Politecnico di Torino

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Master of Science in Civil Engineering

The EU Urban Mobility Indicators as a tool to monitor a Sustainable Urban Mobility Planning process: a comparative study of their applicability in Italy and Colombia

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ABSTRACT

Mobility is the mean that allows the citizens of a community to access of different services, facilities and opportunities for the integral development in areas like education, health and economy. To meet these necessities, the governments provide infrastructure and transport services to facilitate these movements. However, these services are not always the most adequate, since they do not fulfil the peoples' needs and do not adjust to the current challenges in terms of climate changes. According to Statista, transportation is responsible for the 8.24 billion metric tons of carbon dioxide ($GtCO_2$) in 2023 representing a 21% of the global greenhouse gases emissions delivered to our atmosphere thus contributing in great manner to climate change, making it in the second highest emission second worldwide (1). On the other hand, mobility issues such as the traffic jams make quality of life of people is being affected by the long time spent moving to their daily activities.

Considering the above, Sustainable Urban Mobility Plans (SUMPs) have emerged as essential tools for the local authorities as a public policy to improving the urban transport systems mitigating the impacts of mobility problems from the social equity, economic and environmental perspective. To understand how SUMPs are being applied in different latitudes, this thesis aims to identify key areas for improvement and shared learning strategies among the SUMP from Turin (Italy), Valle de Aburrá and Cúcuta (Colombia) metropolitan areas.

This research is based on a comparative analysis of these plans, using statistical data from household surveys that are the basis for the strategies of each SUMPs, complemented with an evaluation of the state of mobility through the Urban Mobility Indicators (UMI) developed by the European Commission. These indicators provide a standardized and comprehensive framework for the comparison across SUMPs, in order to establish baselines, the assessment of urban mobility performance, and the identification of similarities, weaknesses and gaps in sustainability objectives, data collections methods, and strategies approaches.

By comparing the mobility data available in the case studies upon with the respective SUMPs have been built, this thesis assess to which extent UMIs can be used in the present situation, this identifying how data collection activities should be adapted to male more effective their use, and vice-versa which are the limitation of the proposed set of indicators if the goal is to draw comparative analyses across radically different cities. Finally, recommendations on the integration of best practices from each case study are offered.

SOMMARIO

La mobilità è il mezzo che consente ai cittadini di una comunità di accedere a diversi servizi, strutture e opportunità per lo sviluppo integrale in settori come l'istruzione, la salute e l'economia. Per soddisfare queste necessità, i governi forniscono infrastrutture e servizi di trasporto per facilitare questi spostamenti. Tuttavia, questi servizi non sono sempre i più adeguati, poiché non soddisfano le esigenze delle popolazioni e non si adattano alle sfide attuali in termini di cambiamenti climatici. Secondo Statista, i trasporti sono responsabili di 8,24 miliardi di tonnellate metriche di anidride carbonica (GtCO2) nel 2023, che rappresentano il 21% delle emissioni globali di gas serra rilasciate nell'atmosfera, contribuendo così in modo significativo al cambiamento climatico, e sono al secondo posto tra le emissioni più elevate a livello mondiale (1). D'altra parte, i problemi di mobilità, come gli ingorghi, fanno sì che la qualità della vita delle persone sia compromessa dai lunghi tempi di spostamento per le attività quotidiane.

Alla luce di quanto sopra, i Piani Urbani di Mobilità Sostenibile (PUMS – o SUMP nell'acronimo in inglese) sono emersi come strumenti essenziali per le autorità locali come politica pubblica per migliorare i sistemi di trasporto urbano mitigando gli impatti dei problemi di mobilità dal punto di vista dell'equità sociale, economica e ambientale. Per capire come i SUMP vengono applicati a diverse latitudini, questa tesi mira a identificare le aree chiave di miglioramento e le strategie di apprendimento condivise tra i SUMP delle aree metropolitane di Torino (Italia), Valle de Aburrá e Cúcuta (Colombia).

La ricerca si basa su un'analisi comparativa di questi piani, utilizzando dati statistici provenienti da indagini di mobilità che sono alla base delle strategie di ciascun SUMP, integrati da una valutazione dello stato della mobilità attraverso gli Urban Mobility Indicators (UMI) sviluppati dalla Commissione Europea. Questi indicatori forniscono un quadro standardizzato e completo per il confronto tra i SUMP, al fine di stabilire dei valori di riferimento, la valutazione delle prestazioni della mobilità urbana e l'identificazione di somiglianze, debolezze e lacune negli obiettivi di sostenibilità, nei metodi di raccolta dei dati e negli approcci strategici.

Confrontando i dati sulla mobilità disponibili nei casi di studio su cui sono stati costruiti i rispettivi SUMP, questa tesi valuta in che misura gli UMI possono essere utilizzati nella situazione attuale, identificando come le attività di raccolta dei dati dovrebbero essere adattate per renderne più efficace l'uso e, viceversa, quali sono i limiti del set di indicatori proposto se l'obiettivo è quello di tracciare analisi comparative tra città radicalmente diverse. Infine, vengono offerte raccomandazioni sull'integrazione delle migliori pratiche di ogni caso di studio.

ACKNOWLEDGEMENT

This thesis is dedicated to my family, especially to my father who, although he is no longer with me, I am sure that he accompanied me throughout this process and is celebrating this achievement with me. To my mother, my sister, and pepito, who were the strength that sustained me in this process, and to Sebastián, who was day and night giving me his company, support and love in this wonderful chapter of my life.

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I. INTRODUCTION

In the last decade, the rapidly growing of urban areas provoked different problems in terms of transportation, use of land, demographics, and environment, among others. According to INRIX Traffic Scorecard, that provide information about the time that people take in their daily commutes, Istanbul reported the highest traffic daily time with 105 hours, followed by New York City with 102 hours (2). This situation is commonly associated to the big cities, but transportation issues are also found in small cities. For example, Dublin is considered the third most congested city in Europe in the last years, mostly because, the citizens relay on the use of cars creating traffic issues in peak hours (3).

For these reasons, different governments around the world are looking for solutions and alternatives that increase the quality of life of the citizens. One example of this is the case of Ljubljana, Slovenia where the local authorities converted one of the most congested main road in the city, in an attractive public place with sidewalks, cycle paths, reduced the lanes dedicated exclusively to public transport, reducing at the same time the noise and air contamination (4). Considering this background, one example of the actions to find solutions are the Sustainable Urban Mobility Plans (from now on SUMPs), which were born as a transport and land planner instrument composed of plans and strategies focused on sustainable mobility, reducing the most common problems associated to: traffic congestion, accessibility, air pollution, greenhouse gas emissions, efficiency of the public transport system, integration of public transport, cycling infrastructure, pedestrian accessibility and providing innovative mobility solutions.

Regarding SUMPs, in essence they are technical documents developed by local authorities where the current state of mobility is described to propose plans and actions to improve the quality of life of people and in general, to reach the environmental goals in terms of greenhouse emissions as an action to mitigate the climate change, focused on the integration of all transport modes. Additionally, SUMP provides guidelines for sustainable mobility to be understood as a public policy.

One of the processes for evaluating the correct development and implementation of SUMPs is based on standardized Urban Mobility Indicators (UMIs), developed by the European Commission in 2024 (5). These indicators assess seven main areas that are the bases of sustainable mobility: crashes, modal share, noise and air pollution, congestion, greenhouse gas (GHC) emissions and accessibility. Through UMIs, metropolitan areas can check that strategies and goals planned in the SUMPs are being effectively implemented and monitored.

Therefore, the main objective of this thesis is verifying the use of the UMIs as an instrument for evaluating and monitoring the implementation of SUMPs in different urban contexts, concentrated on a comparative analysis of three case studies: Metropolitan Areas of Turin (Italy), Valle de Aburrá and Cúcuta (Colombia). This comparative analysis is based on theory, household travel survey data, and the computation of UMIs, determining the feasibility and adaptability of UMIs to support the SUMP monitoring process.

In order to reach the aim, the thesis is structured as follows:

- **Chapter I** Provides a brief introduction to the current situation of mobility, an overview of the SUMPs, and the thesis objective and methodology are presented.
- **Chapter II** reviews the existing literature about the transition from traditional to sustainable transport planning, including the conceptual foundation of SUMPs in Europe and Colombia, and the role of UMIs in monitoring phase of SUMPs goals.
- **Chapter III** was organized into three main parts:
    1. A description of each case study has been described in terms of geographic location, population, topography, extension of the territory and other general aspects.
    2. Each SUMP is detailed presenting the structure of each plan, the characterization of the demand and supply of its transportation systems, a description of the underlying

    transport model, the expected results and a brief list of objectives, projects, strategies, and activities that the public administration will be implementing to develop the plan.
    3. A comparative analysis among the SUMPs subject of this study is finally presented.
- **Chapter IV** where the data set is described based on the household surveys carried out in each metropolitan area, using univariable and bivariate analysis descriptive statistics. The data set were analysed and valuable data that can be potentially used in the computation of UMIs were identified.
- **Chapter V** was organized into two main parts:
    - The computation of each UMI indicator was carried out for the three case studies.
    - According to the results of the computation, the alignment between the SUMPs and UMIs were evaluated, identifying the easiness of computing these indicators in the SUMPs monitoring process and finally, a recommendation about the inclusion of the UMIs in the monitoring process was assessed.
- **Chapter VI** presents the thesis conclusions.

The methodology used to develop the scope of the thesis consisted in five phases:

Phase 1: Literature Review
A comprehensive literature review is conducted to establish a theoretical foundation of the SUMPs, including:

1. Review the bases and the difference between traditional transport and sustainable transport, called urban mobility paradigms.
2. Compilation of background information related to Sustainable Mobility Plans.
3. Presentation of European Union and Colombian regulations and policies regarding the implementation of SUMPs.
4. Examination of the SUMPs monitoring process and the relation of the UMI framework.

