low-Emission-Zone (LEZ)	-0.517	*3.80E-04*
Commuting travel time	Modal split cycling and walking	-0.656	*9.50E-07*
Commuting travel time	Availability of electric vehicles in car sharing	-0.519	*3.00E-04*

This analysis shows that there are correlations between some of the variables, both positive and negative. The correlation those variables have between each other is due to both contextual and intrinsic factors that provide grounds for effects to each other measurements. The causes and impacts of these effects are certainly ground for further research and study but are out of the objectives posed for this thesis.

An example of a positive correlation found between the indicators *Availability of bike sharing* and *Modal split cycling and walking* can be explained by the direct contribution that the services of bike sharing provide to the citizens and population of urban areas. Those services provide different aspects to support the use of this mode of transport, such as the availability of stations across the city and the ability to make one-way trips if necessary, which help, consequently, in the positive increase of the share of modal split related to cycling (Teixeira et al., 2023). Another example of a positive correlation between indicators can be given by the *Commuting travel time* and *Congestion: increase in the overall travel time* indicators. Those two indicators are surely connected, with the first expressing the impact on the economic losses due to time spent commuting, while the second expresses a combination of time spent and dissatisfaction with congestion situations, which have implications on the environment impacts of congestion itself (Chin & Rahman, 2011). The positive correlation between the two variables can be explained as an increase in travel time while commuting could result in an increase of time loss, and subsequent dissatisfaction, of congestion (Higgins et al., 2018).

On the other hand, an example of a negative correlation is portrayed by the indicators *Availability of electric vehicles in car sharing* and *Air Pollution related to traffic*. The influence that electric vehicles have on the air pollution of communities can be positive, therefore quantified in a reduction of the overall air pollution related to traffic (Hewitt, 2023). This effect can also be maximised when electric vehicles are associated to car sharing services, as opposed to privately owned vehicles (Jung & Koo, 2018).

Those correlations, as the examples portray, are provided to have transparency and more information on the data processed for the index. The correlation values show that the indicators involved tend to fit the trendline, and the smaller the p-value, the stronger this correlation is between the indicators. A correlation does not necessarily indicate a causal relationship between the variables, but it provides insights on how the indicators influence and relate to each other (Chestnut & Mason, 2019). Further research on the index, as will be discussed in chapter 8, can include deeper statistical studies on the correlation between the indicators, also in dependence of the geographic, economic, social, and environmental context of application.

In regard to the missing data from the other indicators, the type of missing data can be considered as NMAR, since the values obtained for the whole set of data belong to secondary data collection, depending on the values themselves. The method chosen to deal with those missing values is *case deletion*, omitting the missing data from the analysis; as assessed in chapter 5.2, the consequences of the missing data from certain indicators influenced the inclusion of said indicators in the calculation of the scores. This approach helps prevent bias from both external factors and the data themselves, unlike when using imputation methods to fill in missing values (Nardo et al., 2008).

5.3. Step 3: Normalisation of data

The normalization of data is a key process in order to operate and assess the calculations with sets of data using different measurement units. There are a number of methods in order to deal with this issue (Nardo et al., 2008):

- *Ranking*: is the simplest normalization technique, which does not depend on the presence of outliers and allows to evaluate the performance of all the data.

- *Standardization*: it converts the values of the indicators into a Normal distribution $N(\mu = 0;\ \sigma = 1)$ with a mean equal to 0 and a standard deviation equal to 1. The impact of extreme outlier values greatly affects this method, which can affect the composite indicator score.

- *Re-scaling*: the method normalizes the indicator in order to have values in the range [0;1]; extreme values and outliers can distort the resulting composite indicator.

- *Distance to a reference*: it measures the relative position of the indicator from a reference point, such as a target or a limit value.

- *Categorical scale*: this method assigns a score to the indicator based on assessed and fixed categories, often based on the percentile of the distribution of the data itself.

- *Mean indicators*: the method provides a score based on the distance of the data from the mean, such as being around, below, or above the mean of the data. This method is not affected by outliers, but the arbitrariness of the threshold level and omission of absolute-level information can be considered a disadvantage.

The method chosen for normalizing the data for the sustainable mobility index consists mainly of ***re-scaling*** in order to have each value for the index calculation expressed in the range [0;1]. This allows to obtain a range of score values to which all types of variables can relate, also amplifying the effect on the composite index by widening values in a very close range, when compared to the *standardisation* method. The obtained values are also directly comparable and usable.

5.3.1. Application

The equation used in order to re-scale the data depends on how the data is considered in terms of contribution to the main concept of sustainability, either positively or negatively. An example of an indicator with values positively contributing to sustainability is the "Modal split of cycling and walking", where higher values contribute more positively to urban mobility sustainability. On the other side, an indicator that can represent the negative contribution is the "*Air pollution indicator*", in which bigger values have a negative impact on the concept of sustainability.

The equations (Nardo et al., 2008) used are reported here with the following definitions:

x_n= **un-scaled** or raw value of a certain indicator *n*,

x_n^s= **scaled** value of a certain indicator *n,*

$MIN(X_n)$ and $MAX(X_n)$ representing respectively the **minimum** and the **maximum** value of a certain indicator *n*.

$\boldsymbol{x_n^s} = \frac{x_n - MIN(X_n)}{MAX(X_n) - MIN(X_n)}$ for ***positive*** contributing indicators.

$\boldsymbol{x_n^s} = 1 - \frac{x_n - MIN(X_n)}{MAX(X_n) - MIN(X_n)}$ for ***negative*** contributing indicators.

A few exceptions to the use of this method are used for the following indicators:

- The indicator *Population Density* is normalized with a categorical scale method based on the value in which density can be considered adequate for achieving sustainable development (Salem, 2023).

$$x^s_{population\ density} = \begin{cases} 0{,}75\ ; & x_{population\ density} > 15.000 \\ 1\ ; & 6.500 \leq x_{population\ density} \leq 15.000 \\ 0{,}5\ ; & x_{population\ density} < 6.500 \end{cases}$$

- Indicators expressed with a **binary variable**, by nature, have their values already expressed in either 0 or 1.

- Indicators expressed with a **multinomial variable**, which can assume discrete values [0,1,2], are normalized using the following expression.

$$x_n^s = \begin{cases} 1\ ; & x_n = 2 \\ 0{,}5\ ; & x_n = 1 \\ 0\ ; & x_n = 0 \end{cases}$$

This expression is derived from a range proportion between the codomain, the range containing all possible outputs, of the multinominal variables and the selected range for the normalisation of the data. Therefore, the extreme values of the multinominal variables' codomain become, in the normalisation of said variables, the extreme values of the normalisation range. In regard of the remaining discrete value assumed by the multinominal variables, being situated in the arithmetic average in the multinominal codomain range, the numerical transposition that preserves the analytical properties of the variable is to give the proportionate one also in the normalisation range. This normalisation allows preserving the scale of the multinominal variable also into the normalisation range, while obtaining a comparable normalised variables that can be processed with the other types of variables, following an analytical process of proportion between ranges (Varberg et al., 2007).

This last assumption can also be changed, assigning a different value to the discrete value in question, therefore posing grounds for different results in the indexes in dependence on the value assigned.

Inside this step, the obtained data is normalised in order to further proceed with the Weighting and Aggregation processes that follow. In table 12, examples of normalized values, categorized by indicators, variable types, and cities are listed. The table displays both the unnormalized and normalized values corresponding to the cities listed.

Table 12 Examples of normalisation application of the different types of variables (own elaboration)

Indicator	**Type of variable**	**City**	x_n	x_n^s
Presence of highest grade of automation transit system	*Binary*	***Dublin***	0	**0**
		Osaka	1	**1**
		Hong Kong	1	**1**
Commuting travel time	*Continuous*	***Dublin***	40.69	**0.621**
		Osaka	25.4	**0.934**
		Hong Kong	42.37	**0.582**
Population density	*Continuous*	***Dublin***	4558.0	**0.75**
		Osaka	11764.7	**1**
		Hong Kong	17311.0	**0.5**
Availability of bike sharing	*Multinominal*	***Osaka***	2	**1**
		Hong Kong	1	**0.5**
		Los Angeles	1	**0.5**
		Lisbon	2	**1**
Availability of electric scooter sharing	*Multinominal*	***Osaka***	1	**0.5**
		Hong Kong	0	**0**
		Los Angeles	2	**1**
		Lisbon	2	**1**

It needs to be observed that the normalised values obtained for the indicator Commuting travel time needs to be taken into view as part of the full array of values associated with the indicator. In this particular case, lower travel time is associated with better performance in terms of sustainability, therefore locations possessing lower travel time have better normalised values, as displayed by the values shown.

5.4. Step 4: Weighting

Weighting the indicators is a process and a step that expresses the judgment given to the values and their importance in the composite index; ideally, those weight values should reflect the contribution of the indicator to the overall index. There are various techniques to provide and assign weights, including statistical methods such as factor analysis, data envelopment analysis, unobserved components models (UCM), or based on participatory methods, such as budget allocation (BAL), analytic hierarchy processes (AHP), and conjoint analysis (CA) (Nardo et al., 2008) & (Hermans et al., 2009). The goal of those techniques is to being able to respect both the theoretical process as well as the properties of the data.

Weights can also be assigned based on how statistically reliable the data is covered; this method, however, can penalize those indicators for which it is more statistically difficult to collect information (Nardo et al., 2008).

Multi-criteria analysis (**MCA**) is a method that does not allow compensability between the indicators, in which linear and, to a lesser extent, geometrical methods might require some indicators to compensate for their performance in certain areas with others to achieve better scores. A non-compensatory logic allows one to achieve and legitimate different goals and objectives equally important, such as the dimensional divisions of the concept of sustainability used for the index developed in this thesis (Nardo et al., 2008).

The chosen MCA type is defined as *Simple Weighted Additive Model*, in which the linear combination between the weights and the associated variables is performed. This type of MCA is indicated for those indexes possessing more than four variables, especially regarding the difficulties related to functions used, which can become difficult to manage with a greater number of variables. An assessment and review of the data and variables taken into account, which can be represented by the pre-analysis previously performed, helps in further assessing the possible dependences and influences across the pool of variables (Dean, 2022).

Three intrinsic properties of the MCA also contribute to the merits of this method (Dean, 2022):

- *Comprehensiveness*, by considering and assessing multiple objectives and criteria.
- *Flexibility*, by having the ability to assess and study different types of data, which can be both quantitative or qualitative in nature, as well as a wide range of the data and information itself.
- *Transparency*, by providing the overall process followed for the quantitative assessment of the analysis, as well as all the data and information collected during the construction and designing phases of the analysis itself.

Concerning the sustainable mobility index developed in the thesis, the weighting will follow the principles of *Multi-Criteria Analysis*, using the *Equal Weighting* method, which is considered as the simplest and most replicable between all the weighting methods (Gan et al., 2017). The assigned weight, used as a base for the scores, is dependent on the type of variables used for each indicator, following the subsequent information:

- **Continuous variables** will receive an associated weight of ***1***.

- **Binary** and **multinominal variables** will receive an associated weight of ***0.5***.

The reason behind the difference in the weights stands behind the mathematical apport that binary and multinominal variables have when compared to the continuous numerical nature of the other variables, which is greater in terms of the extremities of the range of the score. An example can be provided with the following situation.

An equal weight of 1 is considered for both continuous and non-continuous variables in this example. In a scenario where a dimension is composed of only binary variables, if there is a location obtaining a result of ”1” in each of its binary variables, the subsequent performance calculated will be a perfect score. Since the possibility of having a “1” score in a binary variable is mathematically higher compared to a continuous variable, which can assume infinite values by definition, there will be a higher chance to obtain a perfect score associated with binary variables when compared to continuous variables.

In addition to this Equal Weighting assignment to the variables, an increase to the assigned weight of 0,5 is provided when the indicators are considered as a key and central one to the concept of sustainable urban mobility. The following list of consulted literature portrays an arrange of themes and indicators related to the overall concept of sustainable urban mobility, comprising academical articles and a university’s conference report, which involved different stakeholders interested in the theme:

- **RANK** → Chatziioannou, I., Nikitas, A., Tzouras, P. G., Bakogiannis, E., Alvarez-Icaza, L., Chias-Becerril, L., Karolemeas, C., Tsigdinos, S., Wallgren, P., & Rexfelt, O. (2023). Ranking sustainable urban mobility indicators and their matching transport policies to support liveable city Futures: A MICMAC approach (Chatziioannou et al., 2023).
- **IND** → Amoroso, S., Caruso, L., & Castelluccio, F. (2011). *Indicators for sustainable mobility in the cities (Amoroso et al., 2011)*.
- **UITP** → Mordret, A., Murgia, L., & Stainer, L. (2021). *Better Urban Mobility Playbook*. International Association of Public Transport (UITP) (Mordret et al., 2021).
- **POLI** → Politecnico di Milano. (2022). *The future of sustainable urban mobility—How will we move in 2035?* Politecnico di Milano (Politecnico di Milano, 2022).
- **REV** → Gallo, M., & Marinelli, M. (2020). Sustainable Mobility: A Review of Possible Actions and Policies (Gallo & Marinelli, 2020).

Each time one of the indicators, its policies, or the overall purpose, is considered inside the literature mentioned above, an increase of 0.5 is added to the weight of the indicator. A full table indicating which indicators are mentioned in the consulted literature will be provided in the next section, focusing on the application of the methodology.

5.4.1. Application

In table 13 an overview of both the starting weights and the total final weights associated for each indicator is provided. It is also annotated if the indicator, or the variable/theme portrayed by it, is present inside one of the sources of literature consulted. Those literature sources are here subsequently reported with the code used inside the table.

Table 13 Weights of the indicators (own elaboration)

Indicator	Variable Type	Starting Weight	*RANK*	*IND*	*UITP*	*POLI*	*REV*	***Increment***	**Total Weight**	**Normalised weight**
Share of accessible metro stations	*Continuous*	1	X	X	X	X	X	***2.5***	**3.5**	**0.5386**
Airport Passengers	*Continuous*	1						***0***	**1**	**0.1538**
Hours of Metro Operation	*Continuous*	1						***0***	**1**	**0.1538**
Population density	*Continuous*	1						***0***	**1**	**0.1538**
Congestion: increase in the overall travel time	*Continuous*	1	X					***0.5***	**1.5**	**0.1111**
Air Pollution related to traffic	*Continuous*	1	X	X			X	***1.5***	**2.5**	**0.1853**
Presence of Low-Emission-Zone (LEZ)	*Binary*	0.5				X	X	***1***	**1.5**	**0.1111**
Modal split PT	*Continuous*	1		X				***0.5***	**1.5**	**0.1111**
Modal split cycling and walking	*Continuous*	1		x				***0.5***	**1.5**	**0.1111**
Availability of bike sharing	*Multinominal*	0.5				X	X	***1***	**1.5**	**0.1111**
Availability of electric scooter sharing	*Multinominal*	0.5			X	X	X	***1.5***	**2**	**0.1481**
Availability of electric	*Multinominal*	0.5			X		X	***1***	**1.5**	**0.1111**

vehicles in car sharing										
Commuting travel time	*Continuous*	1	X	X				***1***	**2**	**0.3077**
Price of monthly PT pass	*Continuous*	1	X	X			X	***1.5***	**2.5**	**0.3847**
Presence of highest grade of automation transit system	*Binary*	0.5				X		***0.5***	**1**	**0.1538**
Investment in of highest grade of automation transit system	*Binary*	0.5				X		***0.5***	**1**	**0.1538**
City Available on transport apps	*Multinominal*	0.5			X	X	X	***1.5***	**2**	**0.5714**
City/regional comprehensive transport plan	*Binary*	0.5						***0***	**0.5**	**0.1429**
City/regional comprehensive tariff zone	*Binary*	0.5			X			***0.5***	**1**	**0.2857**

5.5. Step 5: Aggregation

Aggregation methods can also vary: **linear aggregation** is useful when all the indicators have the same measurement unit, while **geometric aggregation** is suited for non-comparable and strictly positive indicators expressed in different ratio scales. Overall, linear aggregation rewards indicators based on the weights, while geometric aggregation rewards those indicators with higher values (Nardo et al., 2008).