Phase 2: Case Study and Data Collection
The case study selection to consider the complete and relevant information available about the current implementation of a SUMPs and the possible similarities of each city in terms of various contexts. SUMPs are a concern of the public administration; therefore, the information must come from official sources like the departments of mobility, ministries of transport or corresponding local authorities in the field. Once the information is found, it will be revised that it has all components needed to develop the scope of the project which basically are:

- The technical report of the SUMPs.
- Official reports.
- Household survey data from each metropolitan area to identify key mobility patterns.

Phase 3: Analysis Framework
To start with the comparison of each SUMP, the information collected in phase 2 is examined, beginning with the review, identification and description the presentation of the socioeconomic characteristics of the city, the demand and supply diagnostic, the plan formulation, the objectives and the implementation strategies of each SUMP.

Secondly, the analysis of the household survey data will begin with a list of all the variables found in each of the surveys with their corresponding characterization. Following, the most relevant variables were selected from the surveys, which were studied and described using univariate statistics to assess the behaviour of them, and other considerations about the variable survey were presented.

Finally, indicators were selected considering the most relevant for providing an overview of the state of mobility in each case study.

Phase 4: Application of UMI indicators
Calculation and assessment of the selected UMI indicators based on SUMP documentation, survey data analyzed, and official reports.

Phase 5: Assessment and Recommendations
Based on the results from UMI indicators and the SUMPs comparisons, an assessment was conducted where some similarities and differences were identified in terms of SUMPs goals and strategies, data collection. This approach led to recommendations regarding embedding UMI with the SUMPs, best practices, and complementary learning and opportunities among the case studies.

II. LITERATURE REVIEW

This chapter develops a literature review with the aim of contextualizing Sustainable Urban Mobility Plans (SUMPs) and the role of Urban Mobility Indicators as a tool for their monitoring and evaluation. First, the urban mobility paradigm is explored, focusing on the transition from traditional transport models to sustainable transport planning. Then, the normative and strategic frameworks of SUMPs in the European Union and Colombia are examined, identifying their objectives and implementation process. Finally, the evaluation process of the SUMPs is analyzed, delving into the use and applicability of urban mobility indicators as mechanisms in planning process. This theoretical framework establishes the basis for the comparative analysis carried out in the following chapters.

2.1 The Urban Mobility Paradigms

Transportation is *"the action or process of transporting conveyance (of things or people) from one place to another"* (Oxford English Dictionary, n.d., definition), This action has always been one of the most important aspects of the development of societies, and the search to move, to find new territories, new markets, jobs, or possibilities to access health services, education or recreation activities have been all possible thanks to transportation. The evolution of transportation has always gone hand in hand with the needs generated daily in the territories, making transportation systems more efficient and profitable for the cities (6 pp. 1-2).

Traditional transport planning is mainly focused on improving the distance that people travel within their time and money budgets and therefore, maximizing travel speed through for example, the expansion of roadway capacity or improving the road network (7 p. 2). This approach is based on a set of interconnected steps, starting with the identification of a problem, followed by the collection of data related to traffic speed, traffic flow and vehicle costs. With the analysis of the data it is possible to study the current situation through a model that allows forecasting possible solutions, or new strategies according to the requirements of the community thus, with the results from the forecast, is possible to present the solutions in a plan that can be implemented specially for short or medium terms (6).

The transport system takes many benefits, but it also causes many challenges and problems associated with the traditional transport planning, particularly regarding the climate change and environmental pollution due to the fact that, traditional transportation is a major source of greenhouse gas emissions, congestion and economic costs associated with car-centric infrastructure, land use impacts, social impacts and public health (8).

In the way to reduce the impacts of traditional transport, sustainable transportation was born, which contributes to the sustainable development of the community that owns and uses the system. This by means of introducing transport modes more environmentally friendly, active mobility, improving the user choice of public transport systems, reducing car dependency, using clear fuels and technologies, promoting efficient land use, among others (9 p. 6). In this sense, the transport planning was adapted to these new needs looking for sustainable transport planning, which focuses on the balance mobility needs with the reduction of negative environmental, social and economic impacts, prioritizing the accessibility, equity and environmental sustainability. This model encourages the use of multimodal systems combining walking, cycling and public transport systems; and integrated strategies of equity, public health, and climate change into transportation plans with milestones developed in the long term (10 p. 5).

As a summary, the following Table 1 compares the approaches of traditional transport versus sustainable transport planning:

Table 1
Differences between traditional transport and sustainable transport planning

ASPECT	TRADITIONAL TRANSPORT	SUSTAINABLE TRANSPORT
Objective	Improve the capacity and speed of the road network, in order to reduce congestion and travel times.	Reduce the emissions, improve the accessibility and equity.
Modal focus	Private car is the priority.	Public transport and non-motorized modes and its integration.
Environmental impacts	Considered as an externality generated by the transport mobility.	The impacts are the central point in the planning and decision making.
Key policy	Improve and expansion of vial infrastructure.	Promotion of active modes, use of electric modes and demand management.
Time horizon	Short- and medium-term solutions.	Long-term vision.
Planning experts	Planning by experts like traffic engineering.	Planning by interdisciplinary experts and involving stakeholders and citizens.
Urban planning	Segregation of land uses.	Promote mixed uses.

Source: (11 p. 10)

However, both approaches seek to facilitate the people and goods mobility. Additionally, the infrastructure network is essential although their approach and design differ, and both use transport models to forecast demand patterns like the four-step model. There are key differences between how it traditional and sustainable transport mobility are applied, which are listed in Table 2

Table 2
Different between traditional and sustainable transport design process

ASPECT	TRADITIONAL TRANSPORT	SUSTAINABLE TRANSPORT
Objective	Predict the traffic patterns and build infrastructure to meet the future demand, primarily prioritizing car mode and reduce travel times.	Based on the same steps but reinterpreted them with an emphasis on reduced environmental impacts and improve the quality life.
Trip Generation	The aim is predicting the total number of trips generated by one origin and attracted to one destination, based on factors such as population, their socio-economic characteristics, land uses, number of cars, etc.	The aim is reducing the unnecessary trips by encouraging the contributions of different sustainable policy directions, for example incentives for the use of public transport and/or cycling on home-school or home-work.
Trip Distribution	Used to estimate the total number of trips originated from a specific zone and those trips attracted to specific destinations.	Prioritizes local destinations reducing long-distances travel, including actions to improve access to specific destinations by public transport system.
Modal Split	Predict the portion or number of trips made by each available transport mode to travellers, influenced by the characteristics of each trip maker, the trip characteristics and the transport facility characteristics.	Promotes non-motorized modes of transport (cycling, walking) and efficient public motorized mobility, and the use of car as the last option.
Route Assignment	Represent the demand for travel in the study area, assigning traffic to different routes where trips will be made in the infrastructure network.	Optimizes routes to minimize emissions, travel time and congestion. Prioritizes public transport services, improve the bicycle infrastructure, healthy streets, reorganize the urban system into units that can be enjoyed on foot (15 minutes).

Source: (12) and (11)

2.2 Historical Bases of Sustainable Urban Mobility Planning

2.2.1 Set-up in the European Union

In 1985, the European Parliament brought an action against the Court of Justice of the European Union urging the Council to act and to implement a common transport policy, comprising numerous aspects, such as infrastructure, prices, conditions, social issues, and among others. Following on December 1992, the European Commission adopted the White Paper on the future of the common transport policy, which sets out a framework for sustainable mobility (13).

This was followed in 2001 by the White Paper "European transport policy for 2010: time to decide", which was a milestone in the need to address the environmental impacts produced by transport. This document introduced sixty measures, such as promoting the use of quality and accessible collective public transport for the free movement of people, goods and services, such as the use of railroads to reduce the dependence on cars, international connections to strengthen sustainable mobility polices, environmental protection against greenhouse gas emissions, among others (14).

In 2006, the European Commission presented a review of the 2001 version of White Paper, where commitments were reinforced by including specific sustainable targets for the transport sector. In 2008, a package of measures of green transport was included, based on the internalization of external transport costs (15 p. 2).

By 2009, the European Commission introduced the SUMP concept (Sustainable Urban Mobility Plan) as a strategic approach to help authorities achieve sustainable urban mobility goals. In 2013, SUMP guidelines were published which aim to integrate dynamic developments in various areas of mobility and some experiences related to implementation of the strategies of sustainable urban mobility. These guidelines were updated in 2019 and have been adopted by most cities in the European Union (11 p. 7).

Urban mobility planning has significantly evolved with the integration of new technologies and global climate objectives, so in 2021, the European Commission presented several proposals on decarbonizing transport to achieve climate neutrality by 2050. In 2023, the European Parliament approved a motion for a resolution on the development of a cycling strategy which aims to encourage cycling habits, promoting the construction of more dedicated cycling lanes (15 pp. 3-5).

2.2.2 Sustainable mobility initiatives in Latin America

Regarding Latin America, the rapid urban growing in the last century has made it the most urbanized region in the world, where approximately 80% of the region's population lives in the cities and urban areas. This situation is bringing problems as the infrastructure is not changing in the same way, while the middle classes join to private motorized mobility, incrementing congestion and pollution, the rest of the population depends on a poor public transport and active mobility making that the use of motorcycle increases, worsening in special the impacts on road safety, accessibility and air quality (16 p. 11).

For those reasons, some local governments in that region of the world are now adopting best practices and new paradigms which focus on access and sustainable transport, with the support of different initiatives with parentship form developments countries for example the IDB (Inter-American Development Bank) and the EUROCLIMA+ that supported different regions to adopt a local SUMP's (16 p. 17).

The strategies to move to a sustainability mobility in Latin America started with the bus rapid transit (BRT) that became a popular approach to cost-effectively improve urban mobility for more vulnerable population. Curitiba, Brazil in 1977 was the first city in developed the BRT System, and then based on this model, Bogotá, Colombia, launched TransMilenio in year 2000, being one of the largest BRT systems in terms of mobilizing people. During 2002 and 2013, governments across Latin America begun investing in modern urban systems like the first cable car, which was designed as transport system in Medellín, Colombia in year 2004. Since then, different cities like Caracas, Venezuela, La Paz, Bolivia, Rio de Janeiro, Brazil, have built similar systems (17 pp. 8-13).

Another example is the vehicle driving restriction, where Latin America has been the pioneer on this issue that tries to reduce traffic congestion during peak hours, however, several studies showed that permanent restrictions do not have effect to reduce pollution or traffic, since the households buy a second car (17 pp. 14-15).

Under the Paris Agreement, Latin America nations created National Urban Mobility Policies and Investment Programs (NUMPs) that contains frameworks and strategies with specific targets to reduce the emissions of the transport systems, and fulfill the mobility necessities of people, for example, in Colombia the National Strategy has the aim of promoting walking and cycling options in order to reduce the car dependency. The strategy includes directives in terms of territorial planning, infrastructure, and financial instruments. Another example is Uruguay, that in 2022, presented the guidelines for electric urban mobility were options for the promotion of electric mobility for freight and passenger were formulated (18).

Finally, new strategies will continue to be presented throughout the world, which allow them to meet the decarbonization and reduce the environmental impacts that urban mobility generates.

2.3 Sustainable Urban Mobility Plan in the European Union

2.3.1 Background Information

As mentioned above, the SUMP (Sustainable Urban Mobility Plan) is a strategic plan used in cities across the European Union to develop sustainable transport systems. The first edition of the European Guidelines was published in 2013 as a framework for countries implementing the SUMP, updated in 2019 with the second edition.

The Urban Mobility Package is a set of initiatives aimed at improving urban mobility and reducing environmental impacts and defines the SUMP through eight commonly guiding principles (Table 3).

Table 3
Eight Commonly Guiding Principles

EIGHT COMMONLY GUIDING PRINCIPLES		
1st	**Plan for sustainable mobility in "functional urban area"**	Identifying the functional area is a key concept to representing the flows of people and goods. This helps understand how people and goods move inside and outside the area, ensuring that transport mobility meets all the user's needs. The integration of all transport systems should be efficient, reducing the externalities caused by transport systems and significantly improving the inhabitants' living conditions.
2nd	**Cooperate across institutional boundaries**	Good interaction between different levels of government and institutions in the planning area ensures a good design and implementation of the SUMP, reducing the interference and problems between institutions.
3rd	**Involve citizens and stakeholders**	The SUMP must meet the requirements of citizens and stakeholders within the functional area, involving these actors throughout all phases of the plan.
4th	**Assess current and future performance**	The SUMP builds on an assessment of the current transport system situation in the functional area, providing a baseline for future scenarios.

EIGHT COMMONLY GUIDING PRINCIPLES		
5th	**Define a long-term vision and a clear implementation plan**	The SUMP includes objectives and targets within a long-term vision for transport and mobility in the entire functional urban area.
6th	**Develop all transport modes in an integrated manner**	The SUMP considers all transport systems in the functional urban area, integrating various strategies to achieve plan objectives like improving safety, accessibility, cost efficiency.
7th	**Arrange for monitoring and evaluation**	The SUMP objectives must be monitored through performance indicators.
8th	**Assure quality**	The SUMP must be developed with high quality, ensuring it meets all the requirements and needs of the functional urban area.

Source: (11 pp. 11-13).

These principles aim to create a cycle of activities focused on promoting public transport system by investing in new infrastructure, integrated transport plans for multimodal mobility, encouraging active mobility like walking and cycling, using low or zero-emission vehicles, educating citizens and engaging stakeholders to address the city needs.

An example of SUMP implementation is in the Piedmont region of Italy, where electric buses were procured for regional transport operators through a public-private partnership. The region covers 90% of the new buses cost, and operators cover 10%, expecting to save 769 tons of CO2 per year and approximately € 50,000 over 10 years (11 p. 152).

2.3.2 Goals and Objectives

The goal of the SUMP in the European Union is to *"Improve accessibility and quality of life by achieving a shift towards sustainable mobility"* (11)*,* including social equity, health and environmental quality, and economic viability. Other benefits include improving citizens health, reducing emissions, enhancing road safety, and increasing institutional collaboration for urban development.

2.3.3 Planning and Implementation

Following the guiding principles (Table 3), the SUMP in the European Union is developed in a cyclical manner, adaptable to the needs of each city. This cycle is divided into four phases, each with twelve steps and thirty-two activities. Milestones at the beginning and the end of each phase help evaluate effectiveness.

The SUMP is developed using a bottom-up approach. Once a cycle is completed, a new one begins to ensure efficiency and avoid delays. Effective SUMP planning involves integrating transport, land use, environmental, economic and social authorities, as well as stakeholders, transport system operators and citizens, to create locally adapted plans and avoid unfeasible commitments.

The phases of the SUMP are as follows:

Phase 1: Preparation and analysis
This phase is composed by 3 steps and 10 activities, each activity involves an interdisciplinary group of professionals who initially analyse the current situation, resources, needs, main problems, and opportunities in the functional area that will be improving with the develop of the plan.

Phase 2: Strategy Development
This phase is composed by 3 steps and 6 activities, here is to define objectives and strategies based on future scenarios and establish indicators to monitor progress, all these activities are working with citizens and stakeholders.

Phase 3: Measure Planning
This phase is composed by 3 steps and 9 activities; these involves measure planning to track objective and track progress.

Phase 4: Implementation and Monitoring
This phase is composed by 3 steps and 7 activities, these proposing strategies to improve citizens quality of life through sustainable mobility according to the new challenges for the future.

The subdivision of the SUMP is described in Figure **Error! Reference source not found.**:

Figure 1
Cycle of Sustainable Urban Mobility Plan – Europe Union

Source: (11 p. 31)

2.3.4 Instruments

The SUMP employs several instruments to encourage sustainable mobility in the European Union:

a) Encouraging public transport use through investment in quality infrastructure, making it accessible and affordable for the citizens.
b) Creating more pedestrian and bike infrastructure to promote clean transportation option.
c) Integrated urban transport planning with land use, and environmental considerations to create efficient sustainable transport systems.
d) Utilizing smart mobility and technologies to optimize real-time information like traffic flow and infrastructure control.
e) Advancing low-emission vehicle technologies with stricter regulations and government programs to reduce CO2 emissions.
f) Exploring financial programs like public-private partnerships for sustainable urban mobility projects.
g) Facilitating cooperation between stakeholders and citizens to identify and create innovative plans and strategies for the SUMP.

2.3.5 Implementation in Italy

According to the SUMP Observatory in Italy, since 2014 different municipalities have been implemented the European Guideline, with a total of 80 documents approved, 57 adopted and 74 in development until November 2023 (19), as detailed in the Table 4:

Table 4
Sustainable Urban Mobility Plan in Italy

Region	Approved	Adopted	Under Development
Puglia	8	16	18
Sicilia	8	4	7
Lazio	3	2	6
Piemonte	5	2	1
Campania	0	5	5
Marche	4	0	5
Valle d'Aosta	0	1	0
Toscana	10	2	7
Veneto	2	4	4
Lombardia	11	3	8
Emilia-Romagna	14	2	2
Trentino-Alto Adigio	2	0	0
Sardegna	3	4	5
Molise	1	0	1
Calabria	0	3	2
Abruzzo	1	2	1
Umbria	4	1	1
Liguria	2	2	1
Friuli-Venezia Giulia	2	2	0
Basilicata	0	2	0

Source: (19)

2.4 Sustainable Urban Mobility Planning in Colombia

2.4.1 Background Information

The Congress of Colombia enacted Law 1083 of 2006 replaced by the article 96 of Law 1955 of 2019, establishing norms for urban sustainability planning in Colombia. The aim is to emphasize the use of alternative modes of transport, such as walking, bicycling, or other non-polluting means of transportation, as well as public transport system that run on clean fuels. Each city must apply these norms through a Mobility Plan. Various entities, including the Ministry of Transport, the Ministry of Environment, and the Ministry of Housing, support cities in implementing of this law.

In 2020, the Ministry of Transport published Resolution No. 20203040015885, which provides technical assistance and guidelines for developing and formulating the strategies, programs, and projects of the SUMP. These regulations are based on an analysis of the current mobility situation and the territorial planning model defined in the Territorial Planning Plan (POT), while also recognizing environmental regulations. The SUMP focuses on cities that implement non-motorized or low/zero-emission public transport systems, aiming to reduce emission and ensure the safety of users (20).

An example of this implementation is the Sustainable and Safety Mobility Plan of Bogota D.C., which aims to reduce the use of private car and motorcycle from 20% in 2019 to 15% in 2035, to increase the use of bicycle from 7% in 2019 to 13% in 2035, encourage the use of public transport system from 37% in 2019 to 41,5% in 2035 and reduce the travel time to 35 minutes (21).

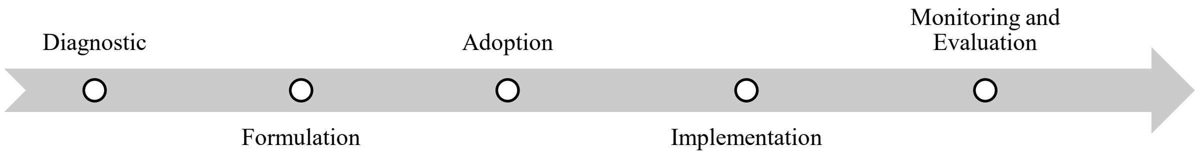
2.4.2 Goal and Objectives

In Colombia, the primary goal of implementing the SUMP is to transform mobility through strategies tailored to each city's specific needs. The objectives include encouraging non-motorized mobility, promoting the use of mass transportation modes, optimized the use of the private vehicle, and promoting safe behaviours on the streets, all aimed at improving the quality of life for citizens (20).