The aggregation method chosen for the sustainable mobility index is linear aggregation. This method consists of the summation of the weighted and normalised individual indicators of each dimension. Moreover, the score obtained by each location in each dimension is then furtherly linearly aggregated with the one obtained by the other dimensions. The equation used is as follows (Nardo et al., 2008):

Given $x_{n,i}^{s}$ the normalised value for the indicator *n* and location *i*, w_n the weight associated with the indicator *n*, the score for the location *i* is then calculated

$$S_i = \sum_{n=1}^{N} x_{n,i} * w_{n,i}$$

with the sum of weights of the variables n $\sum_{n=1}^{N} w_{n,i} = 1$ for each dimension *i*.

This process permits to obtain a score, $S_{j,i}$for each location *i* in each dimension *j*. Therefore, to obtain an overall score S_i^* for each location *i*, the following linear aggregation is performed:

$$S_i^* = \sum_{j=1}^{4} S_{j,i} * 0.25$$

The constant coefficient is the associated weight to each dimension, following the principle assessed in the previous sections, that sees every dimension contributing to the concept of sustainability as progress on one of the Ps needs balance on the other ones to achieve and implement overall supported and shared sustainability (Kaysie, Brown & Krista, Rasmussen, 2019).

5.5.1. Application

Application of the linear aggregation is performed both at the dimensional and overall level, as discussed in the previous section. An example of the aggregation is provided by the computation of the location of Milan.

In the People dimension, Milan has obtained the following scores and normalised scores:

Table 14 Milan's People dimension score (own elaboration)

Indicator	***Unit of measurement***	***Score***	***Normalised score***
Share of accessible metro stations	*Percentage*	**0.81**	
Airport Passengers	*passengers/year*	51477949	**0.33**
Hours of Metro Operation	*number of hours*	19	**0.29**
Population density	*people/square kilometres*	7551.3	**1**

The normalised scores are then inserted into the linear aggregation with the assigned weights as presented and discussed in section 5.4:

Table 15 Computation of Milan's People scores and weights (own elaboration)

Indicator	***Normalised score***	***Assigned weight***
Share of accessible metro stations	0.81	*0.5386*
Airport Passengers	0.33	*0.1538*
Hours of Metro Operation	0.286	*0.1538*
Population density	1	*0.1538*

$$Milan_{People\ score} = 0.81 * 0.5386 + 0.33 * 0.1538 + 0.286 * 0.1538 + 1 * 0.1538 = \mathbf{0.684}$$

This computational process is repeated across all the dimensions, with the following results:

	Indicator	***Normalised score***	***Assigned weight***
Planet dimension	Congestion: increase in the overall travel time	0.974	*0.1111*
	Air Pollution related to traffic	0.861	*0.1853*
	Presence of Low-Emission-Zone (LEZ)	1	*0.1111*
	Modal split PT	0.561	*0.1111*
	Modal split cycling and walking	0.375	*0.1111*
	Availability of bike sharing	1.000	*0.1111*
	Availability of electric scooter sharing	1.000	*0.1481*
	Availability of electric vehicles in car sharing	1.000	*0.1111*
	TOTAL PLANET SCORE	**0.848**	
Prosperity dimension	Commuting travel time	0.723	0.3077
	Price of monthly PT pass	0.977	0.3847
	Presence of highest grade of automation transit system	1	0.1538

	Investment in of highest grade of automation transit system	0	0.1538
	TOTAL PLANET SCORE	**0.752**	
Peace & Partnerships dimension	City Available on transport apps	1	0.5714
	City/regional comprehensive transport plan	1	0.1429
	City/regional comprehensive tariff zone	1	0.2857
	TOTAL PEACE & PARTNERSHIPS SCORE	**1**	

The resulted aggregated overall score can then be calculated as follows:

$$Milan_{overall\ score} = (0.684 + 0.848 + 0.752 + 1) * 0.25 = \mathbf{0.821}$$

5.6. Further steps

The handbook provides the assessment of further steps dealing with robustness and sensitivity, as well as the future steps to be undertaken when assessing the external context in which an index can be applied.

The robustness and sensitivity of an index cover the uncertainty and risk that is intrinsically present when constructing the index. An analysis of those two concepts can help assess the robustness and transparency of the methodology and the results obtained. Uncertainty analysis focuses on the propagation of uncertainty from the input factors and extends over the indicator values. Sensitivity analysis assesses how the individual sources contribute to the overall uncertainty of the output values variance (Nardo et al., 2008). Uncertainty analysis is used more often compared to sensitivity analysis, but nevertheless, those two concepts are treated separately.

Further developments explore possible links to other measured variables outside of the ones included in the indexes, the possibility of deconstruction of the composite indicators in order to further develop the analysis and the presentation and dissemination of the results obtained by the indexes (Munda & Nardo, 2005).

Those last steps are to some extent included in the last research question of the thesis, which is required to comment and interpret the results to provide recommendations and suggestions for the performance of cities to achieve better performance in the future. Therefore, it will be covered in depth in the following sections.

6. Results and Interpretation

The application of the methodology described and assessed in the previous chapter permits the obtainment of the performance of the selected cities in the sustainable urban mobility index. Each city can then be evaluated on both the overall performance as well as on a more specific dimensional level. Overall, these results can define and help in identifying areas in which the city's performance in terms of sustainability can be improved.

6.1. Overall score

The following results were obtained as the overall performance of the selected locations in the sustainable urban mobility index.

Table 16 Overall score of the locations (own elaboration)

City	Score	Rank	City	Score	Rank
Stockholm	0.8275	***1***	Toronto	0.6663	***24***
Amsterdam	0.8209	***2***	San Francisco	0.6628	***25***
Milan	0.8193	***3***	Dubai	0.6625	***26***
Frankfurt	0.8152	***4***	Seoul	0.6572	***27***
Munich	0.8102	***5***	Hong Kong	0.6567	***28***
Barcelona	0.8000	***6***	Los Angeles	0.6212	***29***
Brussels	0.7929	***7***	Moscow	0.6144	***30***
Berlin	0.7777	***8***	New York	0.6136	***31***
Singapore	0.7734	***9***	Jakarta	0.5965	***32***
Lisbon	0.7651	***10***	Mumbai	0.5584	***33***
Madrid	0.7613	***11***	Boston	0.5505	***34***
Paris	0.7482	***12***	Melbourne	0.5472	***35***
Shanghai	0.7354	***13***	Buenos Aires	0.5097	***36***
London	0.7259	***14***	Auckland	0.5057	***37***
Taipei	0.7232	***15***	Perth	0.5052	***38***
Tokyo	0.7218	***16***	Kuala Lumpur	0.4913	***39***
Istanbul	0.7054	***17***	Mexico City	0.4595	***40***
Sao Paulo	0.7046	***18***	Bangkok	0.4229	***41***
Dublin	0.6851	***19***	Lagos	0.3396	***42***
Sydney	0.6809	***20***	Cairo	0.3213	***43***
Chicago	0.6799	***21***	Nairobi	0.3149	***44***
Osaka	0.6798	***22***	Johannesburg	0.2458	***45***
Zurich	0.6663	***23***			

In the next figure, the distribution of the scores can be seen, with the following descriptive statistics highlighted:

Table 17 Descriptive statistics overall scores (own elaboration)

AVERAGE	ST DEVIATION	MEDIAN	1st quartile	3rd quartile
0.6387	0.1469	0.6663	0.5489	0.7548

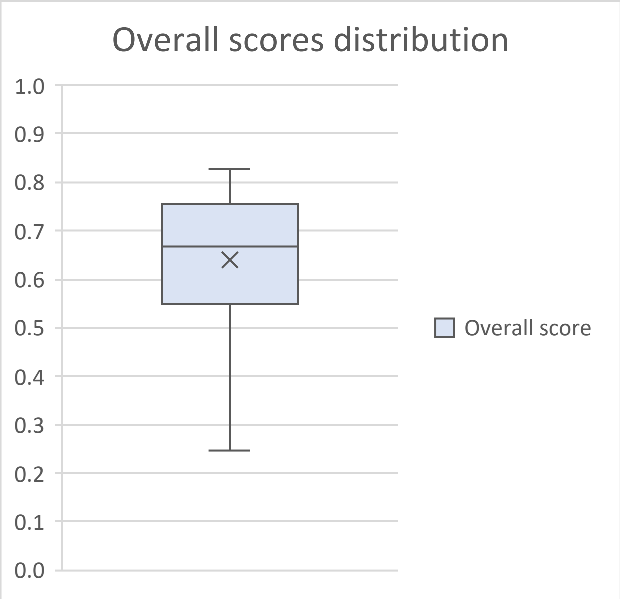

Figure 10 Distribution of the overall scores (own elaboration)

The distribution of the scores can also be obtained, with the division of the scores into ten classes, to pattern and obtain a distribution graph of the scores. The selected number of clusters is chosen as assumption to better plot and visualize the distribution, with every cluster representing 10% of the overall width interval of the scores. Those ten classes are obtained by using the range between the extreme values and by dividing by the number of classes themselves to calculate the width of the range (Manikandan, 2011).

$$Width\ Range = \frac{MAX(Overall\ Score) - MIN(Overall\ Score)}{\#\ classes} = \frac{0.8275 - 0.2458}{10} = 0.05817$$

Table 18 Clusters specifications (own elaboration)

Classes	Number of cities	Average	Std. Deviation
x > 0.77	9	0.804	0.018
0.711 > x > 0.77	7	0.740	0.017
0.653 > x > 0.711	12	0.676	0.016
0.595 > x > 0.653	4	0.611	0.009
0.537 > x > 0.595	3	0.552	0.005
0.479 > x > 0.537	4	0.503	0.007
0.421 > x > 0.479	2	0.441	0.018
0.363 > x > 0.421	0	-	-
0.305 > x > 0.363	3	0.325	0.01
x < 0.305	1	0.246	-

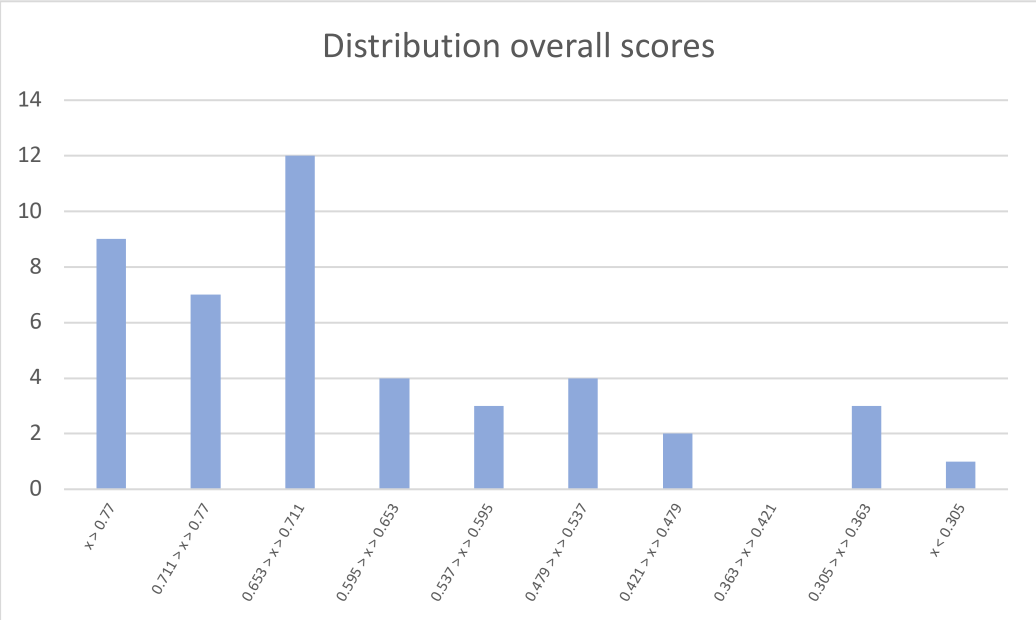

Figure 11 Distribution of the overall scores' performances by interval (own elaboration)

A first observation can be made on the high number of locations performing in the upper part of the scale, with 15 cities belonging to classes having scores higher than 0.70, resulting in 33% of the locations selected. As seen in table 18, the standard deviation of the scores of the two highest ranking clusters is also similar, leading to an even distribution between the locations in the clusters.

In analysing the first ten places of the overall rank, it can be observed that 9 out of 10 are European cities, with Singapore being the only location in the first ten places not being from the European continent. Moreover, the scores in the first ten positions are contained in a range of less than 0.1, and the first three places are in a 0.01 range.

When looking at the opposite side of the ranking, it can be observed that the last 5 positions are mainly composed of African cities, with the exception of an Asian location. The range in which the bottom part of the ranking is included, which is less than 0.2, is wider when compared to the opposite side of the rank.

An average performance by continent is provided in the next graph, showing the distribution of the average score across all four dimensions.

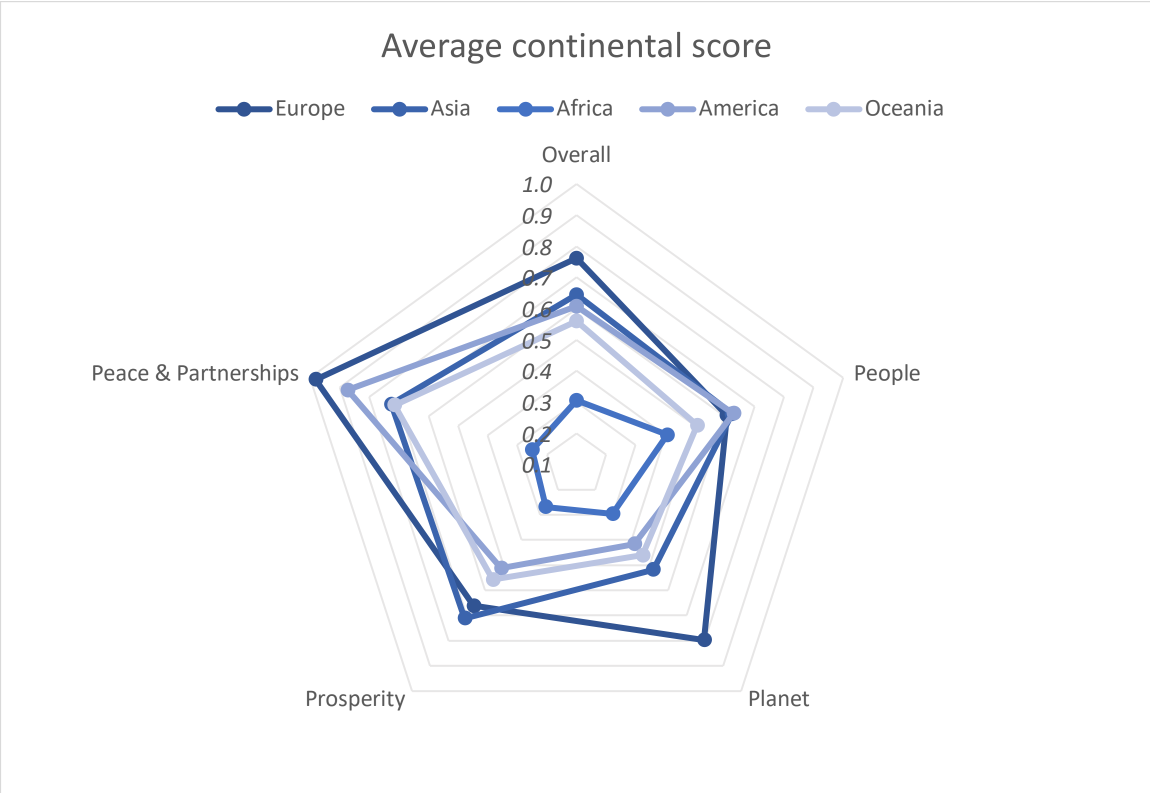

Figure 12 Average performance score by continent (own elaboration)

As seen in the figure above, the continent of Europe has the best overall average performance, as well as in the *Peace & Partnerships* and *Planet* dimensions, possessing notably higher average scores in those categories. The best average performance for the dimensions *People* and *Prosperity* is, respectively, of the American and Asian locations. African cities possess the lowest average performance across both the overall score, as well as all four dimensions.