2.4.3 Planning and Implementation

The SUMP in Colombia is defined by five phases that must be developed sequentially and progressively, as shown in Graph 1:

Graph 1
Phases of the Sustainable Urban Mobility Plan Colombia



Source: (20)

Phase 1: Diagnostic
This phase serves as the baseline of the SUMP, presenting information about land use, the current mobility situation, financial analysis of mobility-related income and expenditure, land structure analysis, infrastructure diagnosis, transport demand analysis (including origin and destination matrix, trip distribution, and travel times), and assessment of externalities generated by mobility.

Phase 2: Formulation:

Based on data collected during diagnostic phase, this phase produces a support document that includes future scenarios aligned with mobility objectives, geographic, environmental, and economic conditions. It also defines strategies, programs, activities and projects with a timetable, as well as indicators for the monitoring phase, feasible financing sources, and risk analysis to evaluate potential hazards affecting sustainable mobility and their corresponding mitigation actions.

The mobility objectives (20 p. 14) are:

1. Articulating mobility systems with the urban-territorial structure of the Territorial Planning Plan (POT) to guarantee accessibility to urban and rural areas for all people, and access to non-motorized means of public transportation with low or zero-emission energy and technologies.
2. Organizing transportation to increase mobility with greater energy efficiency and less pollution in urban, rural, and regional travel, thereby enhancing productivity, competitiveness and regional integration.
3. Organizing the transportation of people and goods, ensuring the proper circulation and operation of all modes of transportation, and promoting non-motorized transport and low or zero-emission technologies to reduce congestion and pollution.

4. Ensuring the safe movement of pedestrians, cyclists, drivers, passengers, and other road users by organizing the transportation of people and goods with the proper operation of all transportation modes.
5. Formulating and implementing parking master plans that adhere to urban standards established in the POT, thereby encouraging the use of public transportation and rationalizing the use of private vehicles.

Phase 3: Adoption
The responsible entity must publish the respective document during each phase and socialize it with stakeholders and citizens at least twice to gather feedback and identify opportunities to improve the SUMP.

Phase 4: Monitoring and Evaluation
In the final phase, the SUMP is evaluated in the functional area using the indicators defined during the formulation phase.

2.4.4 Instruments

The instruments used in the SUMP to encourage sustainable mobility in Colombia include:

a) The implementation of integrated public transport systems combining buses, metros, trams, and mass transit, to reduce congestion and improve accessibility.
b) The use of Bus Rapid Transit (BRT) systems, which operate in exclusive lanes in some Colombia cities, using mostly electric buses to contribute to sustainability.
c) Investment in new cycling infrastructure and incentives for citizens, including programs and specific days dedicated to cycling.
d) Enhancing the pedestrian infrastructure in urban spaces to promote walking and stimulate the growth of new businesses along these roads.
e) Integration of transport planning and land use planning to create efficient programs and policies for the cities.
f) Promoting the adoption of electric vehicles among citizens and creating the necessary infrastructure to support it.
g) Conducting education campaigns to encourage citizens to make a sustainable transportation choice
h) Using a combination of public and private investment as the most common financial method for these programs in Colombia.

2.4.5 Implementation

According to the National Planning Department (DPN) as of December 2021 (22), 74 municipalities of the country must have a Sustainable Mobility Plan, where currently:

- 10 municipalities adopted an updated SUMP according to the resolution No. 20203040015885 of 2020, examples of these municipalities are: Bogotá, Metropolitan area of Valle de Aburrá, and Metropolitan area of Cúcuta and Pereira.
- 29 municipalities are not formulating, or they have not presented any update of the status.
- 25 municipalities have a mobility plan adopted before of the resolution No. 20203040015885 of 2020, like Metropolitan area of Cali.

2.5 Evaluation Process for Sustainable Urban Mobility Plans

The evaluation of Sustainable Urban Mobility Plans (SUMPs) is a fundamental step to ensure that all planned objectives and interventions effectively contribute to sustainable mobility development. The evaluation process can be carried out using key indicators to assess progress towards these goals, identify their strengths and weaknesses, and allocate resources to areas in need of improvement (23 pp. 4-5).

Traditionally, the evaluation of transport systems has fallen under the responsibilities of planners and policy analysts as part of the planning process. The metrics used were typically those that could be modeled and applied to long-term investment decisions such as average travel times or levels of congestion. While these indicators provided useful operational data, they tended to prioritize vehicles movement over people, leading to transport policies centered on car dependency. Furthermore, they rarely captured the impacts of climate change, social inclusion or public health (24 p. 393).

2.5.1 Evaluation indicators in Europe

The concept of sustainability development began to take greater importance thanks to the United Nation's Brundtland Commission in 1987, which defined it as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. In the context of urban mobility, this led to the development of various indicators to evaluate and capture a more comprehensive picture of the transportation systems (9 pp. 5-6).

One significant initiative was the Sustainable Mobility Project (SMP), launched by the World Business Council for Sustainable Development (WBCSD) in the early 2000s, which its objective was establish a vision of sustainable mobility by 2030. The SMP developed twelve indicators that coverts the most important dimensions of sustainable mobility, to name some examples are (25 pp. 18-24):

- ✓ **Accessibility:** Evaluated the percentage of households with access to motorized personal vehicles.
- ✓ **Financial Outlay Required of Users:** Measured the share of individual or family budget devoted to personal travel.
- ✓ **Travel Time:** Analyzed average time from origin to destination, including all switches of vehicle/mode and all waiting time, allowed for financial cost estimations and congestion impacts.
- ✓ **Safety:** Measured total traffic-related deaths and serious injuries.
- ✓ **Greenhouse Gas Emissions (GHGs):** Measured GHG emissions per time period in carbon-equivalent units.

In the case of Europe, the European Commission has launched several programs aimed at promoting inclusive and environmentally friendly urban mobility. These include:

CIVITAS Initiative: it has been testing and implementing innovative urban transport solutions since 2002. One of its projects, CIVITAS ECCENTRIC, focused on enhancing sustainable mobility across different European cities. One of the key components of the project was the development and application of twenty-nine Key Performance Indicators (KPIs) covering seven impact categories to evaluate the effectiveness of mobility actions implemented and provide a qualitative understanding of the behavior and effects of the actions and decision taken. These indicators include (26 pp. 14-45):

- ✓ **Society – People:** Evaluated public acceptance and access to transport system (e.g.: percentage of the population with access to mobility services).
- ✓ **Society – Governance:** Assessed planning processes (e.g.: qualitative assessments of policies, plans and programs changes).
- ✓ **Transport System:** Measured public transport efficiency, shared mobility and changes in modal split (e.g.: number of trips made by each mode for all purposes).
- ✓ **Economy:** Focused on investments, operational and economic performance of mobility solutions (e.g.: capital investment cost).
- ✓ **Environment:** Assessing reductions in emissions and pollution (e.g.: CO_2 tons).
- ✓ **Energy:** Measured energy consumption of different mobility solutions. (e.g.: vehicle energy efficiency MJ/km)

- ✓ **Land Use**: Analyzed the use and attractiveness of space (e.g.: percentage of use for parking space)

The SUMP Concept: Formally developed in the European Commission 2013 guidelines, updated in 2019. The SUMP provides a framework for urban mobility planning, where sustainable transport modes are prioritized. The SUMP recognizes the importance of monitoring process defining a set of strategic indicators to ensure that objectives planned will be achieved, recommending that existing indicators be based on the European Sustainable Urban Mobility Indicators set (SUMI) and the International Standard (MobiliseYourCity) (11 pp. 95-97).

ELTIS (The Urban Mobility Observatory): ELTIS is the leading European urban mobility observatory, which offers different resources, tools, and best practices for developing and implementing SUMPs. A key initiatives is SUMI, which provides nineteen indicators developed by the above mentioned WBCSD to help cities identify strengths and weaknesses of their mobility systems and to prioritize areas for improvement (27), examining issues such as affordability of public transport, quality of public spaces, transport facilities, and others (28).

MobiliseYourCity (MYC): Is a partnership established at COP21 in Paris 2015, which supports over 100 partners, including 79 member cities and 16 member countries, in the development of sustainable urban mobility planning with the aim of transforming urban mobility. MYC provides an indicator framework that guides cities in monitoring and evaluating mobility through two types of indicators (29):

1. **Impact Indicators**:
    a. GHG Impact: E.g. expected GHC emission reduction in (tCO_2e).
    b. Impact related to Sustainable Development Goals (SDG).
        i. Access to Public Transport: E.g. portion of the population living 500 meters or less of public transport stop with a minimum 20-minute service at peak hour.
        ii. Road Safety: E.g. traffic fatalities (road, rail, etc.) in the urban areas per 100.000 inhabitants.
        iii. Air pollution: E.g. mean urban air pollution of particulate matter (in mg PM2.5).
        iv. Modal Share of Non-Motorized and Public Transport: E.g. share of public transport and non-motorized modes in trips.
        v. Affordability of Public Transport: E.g. the proportion, or percentage, of disposable house-hold income spent on public transport for the second quintile household group.
2. **Investment Indicators**: Five investment indicators like km of sidewalk, cycle lines, mass rapid transit, number of city center parking spaces and the amount of mobilized public and private funding.

As an example of how the evaluation of urban indicators in SUMP is carried out within the European Union, Italy provides a representative case. Through the *Gazzetta Ufficiale della Repubblica Italiana* (Serie Generale n. 233, October 5, 2017), official SUMP guidelines were published outlining methodologies, KPIs, and strategic actions aligning with the goals of European Union (30).

The *Gazzetta* mandates post-approval monitoring of the SUMP through the development and application of indicators that will evaluate the effectiveness and efficiency of the proposed actions (30). The following tables in the document set out the indicators:

Table 1 Macro -Objectives (Tabella 1: Macroobiettivi) (30 p. 22): This lists four strategic objectives of sustainable mobility. Some of the indicators associated with these objectives include:

1. **Efficiency of Mobility System:** Increase public transport use (passenger/year per 1000 inhabitants) or modal split (e.g. % of trips by car, public transport, bike, foot, car-sharing).

2. **Energy and Environmental Sustainability:** Annual fuel consumption (fuel consumption/inhabitant) or annual emission of NO_x, PM_{10}, $PM_{2.5}$ (kg of pollutant/inhabitant/year).
3. **Road Safety:** Accident rate (accidents/inhabitant) or road mortality and injury indices (deaths or injuries/inhabitant).
4. **Social Inclusion and Equity:** Level of satisfaction with mobility among vulnerable populations (score from survey) or employment rate (number of employed/active population).

Table 2 Specific Objectives (Tabella 2: Obiettivi specifici) (30 p. 23): This table links individual goals to detailed performance indicators, for example:

- ✓ Improving the attractiveness of public transport: Public transport usage (number of passengers/year/1,000 inhabitants).
- ✓ Improving the attractiveness of shared transport: Participation in carpooling service (number of car polling users/inhabitants).
- ✓ Improving the attractiveness of cycle/pedestrian transport: Bicycle use for non-recreational purposes (weekday flow on cycle paths).
- ✓ Reducing road congestion: Average speed during key time periods (km/h).

Table 3 Strategies and Actions (Tabella 3: Strategie ed azioni) (30 p. 24): This table outlines a structured list of strategic actions aligned with the macro and specific objectives from Table 1 and 2:

- ✓ Integration between transport systems, including mass rapid transport systems, where economically and financially sustainable: New Road network classifications and adequacy of road network (km of new or adequate lanes).
- ✓ Development of collective mobility to improve service quality and increase the commercial speed of public transport: Creation of preferential or reserved lanes for collective transport (bus or tram), which enhance commercial speed, improve safety, and service quality (km of preferential lanes added).

URBAN MOBILITY INDICATORS (UMI)

In July 2024, the European Commission developed the Urban Mobility Indicators (UMI) framework in response to the diversity of mobility indicators assessment methodologies. This framework provides cities with a standardized set of indicators to assess and monitor SUMP, focusing on sustainability, road safety, and accessibility. It services as a foundation for evaluating the effectiveness of policies and strategies implemented by cities to manage urban mobility (5).

The indicators are based on the objectives of Trans-European Transport Network (TEN-T) Regulation[1], which emphasizes integrating urban nodes into the European transport network. They also build on existing data collection practices and aim to align with EU directives to ensure consistency and reduce redundancy. Each of the seven indicator fiches includes detailed information on the following aspects summarized in Table 5 (31):

1. **Indicator Description:** What the indicator measures and its relevance, includes input, output and resulting indicators.
2. **Data Requirements:** Specification of required data and possible sources.
3. **Calculation Methodology:** Set-by-set guidance on computing indicator values.
4. **Indicator Definition:** Clarify key terms and concepts used within the indicator context.
    a. **Input Indicators "I":** Represent resources, infrastructure or demand characteristics (e.g. total road network in km, or car trips per year in the city).

[1] Trans-European Transport Network (TEN-T) is a European Union (EU) policy initiative aimed at developing a multimodal, and interconnected network of roads, railways, airports, and waterways across the EU to improve mobility. https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

b. **Output Indicators "O":** Reflect observed outcomes from current conditions (e.g. number of serious or fatal crashes).
c. **Results Indicators "R":** Measure impacts, such as modal share by walking, cycling or public transport (% of total trips).

Table 5
Summary of Indicator Areas

UMI FICHE	MAIN OBJECTIVE	NUMBER OF INDICATORS
Road Crashes and Injuries	Assessing number and severity of road traffic incidents, using data on kilometer driven, number of trips, and extent of road with safety measure (32 p. 4)	21 input, 6 output and 16 result indicators (33)
Modal Share	This group of indicators analyzes the distribution of different transport modes used by the inhabitants, this being one of the most critical points to evaluate the progress in the development of urban mobility (32 p. 5).	1 input, 20 output and 19 result indicators (34)
Noise Pollution	Number of inhabitants exposed to different noise levels associated with urban transport (road, rail, air transport) (32 p. 4).	1 input, 6 output, 15 result indicators (35)
Air Pollution	Monitoring NO_2, PM_{10} and $PM_{2.5}$ levels of pollutants emitted by transport activities (32 p. 3).	29 output, 42 result indicators (36)
Congestion	Assessing the satisfaction with cycling, public transport and car networks, and the average travel times for different modes during peak and off-peaks hours (32 p. 5).	2 input, 15 output, 12 result indicators (37)
GHC Emissions	Measuring CO_2 equivalent from urban transport especially regarding vehicle kilometer driven and fleet composition (32 p. 4).	1 input, 28 output, 16 result indicators (38)
Access to Mobility Services	Evaluating availability and accessibility of various mobility options (32 p. 5).	3 input, 36 output, 32 result indicators (39)

The UMI framework offers benefits such as the opportunity to compare data across different cities, assessment of SUMP across environmental, social and economic dimensions, improved alignment with the Europe Union strategies, and supports strategic adjustment to mobility policies based on metric evidence. However, the implementation of the UMI framework brings challenges include a lack of technical capacity to collect detailed mobility data especially in small cities, and although the indicators are standardized, they may require more specific adaptation to local contexts.

In conclusion, the UMI framework represents a significant advance in the assessment of urban mobility and sustainability. By standardizing indicators and aligning them with the European Union strategic objectives, UMI provides a powerful tool for cities to monitor and improve mobility systems. While challenges like data collection persist, UMI has strong potential to become the basis for sustainable urban development strategies special in countries where still developing their mobility systems.

2.5.2 Evaluation indicators in Colombia

Finally, in Latin America, the evaluation of SUMPs primarily depends on national policies and support from different international development agencies. In Colombia, as described in 2.4Chapter 2.4

"Sustainable Urban Mobility Planning in Colombia" SUMPs must be development under Resolution No. 20203040015885, October 15, 2020.

This Resolution establishes a structured framework for monitoring and evaluating mobility plans through a system of indicators. It defines four types of mobility management indicators that track intermediate and final activities, resources use, and input requirements to meet sustainable and safety goals within the planned timeframe (20 pp. 29-30) These indicators are subdivided into:

1. **Efficiency Indicators**: Measure related to resource use, including budget allocation and goal achievement.
2. **Physical and Financial Execution Indicators:** Reflect the progress in infrastructure and budget execution, measuring physical and financial completion and geographic investment distribution.

Some examples of these indicators include (20 pp. 30-33):

- ✓ Reduce the average travel time.
- ✓ Average travel time distance reduced.
- ✓ Kilometer of exclusive zone for active mobility.
- ✓ Territorial coverage of the public transport system and infrastructure for non-motorized means and low or zero emissions technologies increased.

All indicators must be reliable, verifiable, measurable, and useful for decision making. They help monitor goal achievement, assess investment efficiency and support continuous improvement.

In the case of the international development agencies, for example, in Colombia MobiliseYourCity in 2023 published a comprehensive framework for developing SUMPs, where some European methodologies are integrated with practical experience from the regions to promote sustainable urban mobility. A central aspect of the guide is the establishment of UMI to monitor and evaluate the effectiveness of mobility Plans, these indicators are subdivided into three main parts (40):

- ✓ **Input Indicators:** Measuring resources allocated (e.g., km of bike lanes constructed, number of parking spaces in the city center).
- ✓ **Output Indicators:** Assessing immediate outcomes (e.g. increase the bicycle trips demand or modal shift towards public transport).
- ✓ **Outcome Indicators:** Evaluating long-term impacts (e.g. reduction in greenhouse gas emissions).

III. CASE STUDY

As stated before, the main objective is to assess the applicability of the Urban Mobility Indicators (UMI) as a monitoring tool for the Sustainable Urban Mobility Plans (SUMPs) from three metropolitan areas. As the metropolitan area of interest in Italy is Turin, it is going to be selected areas in Colombia that match the conditions to be comparable with Turin. Below are stated the criteria to proceed with the selection of the metropolitan areas.

Selection Criteria:
The case studies were selected based on the following criteria:

- Metropolitan area of Turin whose population is 2,249,999 [2019] and its capital Turin with 870,312 inhabitants [2019] (41).

- In Colombia there are many cities that can be compared in terms of population with the metropolitan area of Turin. Among these possibilities are:

    - Metropolitan area of Central West whose population is 735,796 [2023] and its capital Pereira with 481,768 inhabitants [2023] (42).
    - Metropolitan area of Valle de Aburrá with 3,821,797 inhabitants [2016] and its capital Medellín with 2,486,723 inhabitants [2016] (43 p. 18).
    - Metropolitan area of Colombian Southwest with 2,505,573 inhabitants [2024], and its capital Cali with 2,280,522 inhabitants [2024] (42).
    - Metropolitan area of Cúcuta with 908,276 inhabitants [2022], and its capital Cúcuta with 682,961 inhabitants [2022] (44 p. 143).
    - Metropolitan area of Bucaramanga with 1,306,899 [2024], and its capital Bucaramanga with 619.703 inhabitants [2024]. just to name a few (42).

- Existence of official SUMPs documents approved by the local authority, keeping in mind that currently, many cities in Colombia are under update, in process of approval or even at design stage. In this category falls, Medellín whose SUMP was approved by the public administration and is valid since [2020], Cúcuta since [2022] counts with a valid SUMP and Pereira whose SUMP was released and still has validity since [2017].

- Availability of transport-related data including the household surveys. Despite the fact that some cities like Pereira have had their SUMP in validity since [2017] and the technical report is available, the survey has not been published by the public administration. Survey data from Pereira was requested formally to the corresponding authority but they argue the information is under revision. Finally, the cities who have published their household surveys for their SUMPs are Medellín (within the Valle de Aburrá) and Cúcuta. Therefore, the two mentioned are going to be the ones to be used in the scope of this study.