In the following table, which is the source for the continental scores portrayed in figure 12, a comparison between the average scores obtained at the continental level is provided, with also the overall average scores of each dimension.

Table 19 Comparison between average values obtained (own elaboration)

	Overall	People	Planet	Prosperity	Peace & Partnerships
Total	***0.6387***	***0.5903***	***0.5659***	***0.6019***	***0.7968***
Europe	0.7619	0.6078	0.7973	0.6618	0.9810
Asia	0.6450	0.6251	0.5181	0.7114	0.7253
Africa	0.3054	0.4065	0.2966	0.2685	0.2500
America	0.6076	0.6296	0.4160	0.5119	0.8730
Oceania	0.5598	0.5071	0.4606	0.5570	0.7143

As seen in table 19, the **European** continent has an above average score across the whole dimensional framework. The continent of **Asia** obtains an above average performance on the overall scores, as well as in the *People* and *Prosperity* dimensions, obtaining the top rank in this last dimension when compared to the other continental averages. The American continent obtains an above average score in the *People* dimension, with the top average score, and in the *Peace & Partnerships* dimension as well. The continent of **Oceania** and **Africa** performed below average across all the dimensions, with the latest possessing the greater amount of difference when compared to the total average scores obtained.

Some of the reasons behind the scores obtained, which will be furtherly discussed inside section 6.3, can reside behind both the policies and actions implemented especially by the European continent, towards reducing the environmental impact of urban mobility, as well as the integration between the different modes and stakeholders involved in the overall transit system. The cities located in Asia, generally perform above average inside the dimensions portraying *People* and *Prosperity* concepts, thanks to policies directed towards flexibility and accessibility of transit systems, while having the ability of improving economic benefits for both users and operators. On the other hand, African cities lack high performances in all the dimensions. This is possible due to the current state of the transit systems involved, as well as the difficulties surrounding both the introduction of more sustainable alternatives forms of transport and updating current infrastructure and services.

In table 20, an overview of the distribution of the locations divided by continent is provided; the number of locations above and below the overall average score, equal to 0.6387, are represented and classified by continent.

Table 20 Continental distribution of overall scores to the average score (own elaboration)

Classes	**Percentage of continental locations**
Europe > average	$^{14}/_{15}$
Europe < average	$^{1}/_{15}$
Asia > average	$^{9}/_{13}$
Asia < average	$^{4}/_{13}$
Africa > average	$^{0}/_{4}$
Africa < average	$^{4}/_{4}$
America > average	$^{4}/_{9}$
America < average	$^{5}/_{9}$
Oceania > average	$^{1}/_{4}$
Oceania < average	$^{3}/_{4}$

As seen in the table above, the dominance of the European and Asian continents in the scores above average is clear, with more than half of the respective locations having a score above the average. On the other hand, the African and Oceanian locations possess scores below the average, with all African locations belonging to this classification. The American continent is the only one with the locations' scores being above and below the average, almost in the same quantity.

When looking into the best performing cities categorized by continent, based on the overall score, the following graph can be obtained.

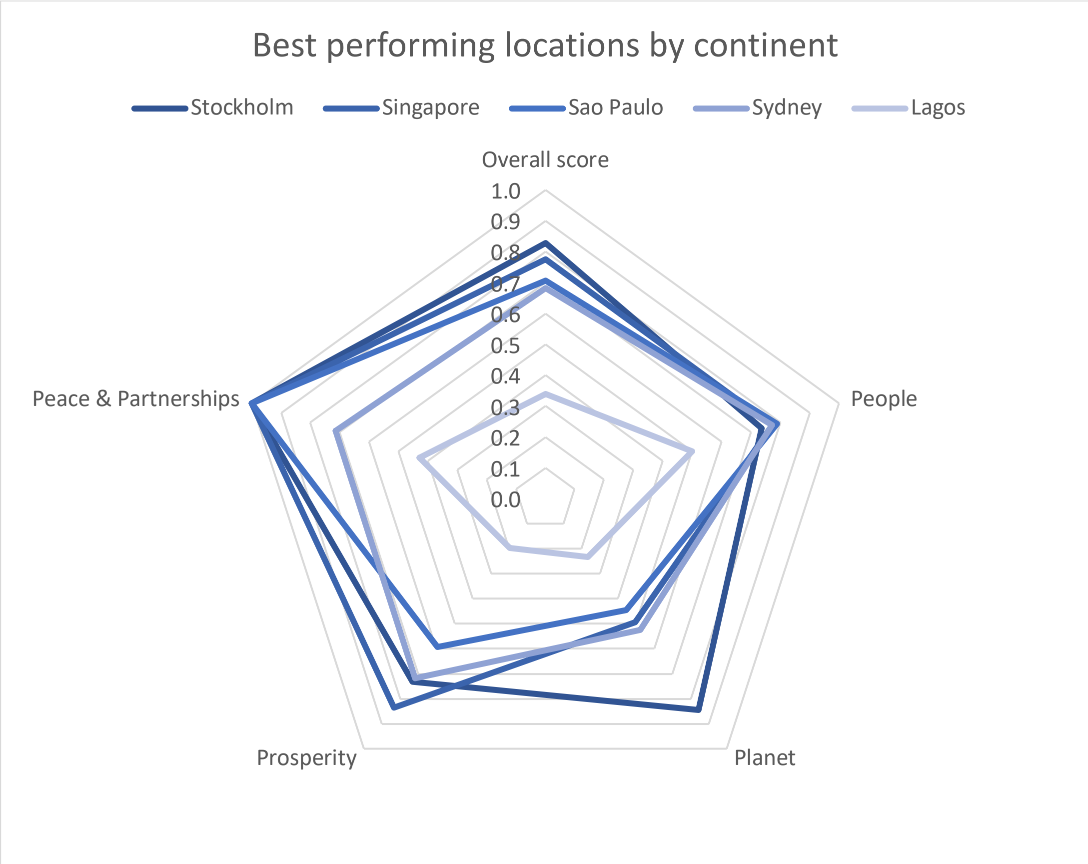

Figure 13 Best performing locations by continent (own elaboration).

It can be observed how the best performing locations of the European, Asian, and American continents distribute themselves and each possess the best scores in at least one of the dimensions. The Oceanian location is overall obtaining similar, or slightly lower scores, while the African location obtains the minimum score in each dimension. It can be observed how this assessed graph confirms the pattern found in the previous one, about the average scores of each continent; the situation there represented can also be found inside Figure 13

Further interpretation of the data will be discussed and analysed inside section 6.3.

6.2. Dimensional scores

The overall score is methodologically defined as a linear aggregation of the four dimensional scores. Therefore, possessing different performances in the dimensional framework can either benefit or negatively impact the overall score.

An overall view of the results obtained can be seen in the next graph, showing the distribution of the score of each dimension, including the statistical variables of the average score, first and third quartile, median and the general presence of eventual outliers.

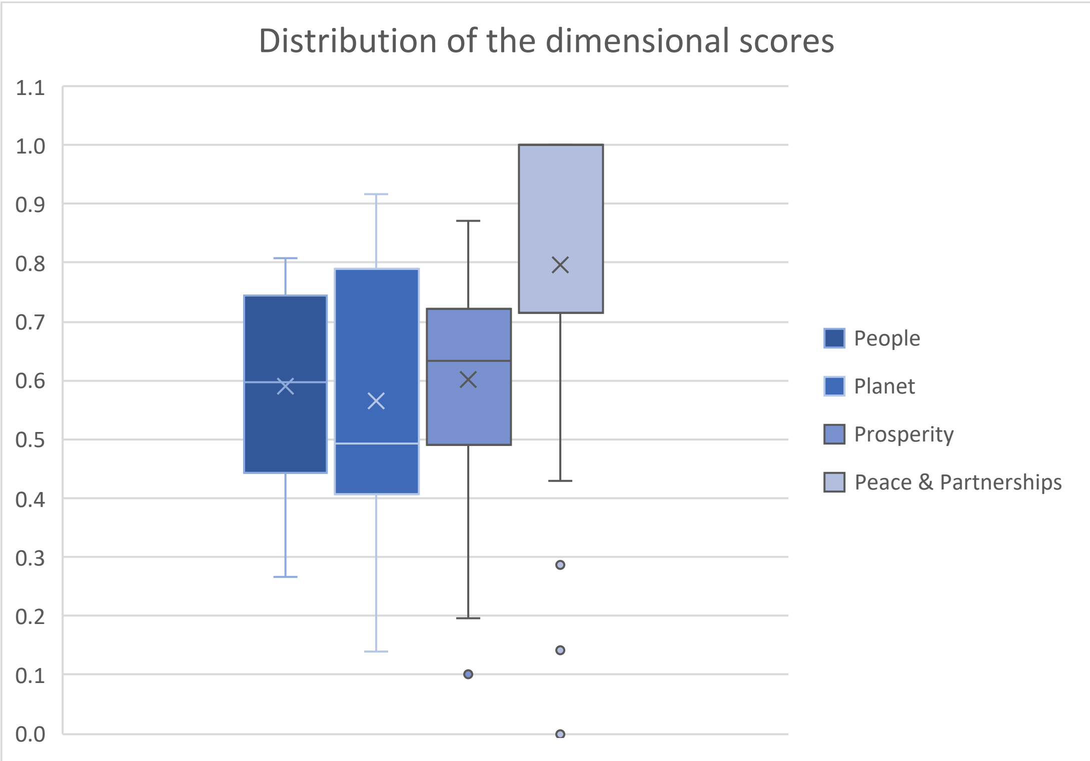

Figure 14 Distribution of the dimensional scores (own elaboration)

As seen in Figure 14, the first three dimensions possess comparable average scores, while the *Peace & Partnerships* dimension is projected higher in the scale. Moreover, the distribution of the *People*, *Planet* and *Prosperity* dimensions is less widespread compared to the *Peace & Partnerships*; this observation can be tracked down to the limited number of indicators, and therefore available scores, when compared to the other three dimensions. In addition, the type of variable used for the indicator of the *Pace & Partnerships* dimension is only of the binary and multinominal type, posing further limitations on the obtainable range distribution.

In the following sections, an overview and assessment of the results obtained will be provided in more detail, to further analyse and quantify the values obtained in the overall scores and to review the performances of the locations in each dimension.

6.2.1. People

The following table represents the performance of the locations in the People dimension based on the indicators and methodology previously discussed.

Table 21 Locations' performances on the People dimension (own elaboration).

City	*Score*	*Rank*	City	*Score*	*Rank*
Los Angeles	0.8071	*1*	**Berlin**	0.5955	*24*
Frankfurt	0.8034	*2*	**New York**	0.5952	*25*
Munich	0.7873	*3*	**Boston**	0.5694	*26*
Sao Paulo	0.7814	*4*	**Madrid**	0.5606	*27*
Dubai	0.7744	*5*	**London**	0.5132	*28*
Shanghai	0.7727	*6*	**Lagos**	0.5000	*29*
Sydney	0.7669	*7*	**Kuala Lumpur**	0.4665	*30*
Singapore	0.7642	*8*	**Dublin**	0.4537	*31*
San Francisco	0.7614	*9*	**Melbourne**	0.4502	*32*
Istanbul	0.7598	*10*	**Moscow**	0.4501	*33*
Osaka	0.7523	*11*	**Zurich**	0.4443	*34*
Chicago	0.7368	*12*	**Taipei**	0.4405	*35*
Stockholm	0.7342	*13*	**Buenos Aires**	0.4296	*36*
Toronto	0.7297	*14*	**Auckland**	0.4091	*37*
Amsterdam	0.7285	*15*	**Perth**	0.4023	*38*
Jakarta	0.7017	*16*	**Johannesburg**	0.4011	*39*
Lisbon	0.7017	*17*	**Bangkok**	0.3910	*40*
Mumbai	0.6803	*18*	**Mexico City**	0.3878	*41*
Milan	0.6768	*19*	**Nairobi**	0.3751	*42*
Hong Kong	0.6740	*20*	**Cairo**	0.3498	*43*
Barcelona	0.6576	*21*	**Seoul**	0.3168	*44*
Tokyo	0.6453	*22*	**Paris**	0.2668	*45*
Brussels	0.5981	*23*			

The following descriptive statistics can be obtained:

Table 22 Descriptive statistics People scores (own elaboration)

AVERAGE	ST. DEVIATION	MEDIAN	1st quartile	3rd quartile
0.5903	0.1594	0.5981	0.4424	0.7446

When looking at the first ten positions, the locations inside this first part of the ranking are dispersed, with cities from Europe, America, and Asia, also being in a range just bigger than 0.05.

An observation can be made on some cities of developed countries that can be found in the bottom part of the ranking, notably Seoul, and Paris, which possess the lowest performances in the *People* dimension.

The reason behind the low score of a city such as Paris can reside to the state of a part of its network, which was developed during the late XIXth century (Compagnon et al., 2023). This can limit and heavily influence the related infrastructure, and its accessibility, as well as the options available when updating and constructing new transit lines. Moreover, cities located in America and Asia can benefit from more modern transit systems, which can benefit especially the infrastructure and its accessibility, which is a variable that heavily influences the performance score of the dimension. The city of Los Angeles, for example, can benefit from a high score in the accessibility indicator, as well as a generally above average performance inside the other indicators of the dimension.

6.2.2. Planet

The following table represents the performance of the locations in the *Planet* dimension based on the indicators and methodology previously assessed.

Table 23 Planet dimension locations performances (own elaboration).

City	*Score*	*Rank*	*City*	*Score*	*Rank*
Berlin	0.917	*1*	**Toronto**	0.476	*24*
Amsterdam	0.906	*2*	**Dubai**	0.465	*25*
Paris	0.880	*3*	**Cairo**	0.459	*26*
Tokyo	0.859	*4*	**Melbourne**	0.456	*27*
Milan	0.848	*5*	**Osaka**	0.455	*28*
Stockholm	0.845	*6*	**Chicago**	0.454	*29*
London	0.844	*7*	**Sao Paulo**	0.444	*30*
Brussels	0.827	*8*	**Auckland**	0.441	*31*
Munich	0.821	*9*	**Istanbul**	0.429	*32*
Madrid	0.818	*10*	**Perth**	0.420	*33*
Frankfurt	0.804	*11*	**San Francisco**	0.406	*34*
Shanghai	0.775	*12*	**Boston**	0.406	*35*
Seoul	0.760	*13*	**Buenos Aires**	0.393	*36*
Lisbon	0.758	*14*	**Jakarta**	0.378	*37*
Taipei	0.752	*15*	**Mumbai**	0.362	*38*
Barcelona	0.740	*16*	**Nairobi**	0.355	*39*
Zurich	0.722	*17*	**Mexico City**	0.303	*40*
New York	0.633	*18*	**Bangkok**	0.287	*41*
Dublin	0.595	*19*	**Los Angeles**	0.253	*42*
Hong Kong	0.580	*20*	**Lagos**	0.233	*43*
Moscow	0.551	*21*	**Kuala Lumpur**	0.198	*44*
Sydney	0.525	*22*	**Johannesburg**	0.139	*45*
Singapore	0.494	*23*			

In the next table, the descriptive statistics of the *Planet* dimension can be seen:

Table 24 Descriptive statistics of the Planet dimension (own elaboration)

AVERAGE	ST. DEVIATION	MEDIAN	1st quartile	3rd quartile
0.5659	0.2183	0.4939	0.4064	0.7892

It can be observed how European and Asian cities dominate the higher part of the ranking, taking all except one of the first twenty positions. On the other side of the ranking, African, American and some remaining Asian locations obtain the lowest scores of this dimension.