Consequently, the following subchapter describes the geographical position of the metropolitan areas under study with the main features about the organization of their territory. Afterwards, the next subchapters show an overview of the SUMPs documents, starting with a description of the current situation in terms of mobility, the transport model and proposed scenarios and a summary of the interventions focused on the execution of the objectives of the three metropolitan areas selected, where each of one may have a different approach from each other but sharing common goals. Finally, a comparison is presented between SUMP documents of the three metropolitan areas. These analyses are part of the preliminary review for subsequent evaluation of the Urban Mobility Indicators.

3.1 Study Areas

3.1.1 Metropolitan Area of Turin

The study area corresponds of the Metropolitan City of Turin created under the Law "Delrio" (n. 56 of 2014) and corresponds to an administrative entity that replaced the ancient Turin Province, is located in the Piemonte Region in the northwest of Italy (45) It is made up by 11 homogeneous zones corresponding to the administrative subdivision with 312 municipalities , with a total area of 6,583 km^2, described in Table *6* (46):

Table 6
Homogeneous Areas of the Municipalities of Metropolitan Area of Turin

#	Zone	Municipality	Population (2019)	Area km^2	Density (population /km^2)
1	Torino città	Torino	870,952	130.06	6696.54
2	Area Metropolitana Torino Ovest	Alpignano, Buttigliera Alta, Collegno, Druento, Grugliasco, Pianezza, Reano, Rivoli, Rosta, San Gillio, Sangano, Trana, Venaria, Villarbasse	237,561	203.29	1168.58
3	Area Metropolitana Torino Sud	Beinasco, Bruino, Candiolo, Carignano, Castagnole P.te, La Loggia, Moncalieri, Nichelino, None, Orbassano, Pancalieri, Piossasco, Piobesi Torinese, Rivalta di Torino, Trofarello, Vinovo, Virle Piemonte, Volvera.	268,978	385.72	697.34
4	Area Metropolitana Torino Nord	Borgaro Torinese, Caselle Torinese, Leinì, Mappano, San Benigno C.se, San Mauro Torinese, Settimo Torinese, Volpiano.	137,178	175.02	783.78
5	Pinerolese	Airasca, Angrogna, Bibiana, Bobbio Pellice, Bricherasio, Buriasco, Campiglione Fenile, Cantalupa, Cavour, Cercenasco, Cumiana, Fenestrelle, Frossasco, Garzigliana, Inverso Pinasca, Luserna San Giovanni, Lusernetta, Macello, Massello, Osasco, Perosa Argentina, Perrero, Pinasca, Pinerolo, Piscina, Pomaretto, Porte, Pragelato, Prali, Pramollo, Prarostino, Roletto, Rorà, Roure, Salza di Pinerolo, San Germano C., San Pietro Val Lemina, San Secondo di P., Scalenghe, Torre Pellice, Usseaux, Vigone, Villafranca Piemonte, Villar Pellice, Villar Perosa.	130,516	1302.23	100.22
6	Valli di Susa e Sangone	Almese, Avigliana, Bardonecchia, Borgone di Susa, Bruzolo, Bussoleno, Caprie, Caselette,	103,500	1246.87	83.01

#	Zone	Municipality	Population (2019)	Area km^2	Density (population /km^2)
		Cesana T.se, Chianocco, Chiomonte, Chiusa di San Michele, Claviere, Coazze, Condove, Exilles, Giaglione, Giaveno, Gravere, Mattie, Meana di Susa, Mompantero, Moncenisio, Novalesa, Oulx, Rubiana, Salbertrand, San Didero, San Giorio di Susa, Sant'Ambrogio di Torino, Sant'Antonino di Susa, Sauze di Cesana, Sauze d'Oulx, Sestriere, Susa, Vaie, Valgioie, Venaus, Villar Dora, Villarfocchiardo.			
7	Ciriacese-Valli di Lanzo	Ala di Stura, Balangero, Balme, Barbania, Cafasse, Cantoira, Ceres, Chialamberto, Ciriè, Coassolo T.se, Corio, Fiano, Front, Germagnano, Givoletto, Groscavallo, Grosso, La Cassa, Lanzo Torinese, Lemie, Lombardore, Mathi, Mezzenile, Monastero di Lanzo, Nole, Pessinetto, Rivarossa, Robassomero, Rocca Canavese, San Carlo Canavese, San Francesco al C., San Maurizio C.se, Traves, Usseglio, Val della Torre, Vallo Torinese, Vauda Canavese, Varisella, Villanova Canavese, Viù.	101,148	972.89	103.97
8	Canavese occidentale	Agliè, Alpette, Bairo, Baldissero C.se, Borgiallo, Bosconero, Busano, Canischio, Castellamonte, Castelnuovo Nigra, Ceresole Reale, Chiesanuova, Ciconio, Cintano, Colleretto C., Cuceglio, Cuorgnè, Favria, Feletto, Forno C.se, Frassinetto, Ingria, Levone, Locana, Lusigliè, Ozegna, Pertusio, Pont Canavese, Prascorsano, Pratiglione, Ribordone, Rivara, Rivarolo Canavese, Ronco Canavese, Salassa, San Colombano B., San Giorgio C.se, San Giusto C.se, Noasca, Oglianico, San Ponso, Sparone, Torre Canavese, Valperga, Valprato Soana, Vialfrè.	82,080	974.51	84.23
9	Eporediese	Albiano d'Ivrea, Andrate, Azeglio, Banchette, Barone C.se, Bollengo, Borgofranco, Borgomasino,	86,980	554.47	156.87

#	Zone	Municipality	Population (2019)	Area km^2	Density (population /km^2)
		Brosso, Burolo, Candia C.se, Caravino, Carema, Cascinette d'Ivrea, Chiaverano, Colleretto Giacosa, Cossano C.se, Fiorano C.se, Issiglio, Ivrea, Lessolo, Loranzè, Maglione, Mercenasco, Montalenghe, Montalto Dora, Nomaglio, Palazzo Canavese, Parella, Pavone Canavese, Perosa Canavese, Piverone, Orio Canavese, Quagliuzzo, Quassolo, Quincinetto, Romano Canavese, Rueglio, Salerano Canavese, Samone, San Martino C.se, Scarmagno, Settimo Rottaro, Settimo Vittone, Strambinello, Strambino, Tavagnasco, Traversella, Valchiusa, Val di Chy, Vestignè, Vidracco, Vische, Vistrorio.			
10	Chivassese	Brandizzo, Brozolo, Brusasco, Caluso, Casalborgone, Castagneto Po, Castiglione Torinese, Cavagnolo, Chivasso, Cinzano, Foglizzo, Gassino Torinese, Lauriano, Mazzè, Montanaro, Monteu da Po, Rivalba, Rondissone, San Raffaele Cimena, San Sebastiano da Po, Torrazza Piemonte, Verolengo, Verrua Savoia, Villareggia.	99,588	422.57	235.67
11	Chierese-Carmagnolese	Andezeno, Arignano, Baldissero Torinese, Cambiano, Carmagnola, Chieri, Isolabella, Lombriasco, Marentino, Mombello di Torino, Montaldo T.se, Moriondo T.se, Osasio, Pavarolo, Pecetto T.se, Pino Torinese, Poirino, Pralormo, Riva presso Chieri, Santena, Sciolze, Villastellone.	131,517	462.30	284.48

Source: (41 pp. 25, 49)

At the end of 2019, the Metropolitan area had approximately 2.25 million residents, forming about 1.05 million households with an average size of 2.14 members. Of the total 34% of households were made up only for one member, and the 16% of households were made up for at least four members, the smallest families were found in the capital where the average size fell by nearly 1.5 members (41 p. 41).

The demographic change during the last forty years, three sectors were identified by (41 p. 39):

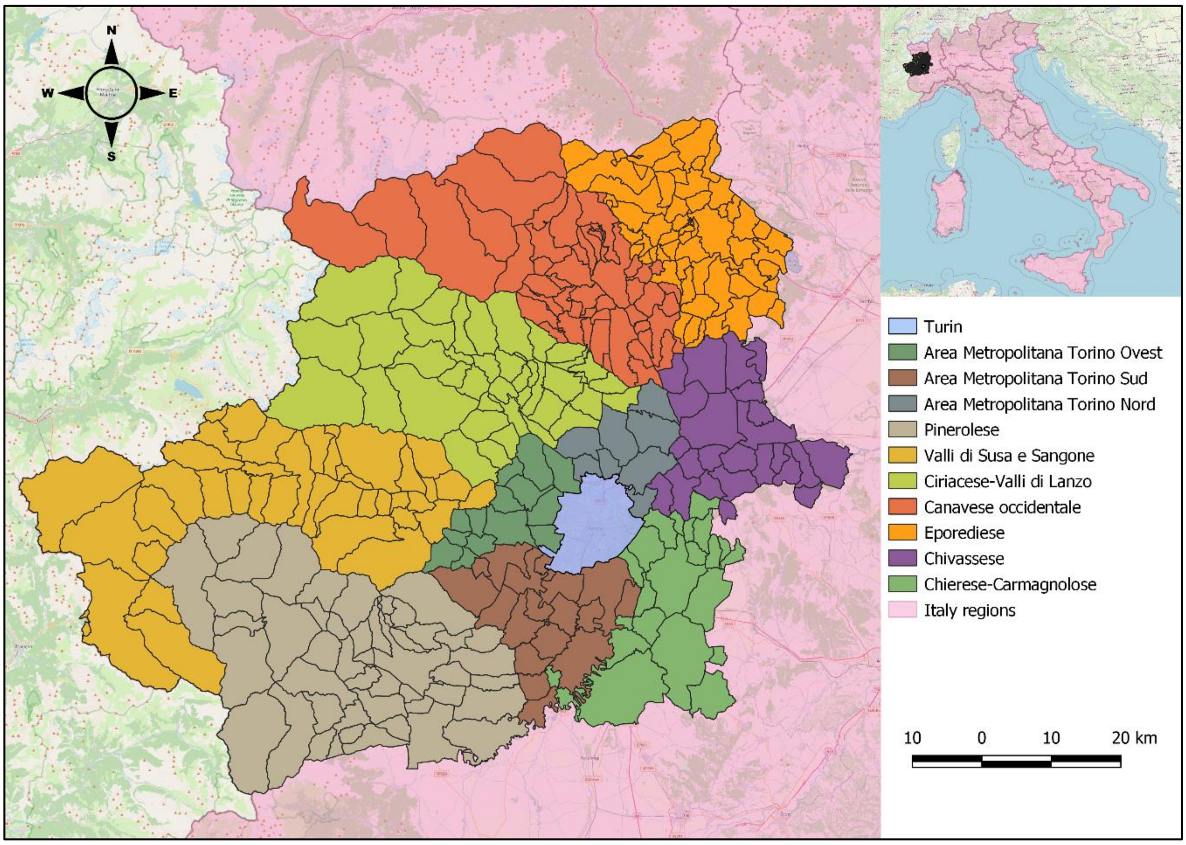
- First is a central metropolitan nucleus made up the capital city and few municipalities in the first belt Moncalieri, Rivoli, Beinasco where the net reduction in population was recorded.

- Second is the wide band that is extended 25 to 30 km around the capital. This band tends to cover the entire plain area up to the first mountain slopes, as well as in the hilly areas, where the population increased.
- Third is an external band that includes the entire mountain sector, where the population decreased, especially in the less accessible areas.

As reported by ISTAT data of the census of 2011, the total workforce was close to 1 million, where approximately 91% were employed and 9% looking for employment, additional it had been estimated that 120,360 were students, 163,000 were housewives, 559,565 were retired and 93,561 had another occupation (41 p. 42).

Regarding to the attractor poles, they are composed of some health services (hospitals, districts of healthcare) offices of civil and judicial administration, education and research services, and tourist zones like the hotels in the city or the Olympic mountains, especially in the capital city there are concentration of the higher-ranking services like (universities or courts) and in the external parts are located the intermediate level services (41 p. 61). The map of the metropolitan area is presented in Figure 2:

Figure 2
Map of the Metropolitan Area of Turin with the 11 homogeneous areas



3.1.2 *Metropolitan Area of Valle de Aburrá*

The study area corresponds to the Metropolitan Area of Valle de Aburrá. It was the first metropolitan area in Colombia, created in 1980, and is the second most populated region in Colombia, after Bogotá. Located in the department of Antioquia, it is a political-administrative entity made up of 10 municipalities (see Table *7*), with Medellín serving as the central hub of the metropolitan area. Additionally, it acts as a vital corridor for the rest of the municipalities to the north and south of the metropolitan area. All the municipalities are not only geographically integrated but also interconnected economically, sharing various services such as transportation, energy, water and telecommunications (47 pp. 25-26).

Table 7
Municipalities of Metropolitan Area of Aburrá Valley

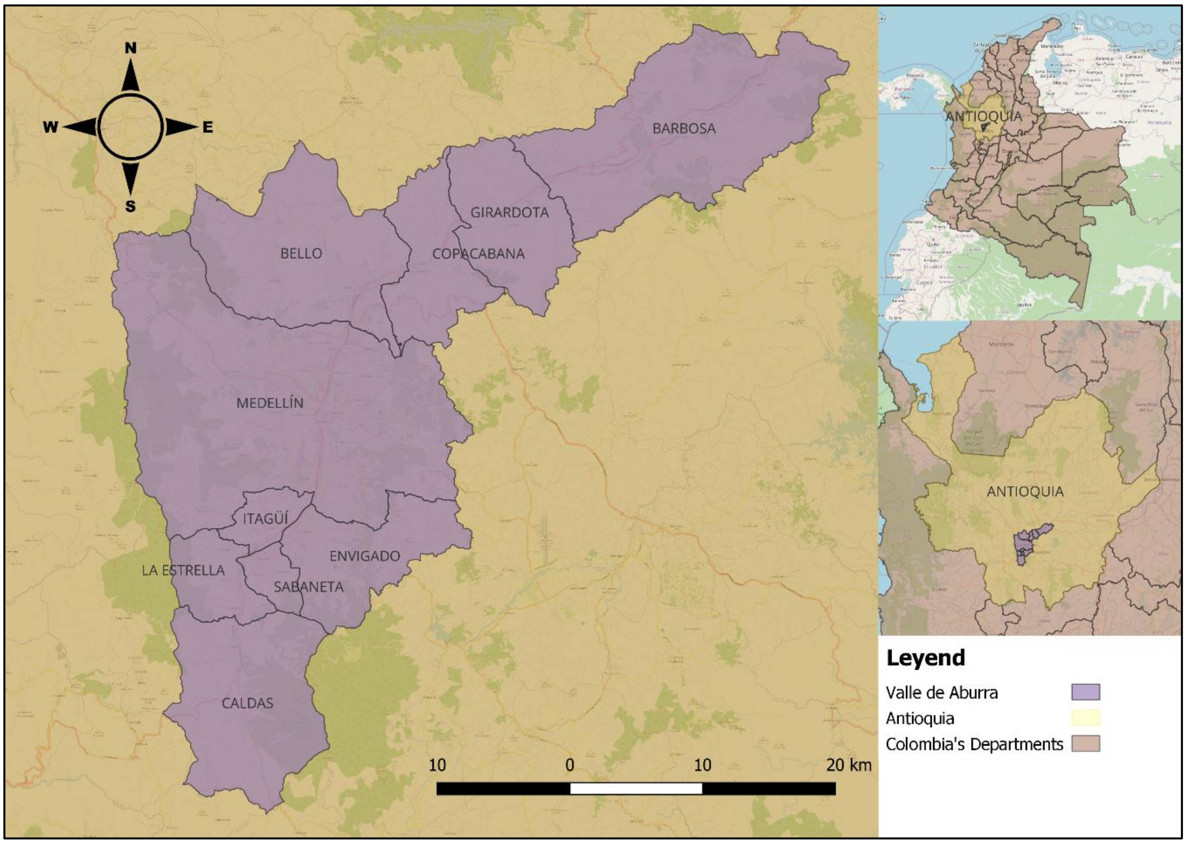
#	Municipality	Population (2016)	Area km^2	Density (population /km^2)
1	Medellín	2,486,723	380.64	6533.00
2	Bello	464,560	149.00	3117.85
3	Itagüí	270,920	21.09	12845.90
4	Envigado	227,599	78.78	2889.05
5	Caldas	78,762	133.4	590.42
6	Copacabana	71,033	70.00	1014.76
7	La Estrella	63,332	35.00	1809.49
8	Girardota	55,477	78.00	711.24
9	Sabaneta	52,559	15.00	3503.93
10	Barbosa	50,832	206	246.76

Source: (43 p. 18)

In 2016, the population of the metropolitan area was 3.82 million, with 65% residing in Medellín, distributed across 1.20 million households, with an average household size of 2.90 to 3.1. Another relevant point to mention is that only 15% of the territory is made up of urban areas, where the cities accounting for the largest urban territories are Itagüi (58%), Medellín (30%) and Sabaneta (24%) (48).

Regarding the geography, Valle de Aburrá is located in the bifurcation towards north, of the Andes central mountain range shaping the valley of river Aburrá. Although it is called Valle de Aburrá Region which means: the Valley of the Aburrá river, the administrative borders of region do not match with the catchment area of the river itself, but the morphology of the area is shaped by the mountains, and it follows the path of the river from Caldas to Yolombo. The topography along the river ranges from 0 to 6 degrees while in the mountains, slopes between 12 and 33 degrees can be found thus, limiting or determining how the municipalities along the valley grow (49). The map of the metropolitan area is presented in Figure 3:

Figure 3
Map of the Metropolitan Area of Valle de Aburrá



3.1.3 Metropolitan Area of Cúcuta

The Metropolitan Area of Cúcuta located in Eastern subregion of the department of Norte de Santander in Colombia. The Metropolitan area was adopted by ordinance number 40 of 1991, it comprises San Jose de Cúcuta its capital and five nearby municipalities as presented in Table *8*. The San Jose de Cúcuta urban area is established as an administrative and service city, while the closes municipalities offer complementary real estate. Additionally, the Metropolitan Area is located in the border area between Colombia and Venezuela, situation that allowed it to consolidate a strong economic and social exchange tie, turning it into a metropolis mostly dedicated to commerce an industrial activity, however, the social and politic situation of the last years these dynamics have been affected (44 pp. 136-138).