An observation can be made regarding the city of Los Angeles, taking the fourth worst score in this dimension. To contrast, by comparison, the best performing city of the American continent, New York, has a score that is twice as higher than Los Angeles. The reason behind this performance can be tracked down to the very low score associated with the *Air Pollution related to traffic*, which has the overall highest amount of CO_2 emitted. Moreover, the low shares of modal split related to both PT and soft mobility, in addition to the lack of LEZ across the city, result in a poor performance in the *Planet* dimension, confirming the car-oriented nature of the city of Los Angeles when compared to Ney York.

6.2.3. Prosperity

In the next table, the representation of the performances of the locations in the *Prosperity* dimension, based on the indicators and methodology previously assessed, can be seen.

Table 25 Prosperity dimension locations performances (own elaboration).

City	*Score*	*Rank*	*City*	*Score*	*Rank*
Kuala Lumpur	0.872	*1*	**Lisbon**	0.600	*24*
Paris	0.846	*2*	**Berlin**	0.598	*25*
Singapore	0.836	*3*	**Sao Paulo**	0.593	*26*
Tokyo	0.812	*4*	**Jakarta**	0.592	*27*
Barcelona	0.802	*5*	**Melbourne**	0.568	*28*
Osaka	0.798	*6*	**London**	0.546	*29*
Mumbai	0.763	*7*	**Chicago**	0.529	*30*
Milan	0.752	*8*	**New York**	0.512	*31*
Brussels	0.746	*9*	**Boston**	0.512	*32*
Stockholm	0.731	*10*	**Buenos Aires**	0.502	*33*
Bangkok	0.728	*11*	**Zurich**	0.499	*34*
Sydney	0.718	*12*	**Perth**	0.484	*35*
Taipei	0.700	*13*	**San Francisco**	0.483	*36*
Dubai	0.697	*14*	**Cairo**	0.476	*37*
Seoul	0.695	*15*	**Toronto**	0.460	*38*
Dublin	0.691	*16*	**Auckland**	0.458	*39*

Shanghai	0.680	*17*	**Moscow**	0.457	*40*
Madrid	0.667	*18*	**Mexico City**	0.433	*41*
Hong Kong	0.659	*19*	**Los Angeles**	0.425	*42*
Frankfurt	0.654	*20*	**Johannesburg**	0.301	*43*
Amsterdam	0.649	*21*	**Lagos**	0.197	*44*
Munich	0.632	*22*	**Nairobi**	0.101	*45*
Istanbul	0.632	*23*			

In the next table, the descriptive statistics of the *Prosperity* dimension are depicted:

Table 26 Descriptive statistics of the Prosperity dimension (own elaboration)

AVERAGE	ST. DEVIATION	MEDIAN	1st quartile	3rd quartile
0.6019	0.1632	0.6324	0.4913	0.7228

It can be observed how in the higher part of the ranking the presence of Asian locations is predominant, followed by European cities.

An observation can be made to the two African cities of Lagos and Nairobi, possessing the lowest scores in this dimension. Those two values are separated by a value greater than 0.1, noticing key areas where these two locations are currently underperforming. Lagos possesses a high commuting time, while Nairobi has a PT monthly price which has a high impact on the average GDP per capita. Moreover, both cities do not possess and are not investing in infrastructure for an automatic transit system; consequently, their score inside the *Prosperity* dimension is below average.

6.2.4. Peace & Partnerships

The following table represents the performance of the locations in the *Peace & Partnerships* dimension based on the indicators and methodology previously assessed.

Table 27 Peace & Partnerships dimension locations performances (own elaboration).

City	*Score*	*Rank*	*City*	*Score*	*Rank*
Paris	1.000	*1*	**Seoul**	0.857	*24*
Singapore	1.000	*2*	**Osaka**	0.714	*25*
Barcelona	1.000	*3*	**Sydney**	0.714	*26*
Milan	1.000	*4*	**Dubai**	0.714	*27*
Brussels	1.000	*5*	**Shanghai**	0.714	*28*
Stockholm	1.000	*6*	**Hong Kong**	0.714	*29*
Taipei	1.000	*7*	**Jakarta**	0.714	*30*
Dublin	1.000	*8*	**Melbourne**	0.714	*31*
Madrid	1.000	*9*	**New York**	0.714	*32*

Frankfurt	1.000	*10*	**Boston**	0.714	*33*
Amsterdam	1.000	*11*	**Buenos Aires**	0.714	*34*
Munich	1.000	*12*	**Perth**	0.714	*35*
Istanbul	1.000	*13*	**Auckland**	0.714	*36*
Lisbon	1.000	*14*	**Mexico City**	0.714	*37*
Berlin	1.000	*15*	**Tokyo**	0.571	*38*
Sao Paulo	1.000	*16*	**Kuala Lumpur**	0.429	*39*
London	1.000	*17*	**Mumbai**	0.429	*40*
Chicago	1.000	*18*	**Lagos**	0.429	*41*
Zurich	1.000	*19*	**Nairobi**	0.429	*42*
San Francisco	1.000	*20*	**Bangkok**	0.286	*43*
Toronto	1.000	*21*	**Johannesburg**	0.143	*44*
Moscow	1.000	*22*	**Cairo**	0.000	*45*
Los Angeles	1.000	*23*			

In the next table, the descriptive statistics of the *Peace & Partnerships* dimension can be seen:

Table 28 Descriptive statistics of the Prosperity dimension (own elaboration)

AVERAGE	ST. DEVIATION	MEDIAN	1st quartile	3rd quartile
0.7968	0.2564	1.0000	0.7143	1.0000

When looking at the ranking, a high number of repeating values can be observed, especially with higher scores. A drop in the scores below the value of 0.5 can be seen only in the last six locations of the ranking.

The most notable observation can be seen in the lowest part of the ranking, with the city of Cairo possessing a score equal to zero, meaning that no contribution to the dimension is provided through the variables portrayed by the indicators in this dimension. This can be explained by the non-implementation of policies or actions by the city of Cairo that can express the indicators of this dimension.

6.3. Interpretation

The results shown in the previous sections can be interpreted in different ways. Regarding the overall performance, table 29 shows the distribution of the scores across the first five positions of the ranking.

Table 29 Distribution of five best overall scores (own elaboration)

	Overall	**People**	**Planet**	**Prosperity**	**Peace & Partnerships**
Stockholm	**0.828**	0.734	0.845	0.731	1
Amsterdam	**0.821**	0.728	0.906	0.649	1
Milan	**0.819**	0.677	0.848	0.752	1
Frankfurt	**0.815**	0.803	0.804	0.654	1
Munich	**0.810**	0.787	0.821	0.632	1
AVERAGE	***0.639***	*0.590*	*0.566*	*0.602*	*0.797*

The scores show how the first five cities, which are all located in the European continent, are distributed across the four dimensions. In general terms, all five cities perform above average in all dimensions, having scores considerably higher than the average obtained scores by all other cities. Fluctuations between scores occurs in most of the top five cities but are above all the different dimensional averages. The top performing city of **Stockholm** possesses the least fluctuation between those scores, which in return results in an overall higher score when compared to the other cities of the ranking. Even if Stockholm does not have the top score in each dimension of the structural framework of the sustainable mobility index, it has the most consistent performance across it, while the other locations obtained scores that lower their overall performance.

When analysing the continental performances, as previously portrayed by table 19 in section 6.1, a central observation is the above average performance of the European cities across all the dimensions, especially in the *Planet* and *Peace & Partnerships* dimensions. In particular, the indicators ***Congestion: increase in the overall travel time*** and ***Presence of LEZ*** for the *Planet* dimension, and **all the indicators** for the *Peace & Partnerships* dimension contribute to giving the European locations the best scores in the respective dimensions considered. This high achieving performance in those two dimensions by the continent of **Europe** can be supported by factors such as the availability of funds and technology to enable policies, as well as the intricate but communal processes that are assessed and discussed in institutions such as the EU (Torres, 2003). The involvement of this supranational institution can help in providing support to those actions aiming to achieve sustainable forms of urban mobility and development. Regarding the development and implementation of policies aimed to improve the sustainability of urban mobility, the communal process in which guidelines and objectives are set, decided, and diffused helps in attracting and involving the different communities, as well as the advancement of those policies (Werland, 2020).

The **Asian** and **American** continents can then be assessed, with similar performances on average terms across all dimensions. Key observations that can be obtained are surely the best average scores for the *Prosperity* and *People* dimensions, respectively obtained by Asian and American locations. In particular, the indicators in the *People* dimension of ***Share of accessible metro stations*** and ***Population Density*** provide above average scores for those two continents, which contribute to better dimensional related scores. Regarding the *Prosperity* dimension, the indicators ***Price of monthly PT pass***, ***Presence of highest form of transit automation***, and ***Investment in highest form of transit automation*** give again high scores that impact the dimensional performance of Asian and American locations. The advantage that these two continents have compared to the locations situated in *Europe*, can reside in different factors. ***Asian*** cities benefit from highly performing economic factors in the urban mobility field, especially with fares being highly profitable to the system, as well as lower cost per trip when compared to other regions. Cities in the **American** continent, especially the ones located in **Latin America**, show comparable trends to the Asian cities, whereas economic profitability of the transit systems is more profitable when compared to the other continents (De Gruyter et al., 2017).

As an example of those last points discussed, the best performing city in Asia, **Singapore**, obtains above average scores in almost every dimension, as displayed in table 30.

Table 30 Singapore scores comparisons (own elaboration)

	Overall	People	Planet	Prosperity	Peace & Partnerships
Overall	0.639	0.590	0.566	0.602	0.797
Asia	0.645	0.625	0.518	0.711	0.725
Singapore	***0.773***	***0.764***	***0.494***	***0.836***	***1***

A notable mention is **São Paulo**, the best performing city on the American continent, despite being in a developing country. In table 31 the dimensional results obtained are shown compared to the overall and continental average. The values show how the city always performs above average when compared to the continental score and scores above the total average in the *overall* performance, as well as across the *People* and *Peace & Partnerships* dimensions. These sores can be explained due to the policies and actions enacted by the local authorities, which will be further discussed in chapter 6.4.3.

Table 31 Sao Paulo scores comparisons (own elaboration)

	Overall	People	Planet	Prosperity	Peace & Partnerships
Total	0.639	0.590	0.566	0.602	0.797
America	0.608	0.630	0.416	0.512	0.873
Sao Paulo	***0.705***	***0.781***	***0.444***	***0.593***	***1***

Regarding the African continent, which has the worst performance compared to other continents, this can be explained by a combination of economic and political factors that make it more challenging to implement policies for achieving sustainable urban mobility.. It needs to be noted, however, that the cities of *Cairo* and *Lagos* possess scores not too far from the average respectively in the *Planet* and *People* dimensions; an explanation of these scores can be provided by the role those cities pose as touristic destination and economic centre of their countries. In particular, the scores obtained in the indicators ***Availability of bike sharing*** and ***Availability of electric scooter sharing*** for *Cairo*, as well as the indicators ***Population Density*** for *Lagos*, contribute to a performance closer to the average score in the respective dimensions. Those two results can affirm the application of sustainable urban mobility policies in the two dimensions that can permit the achievement of well-performing scores when compared to the average ones obtained by the two cities in question.

On a quantitative scale, the three dimensions of *People*, *Planet*, and *Prosperity*, possess comparable descriptive statistics. For example, as shown in table 32, the average scores all belong to a range comprised between 0.56 and 0.61, with some differences in the standard deviation of the data of the scores across the three dimensions.

Table 32 Averages and Std. Deviations comparisons of the index dimensions (own elaboration)

	Overall	People	Planet	Prosperity	Peace & Partnerships
Average	***0.6387***	0.5903	0.5659	0.6019	0.7968
Std. Deviation	***0.1469***	0.1594	0.2183	0.1632	0.2564

Moreover, the overall distribution of the scores for these dimensions, as shown in figure 14 in chapter 6.2, is contained well beyond the extremes set for the numerical range of the scores.

The *Peace & Partnerships* dimension possesses both a higher average, as well as a higher standard deviation; it is also more compressed towards the higher part of the range set for the scores. This point can be explained by two factors:

- *A lower number of indicators when compared to the other dimensions, which can also affect the reaching of less dispersed scores.*
- *The nature of the indicators of the dimension, which only belong to the classification of binary and multinominal variables.*

6.4. Best practices for sustainable urban mobility

In this chapter, the purpose is to provide a benchmark of cities which perform well in terms of the score inside the selected dimensional framework, as well as in terms of the overall performance. A continental overview of the main policies and actions taken by the best-performing cities, is then analysed. This process can help low-performing cities to learn and contextually transfer those best practices, to improve their scores and performances.

The following table provides an overview of the locations obtaining the five best scores in each dimension.

Table 33 Best performing locations in each dimension (own elaboration)

Ranking	**People**	**Planet**	**Prosperity**	**Peace & Partnerships**	**Overall**
1	Los Angeles	Berlin	Kuala Lumpur	Paris	***Stockholm***
2	Frankfurt	Amsterdam	Paris	Singapore	***Amsterdam***
3	Munich	Paris	Singapore	Barcelona	***Milan***
4	Sao Paulo	Tokyo	Tokyo	Milan	***Frankfurt***
5	Dubai	Milan	Barcelona	Brussels	***Munich***

Those cities represent the best performances in each of the dimensions considered, therefore portraying examples in policies and approaches that can be further studied by those cities performing worse. This can help those lower performing locations in improving and raising their score, to achieve better results for both the dimensions and the overall concept of sustainable urban mobility.

An observation needs to be taken on the absence of Stockholm in the top five ranking of the dimensions, while being the overall best performer. As previously discussed in chapter 6.1, the city of Stockholm, when compared to the other locations in the top five overall ranking, performs in a much more steadily pattern, while the other cities possess a wider distribution of their dimensional scores. Table 34 visualizes the scores across all dimensions given to the city of Stockholm, the top performing city in each dimension, and the average dimensional performance. The scores obtained from Stockholm are well beyond the average ones across all dimensions and are not considerably away from the ones obtained by the top performers. Given the more constant performance of Stockholm when compared to the other well performing locations, this results in the Swedish city obtaining the top overall score, as portrayed in table 33.

Table 34 Stockholm scores comparison (own elaboration)

	Overall	**People**	**Planet**	**Prosperity**	**Peace & Partnerships**
Stockholm	***0.828***	***0.734***	***0.845***	***0.731***	***1***
Top performer	-	0.807	0.917	0.872	1
Average	0.639	0.590	0.566	0.602	0.797

In the following sections, a summary of the main policies and activities taken by the recurring cities in the table above will be provided, including all the top five locations as well as the ranking of the overall score, divided by continent.

6.4.1. Europe

- **Paris**

Paris appears most frequently within the top five positions in the dimensional rankings. However, due to its poor performance in the People dimension, it holds the twelfth position in the overall score.

The city of Paris in the last decade has planned, developed, and implemented different policies aiming to achieve better performances in sustainable urban mobility, to tackle the daily challenges suffered by the citizens. In terms of infrastructure, the city and metropolitan governments are aiming to update and expand the reach of public transport to the wider Parisian region, providing faster access to and from the main city. Moreover, this long-term investment plan, aimed to the 2025 horizon, is also developed to keep up with the rising demand that stresses the city transit system, one of the oldest in the world. The increasing share of electric vehicles, both for private and public services, is also beneficial in shifting to less impacting modes of transportation on the environment (Knight, 2017).

Sharing and micromobility options are being implemented, especially with a focus on the cycling mode, by expanding and creating a full cycling network across the whole city. This ambitious plan started in 2015, and was further expanded and funded in 2021, aiming to create by 2026 a full network that covers the city and the adjacent suburbs. It also wants to promote the use of the bicycle as a mode of transportation, for both citizens and tourists, by further widening the resources available to both infrastructure and cycling assets such as charging and parking stations (Ville de Paris, 2024).

- **Barcelona**

The city of Barcelona obtained high scores in the Prosperity and Peace & Partnerships dimensions; the overall score obtained is the best sixth one.

The local government of Barcelona is responsible for developing the plan comprising the actions to be taken in both the short and long term to achieve strategic sustainable urban mobility. Those policies developed for the plan of 2024, on the horizon 2030, comprise the following actions (Ajuntament de Barcelona, 2022):

- P*romoting soft mobility options such as cycling and walking.*
- *Promoting the use of the public transport system, both for citizens and tourists, by expanding, integrating, and updating the infrastructure of the transit system.*
- *Managing the impact of freight and private transport on the social, environmental, and regulatory levels, by also limiting the access of vehicles based on the emissions.*

- *Integration and exploration of the use of new technologies in the policies to improve efficiency, reliability, and sustainability of the overall urban mobility.*

- **Milan**

The city of Milan performs well in the Planet and Peace & Partnerships dimensions, while also achieving the third best overall score.

The urban mobility policies are developed at the metropolitan and regional level, in which those actions are discussed and assessed. The divisions across the policies are taken for different mobility modes, as well with the pertinent indicators portraying and evaluating the effectiveness and monitoring of the results (Sacchi et al., 2021).

The main policies for the 2025-2030 horizon are here listed (Sacchi et al., 2021):

- *Development and expansion of the transit system with modern, efficient, reliable technologies and by integrating the different networks.*
- *Promotion of soft mobility options, especially towards the cycling mode, by improving and expanding the infrastructure available.*
- *Regulating access to vehicles based on emissions and promoting the switch towards clean energy vehicles both for private and public transport.*
- *Integration of new technologies in the development of the policies on the economic, social, and environmental level.*

- **Frankfurt**

Frankfurt performs well in the *People* dimension, as well as obtaining the overall fourth highest score.

The region of Frankfurt developed a comprehensive Sustainable Urban Mobility Plan (SUMP) that encompasses the policies and actions to be undertaken and implemented in order to achieve a transition towards more sustainable forms of urban mobility. The main measures and policies that are set for the 2020-2030 period are as follows (Regional Authority FrankfurtRheinMain, 2020):

- *Expansions and integration of the cycling network, to promote and encourage the use of soft mobility options, as well as enabling pedestrian traffic as alternative.*
- *Creation of multimodal-mobility hubs, providing seamless integration between different modes of transport.*
- *Enabling public transport based on the needs of population, as well as promoting rail-centred land-use planning.*
- *Better integration of commercial transport into the overall scheme of urban mobility.*

- **<u>Munich</u>**

As for the previous portrayed city, Munich performs well in the *People* dimension, and it obtains the fifth best score on the overall ranking.

The extensive transit network of the city supports the transportation of its citizens across the city and the overall metropolitan region with plenty of modal options such as regional and suburban rail, metro, tram and buses. Moreover, the regulations in limiting the access of pollutants emitting vehicles in the city centre, as well as the development of infrastructure dedicated to cycling lanes, helped the city in achieving high results on the overall performance in urban sustainability, with further improvement for the horizon of 2035. The key factors of the transit system of the city, that support an above-average performance, can be represented by affordable transit fares, flexibility in options and alternatives, and fuelling users satisfaction (Oliver Wyman Forum, 2024a).

- **<u>Amsterdam</u>**

The city of Amsterdam obtained the second best performance in the Planet dimension, while also securing the second best score on the overall score ranking.

The development and implementation of policies to achieve sustainable forms of urban mobility, for the timeframe 2019-2025, is held by the local regional government, which focuses on the different aspects and approaches to be undertaken. This development of policies and actions follows two key concepts, which provide the structural framework to work in pursuing the objectives (Gemeente Amsterdam, 2019):

  - *Data and digitalisation*, in order to understand, maintain control, and preview the effectiveness of the policies, by also shifting to a more consolidated integration of the concept of urban mobility. Policies include the use of real-time sensors to provide additional data, for example for crowd management, smart selective access depending on the type of vehicles and destination, a transition from a *traffic* control centre to a *mobility* control centre.
  - *Innovative mobility solutions,* by using new forms of technology and further exploitation of innovation to provide alternative sustainable options of urban mobility for citizens and tourists, with attention to all aspects of economic, social, and environmental sustainability. More specific measures include the creation of mobility hubs as well as logistic hubs, the exploration of new modes of transport such as drones and expanding dedicated spaces to pedestrians and cyclists.

- **<u>Stockholm</u>**

The city of Stockholm, as previously assessed, even though it does not appear in the first five positions of the rankings of the dimensional framework, has the best overall score. Therefore, by possessing the best-performing performance score of the index, it could provide a benchmark with its policies and actions towards sustainable urban mobility.

The main policies and measures that define the actions taken towards sustainable forms of urban mobility are taken by the city of Stockholm. The main policies implemented for the target of 2030 are as follows (International Association of Public Transport, 2024):

- *Creation of two emission-free zones, where only clean energy emitting vehicles can enter, also by promoting sharing services and alternative options with public transport.*
- *Further expanding the electrical support infrastructure for vehicles, encouraging, and enabling higher numbers of vehicles across the population.*
- *Consolidating and expanding the integration across the different modes and options of transportation, between the more traditional forms and sharing and smart modes.*
- *Managing and regulating freight transport towards more sustainable forms, especially in the social and environmental aspects.*
- *General improvement and expansion of the infrastructure supporting the already high share of the cycling mode of transport, to fully enable further incentivization of this form of transportation.*

6.4.2. Asia

- **Singapore**

The city of Singapore performs well in the *Prosperity* and *Peace & Partnerships* dimensions and obtains the ninth best overall performance score.

The local government has developed, and is implementing, a plan to promote the use of sustainable modes of transport, while also transitioning to electric vehicles. This plan consists of providing an integrated, modern, and sustainable-oriented infrastructure and transit system, while also promoting and developing policies in regards of switching to electric vehicles, in line with the 2050 target of net zero emission of the country (Ministry of Transport Singapore, 2024).

Overall actions and policy themes implemented in Singapore can be listed as follows (Diao, 2018):

- *Providing an efficient, improved, and integrated transit system.*
- *Regulating the environmental aspect of vehicles.*
- *Aiming for economic benefits to provide social advantages in the transport system.*

Those points are fundamental for the creation of urban mobility that aims to be sustainable, but also answers to the needs of the citizens, by being flexible, reliable, integrated and dynamic (Diao, 2018).

- **Tokyo**

The city of Tokyo achieved high performances in the *Planet* and *Prosperity* dimensions, but lacked in the other two dimensions, obtaining the fifteenth overall best score.

The policies that are undertaken by the city of Tokyo regarding sustainable urban mobility are based on the use of modern technologies and infrastructures to boost and expand the current transit system. At the same time, regulations, and policies concerning the use of clean energy vehicles are implemented, to further limit the emissions of both private and public transport. The promotion of soft mobility, especially related to cycling, is also undergoing, in terms of both cycling lanes and charging points for electric bikes (Oliver Wyman Forum, 2024c).

Overview, development, and discussion of the plan and policies to be undertaken is done at the government level, with the Tokyo Metropolitan Government being responsible for the plan. This plan covers not only the topic of the sustainable development of urban mobility, but also all the different goals, and respective policies and priorities, across all the SDGs and objectives set for the horizon 2030-2040. (Tokyo Metropolitan Government, 2021).

- **<u>Dubai</u>**

Dubai achieved the fifth best score in the People dimension overall. However, below-average scores in some other dimensions, particularly the Planet dimension, result in a slightly above-average overall performance. Nevertheless, the better performance in the Planet dimension can pose the city as a benchmark regarding other locations in the same region, which aim to improve their *People* score.

Key policies that Dubai is pursuing in aiming for more sustainable forms of urban transportation, set to the 2050 horizon in which emissions aimed to be reduced to zero, include (International Trade Administration - USA, 2023):

- *Promotion of electric vehicles, aiming for a 10% of share of overall vehicles by 2030.*
- *Development and upgrade of 25% of all transportation to an autonomous level by 2030.*
- *Exploring potential new forms of transport, with a focus of connecting neighbouring cities.*
- *Integration of the different modes of transport to improve service quality and reliability.*

6.4.3. America

- **<u>Sao Paulo</u>**

The city of Sao Paulo achieved high performances in the *People* dimension, achieving the best result overall for a location in the American continent.

of the policies and actions towards achieving more sustainable forms of urban mobility are taken by the local government of the city. The goal of a net-free emission city by 2038 is furtherly supported by the following policies, taken in the time interval 2021-2024, with the set horizon of 2028 (Riedemann, 2024):

- *Expansion of bus corridors and cycling lanes across the city.*
- *Transition to a total electric fleet of bus vehicles.*
- *Improving and upgrading the tram and water-buses network.*
- *Switching from diesel to gas-powered vehicles for waste collection.*

6.4.4. Africa

No location belonging to the African continent possesses a score in the top 5 rank of the dimensional framework. The best performing city in terms of the overall score is **Lagos**, which can then pose a benchmark for African cities.

- **<u>Lagos</u>**

The city of Lagos aims to implement policies to promote more sustainable forms of transport. A key focus area is addressing the high rate of motorization, which, combined with rapid urbanization, poses significant concerns for the city's transportation system (Aponjolosun, 2020). The following policies are being implemented towards the horizon aimed at 2030:

- *Promotion of cycling and walking options as mode of transport.*
- *Improving accessibility and safety for pedestrian and cycling on roads.*
- *Study on the feasibility of using cargo bikes for the commercial and informal sector.*
- *Social and environmental promotion of alternatives to the use of private cars.*

6.4.5. Oceania

As in the last chapter, also for the continent of Oceania there are no cities that obtain top scores either overall or for one of the dimensions. The city obtaining the best overall score for this continent is Sydney, which can pose as a more contextual benchmark for those cities belonging to the Oceanian continent.

- **<u>Sydney</u>**

The city of Sydney possesses an extensive fast and reliable multimodal transit network, which provides connections across the greater metropolitan region. A key feature of the road network is the use of an intelligent traffic management system, aimed to reduce the formation of congestion and optimize traffic flows. However, the city particularly suffers from the lack of infrastructure for a softer mode of transportation, as well as general walkability (Oliver Wyman Forum, 2024b).

The responsible entity for developing and implementing the sustainable urban mobility policies is the local department of transport, of the region of New South Wales. Those policies and actions taken on the horizon 2030 include (Oliver Wyman Forum, 2024b):

- *Expansion of the metro network to connect the city centre and the metropolitan area.*

- *Target of 10% of modal share for cycling, by building additional dedicated infrastructure.*
- *Creation of car-free zone to enhance walkability of the city centre.*
- *Improvement and promotion of connections from the airport towards international destinations.*

6.5. Dimensional priorities

In this chapter, a discussion on which pillars all cities should focus will be held. In terms of general performance, this analysis can provide recommendations on the area of the dimensional framework that, on the general level, possess the lowest share and performance.

In table 35 the average score of each dimension is presented, as well as the percentage of cities that performed a score lower than the respective average.

Table 35 Dimensional averages and cities below the values (own elaboration)

	People	**Planet**	**Prosperity**	**Peace & Partnerships**
Average	0.5903	0.5659	0.6019	0.7968
Cities < average	*44%*	*56%*	*49%*	*47%*

The ***Planet*** dimension is the one that has more than half of the cities performing below average, 56%, as well as possessing the lowest dimensional average when compared to the others. Consequently, this dimension could be considered as the **central one** in which all locations should prioritize the development of policies aimed at improving the respective score. Moreover, the ***People*** dimension has the second lowest score, but the smallest percentage of cities performing below average, while the ***Prosperity*** dimension possesses the second highest percentage of cities performing below average. Since improving city scores will also raise the related dimensional average, the People dimension should be the second priority for cities to focus on to enhance their overall performance. Consequently, the ***Prosperity*** dimension should be prioritized as the **third focus** dimension, while the ***Peace and & Partnerships***, supported by the higher average score and share of cities performing below average, should be considered as the **last** dimensional priority.

Cities aimed to improve their respective scores can learn from the top performing locations of their region, as discussed in chapter 6.4, and contextually develop and adapt the policies and actions that helped those cities obtaining better performances.

7. Discussion of the analysis

This chapter critically discusses the developed sustainable mobility index, with a focus on both the results obtained, as well as the main strength and limitations of it.

Key results from the development and calculation of the new sustainable mobility index indicate that, based on the set of cities considered in this thesis, European and Asian cities generally perform above average compared to all the locations considered. Moreover, Europe consolidated their performance thanks to the scores in the *Planet* and *Peace & Partnerships* dimensions, while Asian, and partially American cities as well, can benefit from above average performances in the *People* and *Prosperity* dimensions. Oceanian and African cities, on the other hand, are the locations that generally perform below average, resulting in a gap that those cities can address to improve their performances.

Using sustainable urban mobility indexes can help in evaluating and assessing the context in which the development and implementation of urban mobility policies will be set. Moreover, the ability to benchmark with regional and international locations can help in finding actions that, when contextually adapted, can help in improving the performance over the different dimensions of sustainability. This benchmarking can also be used to evaluate the progress in the implementation of the actions, and the consequent improvement, across the locations under evaluation (Kiba-Janiak & Witkowski, 2019). Indexes play a key role in this development of urban mobility policies, since they produce an evaluation of the state of the urban mobility of a city, from which more specific actions can be implemented to improve specific themes and performances (Persia et al., 2016). Moreover, in the EU, sustainable urban mobility indexes are central tools in monitoring the implementation of policies across all its members, while also acting as a guidance in collecting useful data that can support different sets of policies development across the related themes (European Commission, 2024).

In the next sections, different points of discussion on the new sustainable index will be discussed, as well as some intrinsic limitations associated with the developed index.

7.1. New and old indexes

As discussed in chapters 2 and 3, a key element that characterizes this new developed sustainable index when compared to the ones previously created, is the inclusion of indicators representing the current and future trends in urban mobility. This integration of these variables permits to evaluate the cities on their performance on those topics, which are influencing and will shape the future of urban mobility, an element currently missing from all the indexes consulted in the literature review.

In terms of general strengths of the new sustainable mobility index, those rely on the following points, some of them also previously discussed in chapter 3:

- *Considering a more traditional structural framework of the three pillars of sustainability, while applying the more modern and contemporary structure based on the 5Ps of sustainability and the SDGs.*

- *Balance between the dimensions when calculating the overall score, following the principle of balance between the different Ps.*
- *Focus on the inclusion of indicators portraying current and future trends of urban mobility.*
- *Global reach of the locations considered for the analysis.*

The results calculated can be compared with those obtained by the Arcadis index, as discussed in chapter 2. It should be noted that the results from the 2019 **IDTP** Index, also reviewed in the literature, are not comparable to the newly created sustainable urban mobility index due to the geographical focus on cities solely in North America. Similarly, the **WBCSD** index of 2015 provides guidelines and tools but does not apply them to a specific set of cities, making direct comparison difficult.

7.1.1. Comparison of results with the Arcadis index

In terms of absolute results between the newly created sustainable urban mobility index and the Arcadis index developed in 2017, the following considerations can be made:

- In both indexes, the performances of the top overall cities belong to European and Asian locations, while African and Oceanian cities obtained performances below the general average.
- In the Arcadis dimensions of ***People*** and ***Planet***, which is comparable in terms of concepts expressed to the People and Planet dimensions of the new sustainable mobility index, the trend of top performing European and Asian cities can be identified, respectively in the first and second dimension.
- On the methodological aspect, the overall results obtained from the dimensional framework of the Arcadis index are comparable to those obtained in the newly created sustainable urban mobility index, using a linear balanced aggregation between all the dimensions.

On the other hand, there are some differences between the two indexes, represented by the following points:

- The number of cities considered in the Arcadis index is more than double the ones considered in the newly created sustainable urban mobility index, respectively 100 and 45.
- The Arcadis index uses as structural framework the more traditional concept of the three pillars of sustainability, while the newly created sustainable urban mobility index's dimensional structure is based on the 5Ps of sustainability.
- As discussed in chapter 3, the Arcadis index is missing indicators related to current and future trends of urban mobility, which are included in the newly created sustainable urban mobility index. This can be proven beneficial by policymakers to better assess and contextualize the applications of those trends, in order to improve the overall and dimensional sustainability of their urban mobility.

7.2. Application of the recommendations

The recommendations, and assessment, of the policies undertaken by the best performing cities in the different dimensions of the sustainable urban mobility index can be applied in different ways, across different dimensions such as the geographical, economic, and social context.

A pattern across all the information retrieved can be seen, with many policies focusing on the expansion of the transit systems, by also upgrading and developing new infrastructure and technologies. Moreover, the development of infrastructure is also a key aspect that is retrieved by the promotion of soft mobility options, especially the cycling mode, as portrayed across the cities.

Those actions and policies just overviewed require a significant number of resources, expertise, data, and funds. All those variables are involved when developing the overall plan to reach sustainable urban mobility, as well as the more precise actions and policies to be undertaken. Lacking one of the aspects and variables can determine the development of policies that underestimate and do not properly reflect the context of the application. Moreover, funds are a central factor that all policies and plans share. Without the appropriate allocation of resources and funds, the implementation of sustainable urban mobility policies can fail to achieve the objectives set.

This point is relevant to all locations, but especially for those cities situated in developing countries, which are located mostly in the lowest part of each dimension, as well as the overall score performances. A possible solution can be to provide expertise and knowledge to the stakeholders involved in the development of sustainable mobility solutions, to set and select those policies that can have the bigger impact on the sustainable urban mobility performance, and not waste the precious but often scarce resources involved.

Moreover, in order to fully achieve the objective of improving sustainable urban mobility, the actions and policies to be undertaken need to be properly adapted to the context of application, on geographical, social, economic, and environmental levels. The results of this proper adaptation should see an improvement in the relevant indicators of the sustainable mobility index, reflected also in the performance obtained by it.

7.3. Methodology

Different choices in the methodology can result in different performance scores. The following factors, if applied with a different methodology, can result in different performance scores.

- **Missing data**: the approach used for the consideration of missing data can determine the obtainment of different performances from the locations. In the case of imputation of the missing values, the effect involving the influence of existing data into the inputted one should be considered. As a consequence, four indicators were excluded from the analysis, as the data available inside those was less when compared to the other variables.

- **Normalisation of the data**: this factor as well can determine different results in terms of the score of the locations, in dependence on the method chosen for the normalisation processing of the data.
- **Weights of the indicators**: the weights associated with the indicators are directly responsible for the calculation of the dimensional scores, and by extension, also the overall score. A change in those values heavily influences the results of the sustainable mobility index.
- **Aggregation method**: the method chosen is a linear aggregation, working on the analytical linear combination of the different scores obtained; this is performed both at the dimensional and overall level. A change to a geometric form of aggregation, either at one of the two levels or for both, influences the performance scores. Here reported in table 36 are the changes inside the first fifteen position of the ranking when using the geometric aggregation method, compared to the results obtained with the linear aggregation.

Table 36 Top fifteen rank linear and geometric aggregation comparisons (own elaboration)

Rank	***Linear***		***Geometric***	
	City	**Score**	**City**	**Score**
1	Stockholm	*0.8275*	Stockholm	*0.8206*
2	Amsterdam	*0.8209*	Milan	*0.8107*
3	Milan	*0.8193*	Amsterdam	*0.8091*
4	Frankfurt	*0.8152*	Frankfurt	*0.8060*
5	Munich	*0.8102*	Munich	*0.7996*
6	Barcelona	*0.8000*	Barcelona	*0.7905*
7	Brussels	*0.7929*	Brussels	*0.7795*
8	Berlin	*0.7777*	Berlin	*0.7561*
9	Singapore	*0.7734*	Lisbon	*0.7518*
10	Lisbon	*0.7651*	Singapore	*0.7494*
11	Madrid	*0.7613*	Madrid	*0.7436*
12	Paris	*0.7482*	Shanghai	*0.7343*
13	Shanghai	*0.7354*	Tokyo	*0.7121*
14	London	*0.7259*	London	*0.6974*
15	Taipei	*0.7232*	Taipei	*0.6940*

The results obtained when using the geometric aggregation method for the calculation of the overall results comprise small changes within the score themselves, which are generally slightly lower, as well as changing the ranking positions of some cities. In the top fifteen, some cities are performing better than others using the geometric aggregation, such as the overtake of Amsterdam by Milan for the second top score. Other locations, on the other hand, got worse performances, for example, Paris, which has left the top fifteen ranking, leading to some changes in the ranking of other cities, like the entrance of Tokyo inside the top part of the ranking.

In terms of the validity of the results when related to the methodology, those choices made on the previously represented points define the methodological context of the newly created sustainable urban mobility index. The representation of the new sustainable index for urban mobility, both on the methodological aspect and through the results obtained, is supported on the validity of the choices made on the dimensional level of the 5Ps of sustainability, as well as on the more detailed indicators level, as assessed inside chapter 2 and 3. Moreover, through assessing those limitations and gaps that both the literature and the existing indexes portray, the new sustainable index works towards the filling of these gaps, further validating its role and contribution on the topic.

The inclusion of the results obtained through the geometric aggregation in this section wants to be a review and point towards possible future applications, with reflection on the methodology used, without undermining the results obtained. As the choices made in the methodology define the quantitative calculation, changes on the parameters used, as shown by the use of the geometric aggregation method for the overall score, can lead to changes in the scores, and consequently in the ranking of the cities.

7.4. Limitations

In this chapter, the main limitations that influence both the results and the decisions taken in the development of the sustainable urban mobility index will be assessed, regarding their impact to what was obtained.

7.4.1. Data availability

A main limitation that was already assessed in chapter 4 is the availability of data. Since data was collected from secondary sources, eventual discrepancy and missing values in the databases and sources consulted, are directly transferred to the sustainable urban mobility index as well. This limitation was the reason behind the exclusion of the indicators *Share of Accessible bus network* and *Customer Satisfaction* of the ***People*** dimensions, and the *Average city expenditure on mobility* and the *Utilization of public transport*, both belonging to the ***Prosperity*** dimension.

In terms of impact on the results, the exclusion of those indicators leads to the reduction of the variables available for the *People* and the *Prosperity* dimensions. The quantitative consequences are related to the distribution of the indicator scores in the two dimensions, which by reducing the number of indicators available, portray a representation with less data. On the other hand, by excluding those indicators, given the lowest share of available data, it limits the phenomenon of dealing with missing data, and the consequences described in previous sections that are related with it.

7.4.2. Peace & Partnership dimension

In regard to the dimensional framework, a limitation needs to be recognised with respect to the dimension *Peace & Partnerships*. As previously assessed in chapter 3.1.3, this dimension was created to unify and portray the two concepts of **Peace** and **Partnerships** of the **5Ps** of sustainability. The reason behind this union of concepts into one dimension was the difficulty in portraying the two Ps with quantitative indicators. In the dimensional application into the index, three indicators were selected and developed in order to portray it. The number of indicators associated with the Peace & Partnership dimension is below the number of indicators associated with all the other dimensions assessed. The consequences and impacts to the results obtained is certainly a quantitative limitation of scores obtained, in terms of absolute numbers and score range, when compared to the other dimensions of the sustainable mobility index.

An expansion of the indicators inside this dimension can bring further development both in terms of insights and performances associated with the locations. In addition, the indicators used for the sustainable urban mobility index developed during this thesis are only belonging to the binary and multinominal type. Therefore, the inclusion of quantitative indicators of the continuous type can expand and diversify more the performances of the cities. Useful indicators could cover topics and themes in more details such as the **easiness** for users to switch between different modes, the **integration** availability of last-mile soft mobility options with more traditional modes, or the **overall level** of coordination, integration, and flexibility of the locations' transit system.

7.5. Contribution of Culture

This chapter wants to provide a reflection on the possibility of using a dimensional framework comprising the addition of the fourth pillar to the three representing the concept of sustainability. The decision taken over the dimensional framework of the new sustainable mobility index was based on the use of the 5Ps of sustainability. However, the reflection started from the three pillars of sustainability, in which a discussion on the addition of the Culture pillar is part of the debate surrounding it.

As the process of finding a balance between the three pillars is a constant debate focused on values, those discussions can be depicted as cultural debates. A sustainable society depends on sustainable policies, which are driven by a sustainable culture; cultural action is required to provide the framework and groundwork for developing policies and actions that reflect the desired sustainability (Hawkes, 2001). Moreover, the contribution that the cultural heritage provides to both the concept of sustainability itself as well as the three pillars is recognised, therefore achieving the needed direct connection between culture and sustainable development (Astara, 2014). Cultural heritage is deeply linked to the three pillars in many aspects, providing a powerful asset for economic growth, a fundamental component for socially inclusive development, and a historical combination of knowledge and skills towards environmental preservation.

In support of this last consideration, there is the evaluation that cultural instances and their expression cannot be entirely comprised inside one of the three pillars alone, therefore requiring a pillar that can encompass culture and include the complex interaction with the environmental, social, and economic aspects of sustainable development (Sabatini, 2019).

On general terms, the addition of this pillar to the three could also be used to assess better the changes and trends that are taking place in the topic of sustainability, portraying a possible new class of indicators. This can be considered the main advantage of including a new pillar that is able to intercept the need to add indicators that reflect current and future mobility trends and variables.

However, a disadvantage is the concept of cultural sustainability itself, especially when compared to societal sustainability. As priorly portrayed, the content of cultural sustainability is especially focused on how the changes needed are part of a cultural change, which is required to develop policies and actions to achieve the desired sustainability (Hawkes, 2001); therefore, the close connection to the societal aspect of sustainability can be seen as a reason and support for not adding the culture pillar by itself.

When considering the relation that the concept of Culture has onto the used dimensional framework of the new sustainable mobility index, based on the 5Ps, the UNESCO found that culture contributes to the 5Ps in many ways, as reported in table 37:

Table 37 Contribution of culture to the 5Ps (UNESCO, 2018)

The 5Ps	**Ways in which culture contributes to the 5Ps**
People	• Identity and knowledge: cultural assets are protected and safeguarded • Inclusion and participation: access to cultural life and diverse cultural expressions is supported • Artistic freedom, creativity and innovation are nurtured
Planet	• Natural heritage and biodiversity are protected • Positive relationships between cultural and natural environments are strengthened • Resilience, including cultural resilience, is enhanced
Prosperity	• Livelihoods based on culture and creativity are enhanced • Openness and balance in the trade of cultural goods and services is achieved
Peace	• Cultural diversity and social cohesion are promoted • Sense of identity and belonging is enhanced • Restitution of cultural goods and rapprochement are promoted
Partnerships	• Governance of culture is transparent, participatory and informed • Safeguarding tangible and intangible heritage • Global trade of cultural goods and mobility of creative producers • Global inequities in the safeguarding and promotion of culture are reduced

Therefore, it can be assessed that the contribution of the concept of culture into the structural framework of the 5Ps is wide and already recognised. This discussion adds a point of view on the validity of the structural framework chosen for the new sustainable mobility index, which can overcome a central theme of discussion that surrounds the three pillars of sustainable as possible framework.

8. Conclusions and further research

This thesis aimed to develop a sustainable index evaluating the performance on urban mobility of different locations worldwide. The elaborated research questions and consequent objectives were developed, and the thesis structure was created to follow logical and integral steps for creating this sustainable mobility index.

An overview of the available literature on the topic was explored to determine the information available on the topics and concepts central to the development and application of the sustainable mobility index. This passage included the assessment of three key indexes, their methodologies, and the indicators portrayed inside. This process highlighted missing features inside those indexes, such as the expression of current and future trends of urban mobility with the indicators. The overall literature review supported in laying the framework of characteristics that the new sustainable mobility index needed to provide. This structural framework selected relies on the concepts of the Ps of sustainability, in which four dimensions were created, reflecting the different sustainability concepts. Subsequently, the indicators used inside the analysed indexes were assessed to check and discuss their relevance in the new sustainable urban mobility index. In addition to the chosen indicators, the development of new ones was carried out, in order to portray current and future trends of mobility adequately.

A set of cities was selected to apply the newly created sustainable urban mobility index to. The criteria followed different factors that helped assess this selection on a global level to portray different geographical, economic, and social contexts. The performances of the selected locations were then calculated and assessed, obtaining a score in each of the dimensions of the sustainable urban mobility index and an overall score based on the linear aggregation of the dimensional scores. The obtainment of the performance scores helped determine the best-performing cities in each dimension. Those cities were then used to assess and determine the policies, actions, and plans that can help those cities less performing to get inspiration on the areas and actions needs to improve their score.

Overall, the new sustainable mobility index found that the performance of European and Asian cities was, on average, better when compared to the selected locations in the other continents. On the other hand, African locations obtained scores below the overall average across the whole dimensional framework. The reason behind those performances can be found across different factors, such as the availability of funds and resources, as well as more intrinsic societal and economic context across the regions.

Further research on the topic should perform and collect an analysis repeated over time of the performances as calculated in the index can help in assessing not only the pattern the cities are having but also allows the creation of historical data and trends of both the variables considered and the dimensional performances. This is a crucial point, especially concerning those cities currently possessing a lower performance, to which the implementation of contextually adapted policies, applied in the best-performing locations, could help improve their sustainable urban mobility. Furthermore, an investigation of the possibility of expanding the variables inside the Peace &

Partnerships dimension, can expand the overview of the concept expressed and improve the overall analysis of sustainable urban mobility.

This new sustainable mobility index was aimed to fill the gap between sustainable mobility indexes and their inclusion of current and future mobility trends. Moreover, comparing the results obtained in the global set of cities enables us to assess the actions implemented by the ones performing at the top of the dimensions as a benchmark for the other regional locations, which aim to improve their scores.

In conclusion, this thesis wants to underline the validity and support that a sustainable mobility index can bring, not only to assess the current situation in cities across the world but also to help them contextually implement the policies used by well-scoring cities to improve the ones more struggling in achieving better performances.

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Appendix

Appendix 1 Global City Power Index 2023 (Yamato et al., 2023)

Position	City	Position	City
1	London	25	Chicago
2	New York	26	Geneva
3	Tokyo	27	San Francisco
4	Paris	28	Dublin
5	Singapore	29	Boston
6	Amsterdam	30	Istanbul
7	Seoul	31	Helsinki
8	Dubai	32	Vancouver
9	Melbourne	33	Milan
10	Berlin	34	Moscow
11	Copenhagen	35	Taipei
12	Sydney	36	Washington, DC
13	Vienna	37	Osaka
14	Madrid	38	Bangkok
15	Shanghai	39	Sao Paulo
16	Stockholm	40	Tel Aviv
17	Beijing	41	Kuala Lumpur
18	Hong Kong	42	Fukuoka
19	Zurich	43	Mexico City
20	Frankfurt	44	Buenos Aires
21	Los Angeles	45	Jakarta
22	Barcelona	46	Johannesburg
23	Toronto	47	Cairo
24	Brussels	48	Mumbai

Appendix 2 List of Alpha category cities of GaWC 2020 Edition (GaWC - The World According to GaWC 2020, 2020)

Category	Cities
Alpha ++	• London • New York
Alpha +	• Hong Kong • Singapore • Shanghai • Beijing • Dubai • Paris • Tokyo

Alpha	• Sydney • Los Angeles • Toronto • Mumbai • Amsterdam • Milan • Frankfurt • Brussels	• Mexico City • Sao Paulo • Chicago • Kuala Lumpur • Madrid • Moscow • Jakarta
Alpha -	• Warsaw • Seoul • Johannesburg • Zurich • Melbourne • Istanbul • Bangkok • Stockholm • Vienna • Guangzhou • Dublin • Taipei • Buenos Aires	• San Francisco • Luxembourg • Montreal • Munich • Delhi • Santiago • Boston • Manila • Shenzhen • Riyadh • Lisbon • Prague • Bangalore

Appendix 3 Cities pool and dimensional assessment

Cities	**Top 20 Euromonitor CDI 100**	**GPCI 2023**	**Megacities**	**Globalization and World Cities Research Network**			
				Alpha ++	*Alpha +*	*Alpha*	*Alpha-*
Paris	X	X			X		
Dubai	X	X			X		
Madrid	X	X				X	
Tokyo	X	X	X		X		
Amsterdam	X	X				X	
Berlin	X	X					
New York	X	X		X			
Barcelona	X	X					
London	X	X		X			
Singapore	X	X			X		
Munich	X						X
Milan	X	X				X	
Dublin	X	X					X
Osaka	X	X					
Hong Kong	X	X			X		
Los Angeles	X	X				X	
Lisbon	X						X
Melbourne		X					X
Sydney		X				X	

Shanghai		X	X		X		
Stockholm		X					X
Zurich		X					X
Frankfurt		X				X	
Toronto		X				X	
Brussels		X				X	
Chicago		X				X	
San Francisco		X					X
Boston		X					X
Istanbul		X					X
Moscow		X				X	
Taipei		X					X
Bangkok		X					X
Sao Paulo		X				X	
Kuala Lumpur		X				X	
Mexico City		X	X			X	
Buenos Aires		X					X
Jakarta		X				X	
Johannesburg		X					X
Cairo		X	X				
Mumbai		X	X			X	
Seoul	X	X					X
Rome	X						
Vienna	X						
Copenhagen		X					
Geneva		X					
Helsinki		X					
Vancouver		X					
Washington, DC		X					
Tel Aviv		X					
Fukuoka		X					
Dhaka			X				
Karachi			X				
Lagos			X				
Warsaw							X
Guangzhou							X
Luxembourg							X
Montreal							X
Santiago							X
Manila							X
Shenzhen							X
Riyadh							X
Prague							X
Bangalore							X

Appendix 4 List of sources for the data collection

Ind.	City	Company / Institution and relative website reference	
Share of accessible metro stations	**Paris**	Citytransit	https://citytransit.uitp.org/paris#
	Dubai	VisitDubai	https://www.visitdubai.com/en/articles/accessibility-guide-dubai
	Madrid	Citytransit	https://citytransit.uitp.org/madrid#percentageStepFreeMetroAccess
	Tokyo	Tokyometro	https://www.tokyometro.jp/lang_en/station/search_accessibility/oneroot.html
	Amsterdam	City of Amsterdam	https://www.iamsterdam.com/en/travel-stay/accessibility/public-
	Berlin	Citytransit	https://citytransit.uitp.org/berlin#
	New York	MTA	https://new.mta.info/accessibility/
	Barcelona	Citytransit	https://citytransit.uitp.org/barcelona
	London	Citytransit	https://citytransit.uitp.org/london
	Singapore	Citytransit	https://citytransit.uitp.org/singapore#percentageStepFreeMetroAccess
	Munich	MVV	https://www.mvv-muenchen.de/en/mobility/barrier-free/index.html
	Milan	ATM	https://www.atm.it/it/AltriServizi/Disabili/Pagine/atmperidisabili.aspx
	Osaka	OsakaMetro	https://subway.osakametro.co.jp/en/barriafree/subway/barriar_free_subway/barriar_free_subway.p hp
	Hong Kong	Citytransit	https://citytransit.uitp.org/hong-kong#percentageStepFreeMetroAccess
	Los Angeles	Citytransit	https://citytransit.uitp.org/los-angeles#percentageStepFreeMetroAccess
	Lisbon	Metro Lisboa	https://www.metrolisboa.pt/en/travel/diagrams-and-maps/
	Sydney	Citytransit	https://citytransit.uitp.org/sydney#percentageStepFreeMetroAccess
	Shanghai	Wheelchairtravel	https://wheelchairtravel.org/shanghai/public-transportation/
	Stockholm	Citytransit	https://citytransit.uitp.org/stockholm#percentageStepFreeMetroAccess
	Frankfurt	VGF	https://www.vgf-ffm.de/en/services/service-for-passengers/mobility-for-all
	Toronto	TTC	https://cdn.ttc.ca/-/media/Project/TTC/DevProto/Images/Home/Routes-and-Schedules/Landing-page-pdfs/TTC_SubwayStreetcarMap_2021-11.pdf?rev=b9ab97e4c76549549c0cb09c210c508e
	Brussels	Mobiliteit Brussel	https://mobilite-mobiliteit.brussels/en/projects/accessibility-of-metro-stations
	Chicago	Transit Chicago	https://www.transitchicago.com/accessibility/asap
	San Francisco	SFMTA	https://www.sfmta.com/getting-around/accessibility/muni/muni-access-guide/access-muni-metro
	Boston	MBTA	https://www.mbta.com/stops/subway#subway-tab
	Istanbul	Metro Istanbul	https://www.metro.istanbul/en/YolcuHizmetleri/AgHaritalari
	Moscow	Citytransit	https://citytransit.uitp.org/moscow#percentageStepFreeMetroAccess
	Sao Paulo	Metro SP	https://www.metro.sp.gov.br/wp-content/uploads/2023/05/Desktop_Guide_abr_2022_v2.pdf

	Kuala Lumpur	Wheelchairtravel	https://wheelchairtravel.org/kuala-lumpur/public-transportation
	Mexico City	Metro CDMX	https://metro.cdmx.gob.mx/la-red/mapa-de-la-red
	Buenos Aires	Citytransit	https://citytransit.uitp.org/buenos-aires#percentageStepFreeMetroAccess
	Mumbai	Mumbai Metro	https://www.reliancemumbaimetro.com/features#StationFacilities
	Seoul	Visit Seoul	https://english.visitseoul.net/essential-Info-article/Accessibility_/398
Airport Passengers	**Paris**	ADP	https://presse.groupeadp.fr/2023fy-traffic/?lang=en
	Dubai	Reuters	https://www.reuters.com/business/aerospace-defense/dubai-airport-expects-surpass-pre-pandemic-passenger-numbers-2023-2023-11-15
	Madrid	Barajas Airport	https://madridbarajasairport.net/statistics/
	Tokyo	NAA and TIAT	https://www.naa.jp/en/airport/pdf/statistics20240125.pdf https://www.tiat.co.jp/en/result/docs/04185b191d67dc75b9760c93c7dd4da7e4f73ad0.pdf
	Amsterdam	ETIAS	https://etias.com/articles/2023-schiphol-airport-traffic-analysis
	Berlin	Berlin Airport	https://corporate.berlin-airport.de/content/dam/corporate/en/unternehmen-presse/ber/verkehrsstatistik/2023/20241101_Traffic_Statistics_December.pdf
	New York	Bloomberg	https://www.bloomberg.com/news/articles/2024-01-31/nyc-airports-hit-record-year-in-2023-with-144-million-travelers
	Barcelona	AENA	https://www.aena.es/en/press/aena-airports-in-spain-close-2023-with-more-than-283-million-passengers.html&p=1575076641928
	London	Statista, London City Airport	https://www.statista.com/statistics/303654/number-of-arriving-and-departing-passengers-in-united-kingdom-airports https://www.londoncityairport.com/corporate/corporate-info/facts-and-figures
	Singapore	Changi Airport	https://www.changiairport.com/corporate/media-centre/newsroom.html#/pressreleases/changi-airports-2023-passenger-traffic-recovers-to-86-percent-of-pre-covid-level-boosted-by-strong-q4-growth-3298791
	Munich	Munich Airport	https://www.munich-airport.com/press-air-traffic-continues-to-grow-significantly-in-2023-22055468
	Milan	Assaeroporti	https://assaeroporti.com/statistiche/
	Dublin	Dublin Airport	https://www.dublinairport.com/latest-news/2024/01/24/almost-32-million-through-dublin-airport-s-terminals-in-2023
	Osaka	Kansai Airport	http://www.kansai-airports.co.jp/en/news/2023/1026/E_240125_TrafficReport_December2023.pdf
	Hong Kong	Aviation24	https://www.aviation24.be/airports/hong-kong-hkg/hong-kong-air-traffic-recovery-continues-in-2023-as-december-sees-post-pandemic-new-heights/
	Los Angeles	LAWA	https://www.lawa.org/lawa-investor-relations/statistics-for-lax/10-year-summary/passengers
	Lisbon	VINCI	https://www.vinci.com/commun/communiques.nsf/6D529D6EECC7BC2AC1258AA6003CE67E/$file/vinci-airports--traffic-31-december-2023.pdf
	Melbourne	Melbourne Airport	https://www.melbourneairport.com.au/corporate/melbourne-airport-passenger-performance-june-2023-and-fy23
	Sydney	Sydney Airport	https://www.sydneyairport.com.au/corporate/media/corporate-newsroom/sydney-airport-traffic-performance-december-2023
	Stockholm	Arlanda Airport	https://arlandastockholmairport.com/statistics/
	Zurich	Flughafen Zurich	https://www.flughafen-zuerich.ch/newsroom/en/zurich-airport-passenger-numbers-closer-to-pre-covid-levels/

	Frankfurt	FRA Airport	https://www.fraport.com/en/newsroom/press-releases/2024/traffic-figures/fraport-traffic-figures-2023--passenger-demand-continues-recover.html
	Brussels	Brussels Airport, LeSoir	https://www.brusselsairport.be/brusselsairportnews/en/january-2024/22-2-million-passengers-in-2023 https://www.lesoir.be/565140/article/2024-01-31/le-secteur-aerien-retrouve-des-couleurs-32-millions-de-passagers-en-belgique-en
	Chicago	City of Chicago	https://www.chicago.gov/city/en/depts/doa/provdrs/dbata/news/2024/march/03062024.html
	San Francisco	FlySFO	https://www.flysfo.com/sites/default/files/2024-01/Dec%202023%20and%20CYTD%20SFO%20Air%20Traffic%20Summary.pdf
	Boston	MASSPort	https://www.massport.com/sites/default/files/2024-01/avstats-airport-traffic-summary-dec23.pdf
	Istanbul	Reuters, Statista	https://www.reuters.com/business/aerospace-defense/istanbul-airport-targets-85-mln-passengers-2024-acting-ceo-2023-12-29/ ; https://www.statista.com/statistics/1421702/turkeyi%25CC%2587stanbul-sabiha-goekcen-airport-traffic-by-passenger-type/
	Taipei	Taoyuan Airport	https://www.taoyuanairport.com.tw/passengervolume?lang=en
	Bangkok	Statista	https://www.statista.com/statistics/1020260/thailand-total-number-of-air-passengers-by-airport
	Sao Paulo	Panrotas, Viracopos	https://www.panrotas.com.br/aviacao/aeroportos/2024/01/aeroporto-de-guarulhos-registra-413-milhoes-de-passageiros-em-2023_202515.html https://www.viracopos.com/data/files/55/11/04/CE/0EC0D810710CF7C84918E9C2/RMA%202023%20DEZ%202023%20-%20elaborado%20em%20JAN2024.pdf
	Kuala Lumpur	MAHB	https://mahb.listedcompany.com/newsroom/MAHB_Traffic_Snapshot_-_December_2023_20240131.pdf
	Mexico City	AICM	https://www.aicm.com.mx/acercadelaicm/archivos/files/Estadisticas/EstadisticasDic2023.pdf https://datos.anac.gob.ar/estadisticas/article/720c108f-3f8c-436c-8159-5fd0506b75e6 https://www.menpan.go.id/site/berita-terkini/berita-daerah/penumpang-pesawat-bandara-ap-ii-tembus-80-14-juta-di-2023
	Buenos Aires	Airports of Argentina	https://www.airports.co.za/airports/or-tambo-international-airport/statistics/passenger
	Cairo	Egypt Air Show	https://www.egypt-air-show.com/news/passenger-traffic-soars-28-egyptian-airports-2023
	Mumbai	Economic Times of India	https://economictimes.indiatimes.com/industry/transportation/airlines-/-aviation/passenger-traffic-rose-35-pc-to-51-58-million-at-mumbai-airport-in-2023/articleshow/107091351.cms?from=mdr
	Seoul	Incheon Airport	https://incheonseoulairport.com/statistics/
	Auckland	Auckland Airport	https://corporate.aucklandairport.co.nz/news/publications/monthly-traffic-updates
	Perth	Perth Airport	https://www.perthairport.com.au/Home/corporate/about-us/airport-statistics
	Lagos	ACI Africa	https://www.aci-africa.aero/files/Africa-Air-Traffic-Performance-2022-EN-Final-270423.pdf
	Nairobi	ACI Africa	https://www.aci-africa.aero/files/Africa-Air-Traffic-Performance-2022-EN-Final-270423.pdf
Hours of metro operation	**Paris**	RATP	https://www.ratp.fr/visite-paris/francais/accedez-aux-gares-et-aeroports
	Dubai	City of Dubai	https://www.visitdubai.com/en/articles/guide-to-dubai-metro
	Madrid	City of Madrid	https://www.esmadrid.com/en/madrid-metro
	Tokyo	City of Tokyo	https://www.gotokyo.org/en/plan/getting-around/subways/index.html
	Amsterdam	City of Amsterdam	https://www.introducingamsterdam.com/metro
	Berlin	City of Berlin	https://www.berlin.de/en/public-transportation/1742343-2913840-underground- subway.en.html
	New York	MTA	https://new.mta.info/guides/riding-the-subway

	Barcelona	TMB	https://www.tmb.cat/en/barcelona/operating-hours-metro-bus
	London	VISITLONDON	https://www.visitlondon.com/traveller-information/getting-around-london/london-tube
	Singapore	City of Singapore	https://www.lta.gov.sg/content/ltagov/en/getting_around/public_transport/rail_networ k.html
	Munich	City of Munich	https://www.introducingmunich.com/u-bahn
	Milan	City of Milan	https://www.yesmilano.it/en/subway-trams-and-buses
	Osaka	JAPAN-EXPERIENCE	https://www.japan-experience.com/decouvrir/osaka/attractions-excursions/les-transports-en-commun-a-osaka
	Hong Kong	MAPWAY	https://www.mapway.com/travel-guides/hong-kong-travel-guide
	Los Angeles	City of Los Angeles	https://www.introducinglosangeles.com/metro-rail
	Lisbon	METROLISBOA	https://www.metrolisboa.pt/en/travel/timetables-and-frequency
	Sydney	NSW Transport	https://transportnsw.info/documents/timetables/93-M-Sydney-Metro-North-West- 20230929.pdf
	Shanghai	City of Shanghai	https://service.shmetro.com/en/hcskb/index.htm
	Frankfurt	RMV	https://www.rmv.de/c/de/fahrplan/fahrplaene/linienfahrplaene/
	Toronto	TTC	https://www.ttc.ca/customer-service/TTC-Service-Details
	Brussels	City of Brussels	https://www.introducingbrussels.com/metro
	Chicago	City of Chicago	https://www.choosechicago.com/plan-your-trip/getting-around
	San Francisco	City of San Francisco	https://www.sanfrancisco.net/subway
	Boston	City of Boston	https://www.mbta.com/guides/subway-guide
	Istanbul	Metro Istanbul	https://www.metro.istanbul/en/SeferDurumlari/SeferDetaylari
	Moscow	City of Moscow	https://transport.mos.ru/en/faq
	Taipei	Metro Taipei	https://english.metro.taipei/News_Content.aspx?n=034BD8E0AB821D47&s=A3E779360436C045
	Bangkok	THAIZER	https://www.thaizer.com/bangkok-metro-mrt-underground-train
	Sao Paulo	Metro SP	https://www.metro.sp.gov.br/wp- content/uploads/2023/05/Desktop_Guide_abr_2022_v2.pdf
	Kuala Lumpur	MyRapid	https://myrapid.com.my/bus-train/rapid-kl/lrt-operating-hours
	Mexico City	City of Mexico City	https://mexicocity.cdmx.gob.mx/e/getting-around/mexico-city-metro-faq
	Buenos Aires	City of Buenos Aires	https://turismo.buenosaires.gob.ar/en/article/getting-around
	Jakarta	Jakarta MRT	https://jakartamrt.co.id/en
	Cairo	Cairo Metro	https://cairometro.gov.eg/en/operations/1
	Mumbai	Mumbai Metro	https://www.reliancemumbaimetro.com/metro-train-
	Seoul	Visit Seoul	https://english.visitseoul.net/transportation
Population Density	**Paris**	Statista	https://www.statista.com/statistics/1047176/population-density-ile-de-france-paris-region-by-department-france/
	Dubai	WorldPopulationReview	https://worldpopulationreview.com/world-cities/dubai-

	Madrid	WorldPopulationReview	https://worldpopulationreview.com/world-cities/madrid-
	Tokyo	WorldPopulationReview	https://worldpopulationreview.com/world-cities/tokyo-
	Amsterdam	WorldPopulationReview	https://worldpopulationreview.com/world-cities/amsterdam-
	Berlin	Statista	https://www.statista.com/statistics/1109974/population-density-berlin-germany
	New York	WorldPopulationReview	https://worldpopulationreview.com/us-cities/new-york-city-ny-population
	Barcelona	WorldPopulationReview	https://worldpopulationreview.com/world-cities/barcelona-population
	London	WorldPopulationReview	https://worldpopulationreview.com/world-cities/london-population
	Singapore	WorldPopulationReview	https://worldpopulationreview.com/countries/singapore-population
	Munich	WorldPopulationReview	https://worldpopulationreview.com/world-cities/munich-population
	Milan	WorldPopulationReview	https://worldpopulationreview.com/world-cities/milan-population
	Dublin	WorldPopulationReview	https://worldpopulationreview.com/world-cities/dublin-population
	Osaka	WorldPopulationReview	https://worldpopulationreview.com/world-cities/osaka-population
	Hong Kong	WorldPopulationReview	https://worldpopulationreview.com/countries/hong-kong-population
	Los Angeles	WorldPopulationReview	https://worldpopulationreview.com/us-cities/los-angeles-ca-population
	Lisbon	TML Mobilidade	https://www.tmlmobilidade.pt/wp-content/uploads/2023/06/Relatorio_04_TML_2023_Reg1370_2022.pdf
	Melbourne	WorldPopulationReview	https://worldpopulationreview.com/world-cities/melbourne-population
	Sydney	City of Sydney	https://www.cityofsydney.nsw.gov.au/guides/city-at-a-glance
	Shanghai	WorldPopulationReview	https://worldpopulationreview.com/world-cities/shanghai-population
	Stockholm	WorldPopulationReview	https://worldpopulationreview.com/world-cities/stockholm-population
	Zurich	WorldPopulationReview	https://worldpopulationreview.com/world-cities/zurich-population
	Frankfurt	WorldPopulationReview	https://worldpopulationreview.com/world-cities/frankfurt-population
	Toronto	WorldPopulationReview	https://worldpopulationreview.com/canadian-cities/toronto-population
	Brussels	WorldPopulationReview	https://worldpopulationreview.com/world-cities/brussels-population
	Chicago	US Census	https://www.census.gov/quickfacts/fact/table/chicagocityillinois/PST045222
	San Francisco	WorldPopulationReview	https://worldpopulationreview.com/us-cities/san-francisco-ca-population
	Boston	WorldPopulationReview	https://worldpopulationreview.com/us-cities/boston-ma-population
	Istanbul	WorldPopulationReview	https://worldpopulationreview.com/world-cities/istanbul-population
	Moscow	WorldPopulationReview	https://worldpopulationreview.com/world-cities/moscow-population
	Taipei	Statista	https://www.statista.com/statistics/1317802/taiwan-population-density-by-region
	Bangkok	Statista	https://www.statista.com/statistics/1422857/thailand-population-density-in-bangkok
	Sao Paulo	WorldPopulationReview	https://worldpopulationreview.com/world-cities/sao-paulo-population

	Kuala Lumpur	WorldPopulationReview	https://worldpopulationreview.com/world-cities/kuala-lumpur-population
	Mexico City	WorldPopulationReview	https://worldpopulationreview.com/world-cities/mexico-city-population
	Buenos Aires	WorldPopulationReview	https://worldpopulationreview.com/world-cities/buenos-aires-population
	Jakarta	Statista	https://www.statista.com/statistics/1423885/indonesia-jakarta-population-density
	Johannesburg	WorldPopulationReview	https://worldpopulationreview.com/world-cities/johannesburg-population
	Cairo	WorldPopulationReview	https://worldpopulationreview.com/world-cities/cairo-population
	Mumbai	WorldPopulationReview	https://worldpopulationreview.com/world-cities/mumbai-population
	Seoul	Statista	https://www.statista.com/statistics/1112322/south-korea-population-density-by-province/
	Auckland	WorldPopulationReview	https://worldpopulationreview.com/world-cities/auckland-population
	Perth	WorldPopulationReview	https://worldpopulationreview.com/world-cities/perth-population
	Lagos	WorldPopulationReview	https://worldpopulationreview.com/world-cities/lagos-population
	Nairobi	WorldPopulationReview	https://worldpopulationreview.com/world-cities/nairobi-population
Presence of Low Emission Zone (LEZ)	**Paris**	City of Paris	https://www.paris.fr/pages/la-zone-a-faibles-emissions-zfe-pour-lutter-contre-la-pollution-de-l-air-16799
	Madrid	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/spain/madrid-lez
	Tokyo	Tokyo City	https://www.kankyo.metro.tokyo.lg.jp/en/automobile/diesel.html
	Amsterdam	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/netherlands-mainmenu-88/amsterdam
	Berlin	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/germany-mainmenu-61/berlin
	Barcelona	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/spain/barcelona
	London	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/united-kingdom-mainmenu-205/london
	Munich	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/germany-mainmenu-61/munchen
	Milan	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/italy-mainmenu-81/lombardia/milano
	Hong Kong	City of Hong Kong	https://www.info.gov.hk/gia/general/201512/31/P201512310204.htm
	Lisbon	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/portugal/lisbon
	Stockholm	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/sweden-mainmenu-248/stockholm
	Frankfurt	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/germany-mainmenu-61/frankfurt
	Brussels	UrbanAccessRegulation	https://urbanaccessregulations.eu/countries-mainmenu-147/belgium/bruxelles-brussel-brussels
	Moscow	Science Direct	https://www.sciencedirect.com/science/article/pii/S1462901115301003
	Jakarta	DETIK	https://news.detik.com/berita/d-6285913/low-emission-zone-artinya-apa-lez-berlaku-di-kota-tua-jakarta
	Seoul	TrueInitiative	https://www.trueinitiative.org/media/792173/remote-sensing-seoul-true-paper.pdf
City/regional comprehensive tariff zone	**Paris**	Ile de France Mobilites	https://www.iledefrance-mobilites.fr/
	Dubai	RTA	https://www.rta.ae/wps/portal/rta/ae/public-transport

	Madrid	Madrid Region	https://www.comunidad.madrid/servicios/transporte
	Amsterdam	City of Amsterdam	https://www.iamsterdam.com/en/travel-stay/getting-around/public-transport
	Berlin	VBB	https://www.vbb.de/en/
	New York	MTA	https://new.mta.info/fares
	Barcelona	ATM	https://www.atm.cat/atm/el-consorci
	London	TFL	https://tfl.gov.uk/corporate/about-tfl/what-we-do?intcmp=2582
	Singapore	LTA Singapore	https://www.lta.gov.sg/content/ltagov/en/getting_around/public_transport/plan_your_journey.html
	Munich	MVV	https://www.mvv-muenchen.de/mvv-und-service/der-mvv/der- verbundgedanke/index.html
	Milan	Agenzia TPL	https://www.agenziatpl.it/agenzia/chi-siamo
	Dublin	National Transport	https://www.nationaltransport.ie/about-us/
	Osaka	City of Osaka	https://osaka-info.jp/en/information/ticket/travel-passes/
	Hong Kong	Octopus	https://www.octopus.com.hk/en/consumer/octopus-cards/about/index.html
	Los Angeles	Metro	https://www.metro.net/about/
	Lisbon	Metro Lisboa	https://www.metrolisboa.pt/comprar/
	Melbourne	City of Melbourne	https://www.melbourne.vic.gov.au/SiteCollectionDocuments/transport-strategy-2012- 03-effective-integrated-public-transport.pdf
	Sydney	Transport NSW	https://www.transport.nsw.gov.au/system/files/media/documents/2020/CC017-10-Year-Blueprint-ext.pdf
	Shanghai	City of Shanghai	https://english.shanghai.gov.cn/en-Transportation/20231214/c727f5e15eff4b8c9340651dd95f3f7c.html
	Stockholm	City of Stockholm	https://sl.se/sl/om-sl/det-har-ar-sl
	Zurich	City of Zurich	https://www.stadt-zuerich.ch/jetztmorgen
	Frankfurt	RMV	https://www.rmv.de/c/de/informationen-zum-rmv/der-rmv/aufgaben-der-rmv-gmbh
	Toronto	TTC	https://www.ttc.ca/about-the-ttc
	Brussels	STIB	https://www.stib-mivb.be/article.html?l=fr&_guid=d0707200-2683-3410-479e-b21a51d668f0
	Chicago	Transit Chicago	https://www.transitchicago.com/about/
	San Francisco	Clipper Card	https://www.clippercard.com/ClipperWeb/
	Boston	MBTA	https://www.mbta.com/about/how-to-ride-the-mbta-the-basics
	Istanbul	Metro Istanbul	https://www.metro.istanbul/en/SeferDurumlari/BiletUcretleri
	Moscow	Introducing Moscow	https://www.introducingmoscow.com/tickets-travelcards
	Taipei	Metro Taipei	https://www.metro.taipei/cp.aspx?n=CEF54168B23F73B4
	Sao Paulo	SP Trans	https://www.sptrans.com.br/tarifas
	Mexico City	City of Mexico City	https://mexicocity.cdmx.gob.mx/e/getting-around/mexico-city-metro-faq/
	Buenos Aires	State of Argentina	https://www.argentina.gob.ar/redsube

	Jakarta	City of Jakarta	https://smartcity.jakarta.go.id/en/blog/aneka-metode-pembayaran-transportasi-di- jakarta/
	Johannesburg	City of Johannesburg	https://joburg.org.za/Campaigns/Documents/2014%20Documents/CoJ%20SITPF%20Draft%2013%20May%202013%20(1).pdf
	Auckland	AT	https://at.govt.nz/about-us/our-role-organisation
	Perth	TransPerth	https://www.transperth.wa.gov.au/about-us
	Lagos	LAMATA	https://www.lamata-ng.com/company-overview/
City/regional comprehensive tariff zone	**Osaka**	City of Osaka	https://www.city.osaka.lg.jp/contents/wdu020/enjoy/en/overview/policies_and_measures/transportation.html
	Melbourne	City of Melbourne	https://www.melbourne.vic.gov.au/SiteCollectionDocuments/transport-strategy-2030-city-of-melbourne.pdf
	Sydney	NSW	https://www.future.transport.nsw.gov.au/future-transport-plans/greater-sydney-services-and-infrastructure-plan
	Istanbul	City of Istanbul	https://www.ibb.gov.tr/tr-TR/kurumsal/Birimler/ulasimPlanlama/Documents/%C4%B0UAP_Ana_Raporu.pdf
	Taipei	City of Taipei	https://english.dot.gov.taipei/cp.aspx?n=D6B1F24203FE7B57
	Sao Paulo	City of Sao Paulo	https://gestaourbana.prefeitura.sp.gov.br/wp-content/uploads/2015/01/Plano-Diretor-Estrat%C3%A9gico-Lei-n%C2%BA-16.050-de-31-de-julho-de-2014-Estrat%C3%A9gias-ilustradas.pdf
	Kuala Lumpur	City of Kuala Lumpur	https://cms.uitp.org/wp/wp-content/uploads/2022/10/22-10-Brief-SMMR-WEB-300DPI.pdf
	Mexico City	City of Mexico City	https://www.movilidad-integrada.tianguisdigital.cdmx.gob.mx/docs/plan-estrategico-de-movilidad-2019.pdf
	Buenos Aires	City of Buenos Aires	https://buenosaires.gob.ar/movilidad/institucional-subsecretaria-de-planificacion-de-la-movilidad
	Jakarta	UNESCAP	https://www.unescap.org/sites/default/files/4.1%20%20Planning%20and%20development%20of%20urban%20transport%20systems%20in%20Jakarta.pdf
	Johannesburg	City of Johannesburg	https://joburg.org.za/Campaigns/Documents/2014%20Documents/CoJ%20SITPF%20Draft%2013%20May%202013%20(1).pdf
	Mumbai	City of Mumbai	https://mmrda.maharashtra.gov.in/planning/regional-plan/final-rp-for-mmr
	Seoul	City of Seoul	https://www.seoulsolution.kr/sites/default/files/gettoknowus/Seoul%20Transportation%202030.pdf
	Lagos	State of Lagos	https://transportation.lagosstate.gov.ng/2023/10/19/commissioner-for-transportation-mr-oluwaseun-osiyemi-center-was-joined-by-the-technical-adviser-corporate-and-investment-planning-lamata-engr-osa-konyeha-left-and-dr-moshe-hirsh-from-rom
Availability of electric scooter sharing			Cityscoot website; Riba website; Rabbit website; HUBChari website; Ewaka website; Felyx website; Voi website; Joon website; Klook website; HelloCycling website; Go-Sharing website; Docomocycle website; Lyft Scooter website; Bird website; Scooty website; Tier website; Lime website; Bolt website; Shanghai municipal website; Scooby website; Veoride website; Helbiz website. https://www.seoulz.com/top-e-bike-and-e-scooter-startups-in-korea-micromobility/
Availability of electric vehicles in car sharing			ShareNow website; Free2Move website; Socar website; Zipcar website; Mobility website; Careco website; GoCar website; AIMO website; SIXT website; Yourcar website; Virtuo website; Enjoy website; Carrot website; GoGet website; Cityhop website; Ubeeqo website
Presence of highest grade of automation transit system			Hitachi website, Alstom website; Siemens website; Thales website

	https://cms.uitp.org/wp/wp-content/uploads/2020/06/Statistics-Brief-Metro-automation_final_web03.pdf
Investment in highest grade of automation transit system	Hitachi website, Alstom website; Siemens website; Thales website https://cms.uitp.org/wp/wp-content/uploads/2020/06/Statistics-Brief-Metro-automation_final_web03.pdf
City Available on transport apps	Citymapper website, Moovit website

Appendix 5 Continental performance across average dimensional scores

Classes	**Perc Overall**	**Perc People**	**Perc Planet**	**Perc Prosperity**	**Perc P&P**
Europe > average	93%	67%	93%	67%	87%
Europe < average	7%	27%	0%	27%	7%
Asia > average	69%	62%	46%	77%	38%
Asia < average	31%	38%	54%	23%	62%
Africa > average	0%	0%	0%	0%	0%
Africa < average	100%	100%	100%	100%	100%
America > average	44%	44%	0%	22%	44%
America < average	56%	44%	89%	67%	44%
Oceania > average	25%	25%	0%	0%	25%
Oceania < average	75%	75%	100%	100%	75%