Table 8
Municipalities of Metropolitan Area of Cúcuta

Municipality	Population (2022)	Area km^2	Density (population /km^2)
San Jose de Cúcuta	682,961	1131.30	603.70
El Zulia	19,416	490.48	39.59
Los Patios	88,013	127.13	692.31
Puerto Santander	8,530	44.14	193.25
San Cayetano	6,384	141.99	44.96
Villa del Rosario	102,972	92.48	1113.45

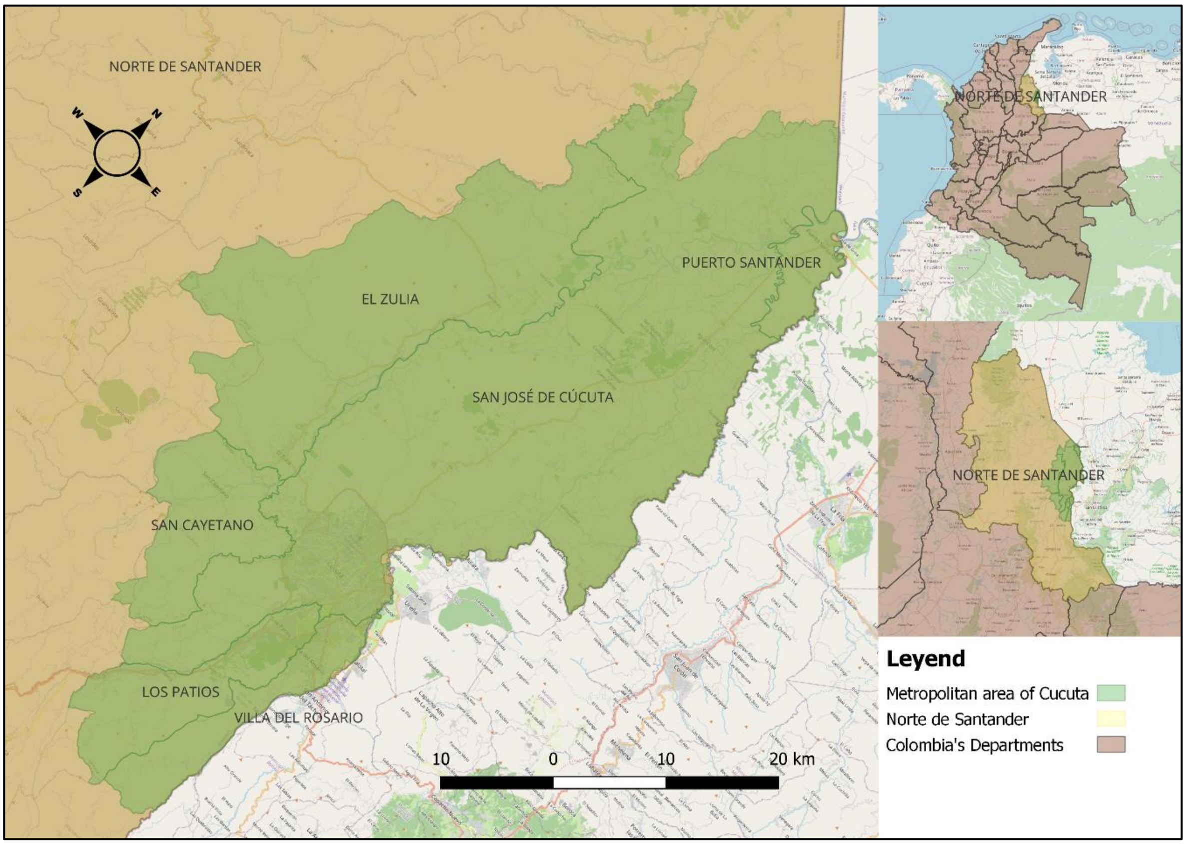
Source: (44 p. 143)

In 2022, the population of Metropolitan Area was 908,276, with 682,961 inhabitants in the capital that were concentrated in the urban zone of the city that is the 4.3% of the area (66.49 km^2) and 225,315 inhabitants in the rest of municipalities, integrated into a total of 283,115 households, with an average household size was 2.90 (44 p. 149).

The city center is one of the most significant attractors poles of trips in the Metropolitan Area considering that the land has mainly commercial, service and industry use. Additionally, there were 155,000 students in San Jose de Cúcuta, making schools another important trip attractor (44 p. 267). Regarding the urban component, the metropolitan area has very small urban zones when compared to the rural part, accounting for 5.66% and 92.78% respectively. The reaming territory is classified as soils for expansion (44 p. 144).

From the geographical perspective, the predominant slopes across the north of the region are between 0 and 3 % but it is not the case for the rest of the territory where the eastern Andes Mountain range act as a constraint on the west and south, with slopes ranging from 12% to 50 %. Although the north of the region is the flattest, the majority of the urban territory is located in the south of the region. The region has another constraint for its expansion which is the political border between Colombia and Venezuela shaped by Tachira river (44 p. 155). The map of the metropolitan area is presented in Figure 4:

Figure 4
Map of the Metropolitan Area of Cúcuta



3.1.4 Comparison of metropolitan areas

The Table 9 and Table 10 present demographic and geographic characteristics of three metropolitan areas, especially in terms of urbanization:

Table 9
Comparison of the metropolitan areas

Metropolitan Area	Total Population	Total Surface (km2)	Population Density (inhabitants/km2)	% Urban Surface
Turin	2,249,998 (2019)	6,380	329,43	4%
Valle de Aburrá	3,821,797 (2016)	1,167	3,257.14	15%
Cúcuta	908,276 (2022)	2,028	447.97	5%

Table 10
Urbanization Indicators

Metropolitan Area	Municipalities	% Urban Surface
Turin	Torino città	31%
	Area Metropolitana Torino Ovest	11%
	Area Metropolitana Torino Sud	8%
	Area Metropolitana Torino Nord	11%
	Pinerolese	2%
	Valli di Susa e Sangone	2%
	Ciriacese-Valli di Lanzo	2%
	Canavese occidentale	1%
	Eporediese	3%
	Chivassese	4%
	Chierese-Carmagnolese	3%
Valle de Aburrá	Medellín	30%
	Bello	16%
	Itagüí	58%
	Envigado	16%
	Caldas	1%
	Copacabana	7%
	La Estrella	10%
	Girardota	4%
	Sabaneta	24%
	Barbosa	1%
Cúcuta	San Jose de Cúcuta	5%
	El Zulia	1%
	Los Patios	8%
	Puerto Santander	1%
	San Cayetano	1%
	Villa del Rosario	34%

- **Population Density:** Valle de Aburrá has the highest population density, indicating a highly urbanized area. Cúcuta has a moderate density, suggesting a mix of urban and rural characteristics and Turin displays lowest density, indicating a significant presence of rural or semi-urban zones.
- **Urban Surface Ratio:** Valle de Aburrá has the highest urban surface proportion of 15%, reflecting an urban development within a relatively small geographic area in comparison of the other metropolitan areas, particularly in municipalities like Itagui and Medellin.
  In contrast, Cúcuta has a significant lower urban surface rate with 5%, suggesting a more dispersed urban form with an important part of the territory still classified as rural, and Turin shows the lowest percentage with only 4% of its metropolitan area considered urban. This low

rate is consistent with the larger total area and relatively low population density indicating more balanced urban-rural distribution.

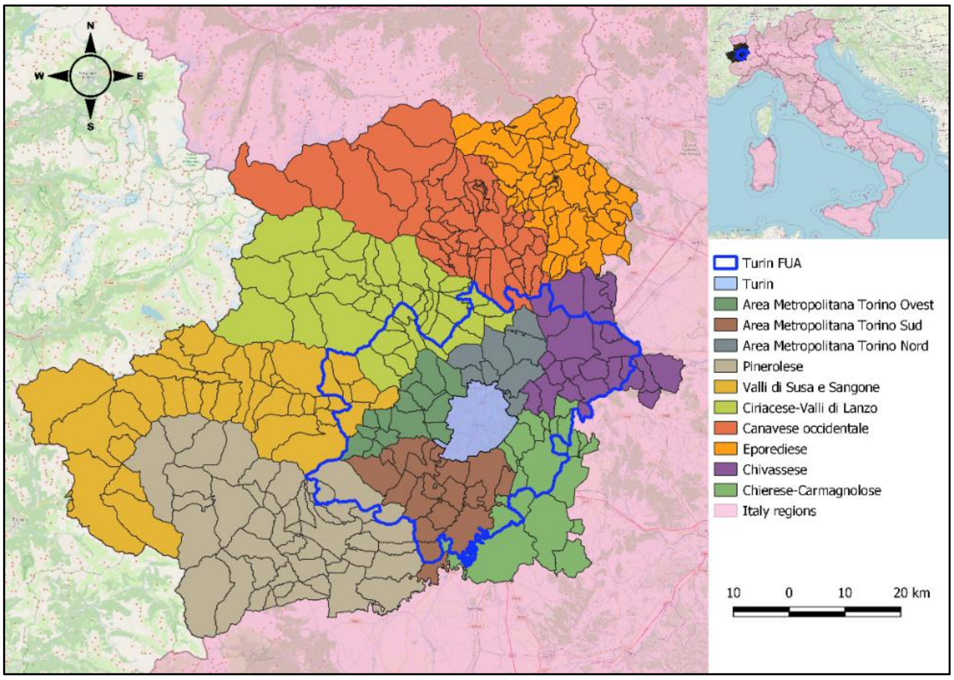
In order to draw meaningful comparisons across different urban areas whose administrative boundaries are only weakly related to traffic catchment areas, it would be convenient to consider study areas that are better suit to transportation studies. One possibility could be to consider functional urban areas, that have already been defined for a number of cities around the world. According to the methodological manual *Applying the Degree of Urbanization* (50 p. 53), produced by international organizations such as European Union, FAO, UN-Habitat, OECD, and The World Bank, a Functional Urban Area (FUA) is defined as: "*A functional urban area (or metropolitan area) is composed of a city plus its surrounding, less densely populated spatial units that make up the city's labour market, its commuting zone. This commuting zone generates a daily flow of people into a city and back (home to their dwelling). Such areas are often referred to as 'functional' because they capture the full economic function of a city. A functional urban area classification is particularly useful to inform policymaking in a number of domains, including transport, economic development and planning. Several national statistical authorities, including those of Brazil, Italy, Japan and the United States, complement their urban and rural area classifications with a classification of metropolitan areas*".

Additionally, they provide a four-steps methodology for identifying a FUA (50 p. 54):

- *"Identify an urban centre — a set of contiguous grid cells with a density of at least 1 500 inhabitants per km² and with a collective population of at least 50 000."*
- *"Identify a city — one or more small spatial units that have at least 50 % of their population in an urban centre."*
- *"Identify a commuting zone — a set of contiguous small spatial units that have at least 15 % of their employed residents working in a city."*
- *"A functional urban area (metropolitan area) is a city plus its commuting zone."*

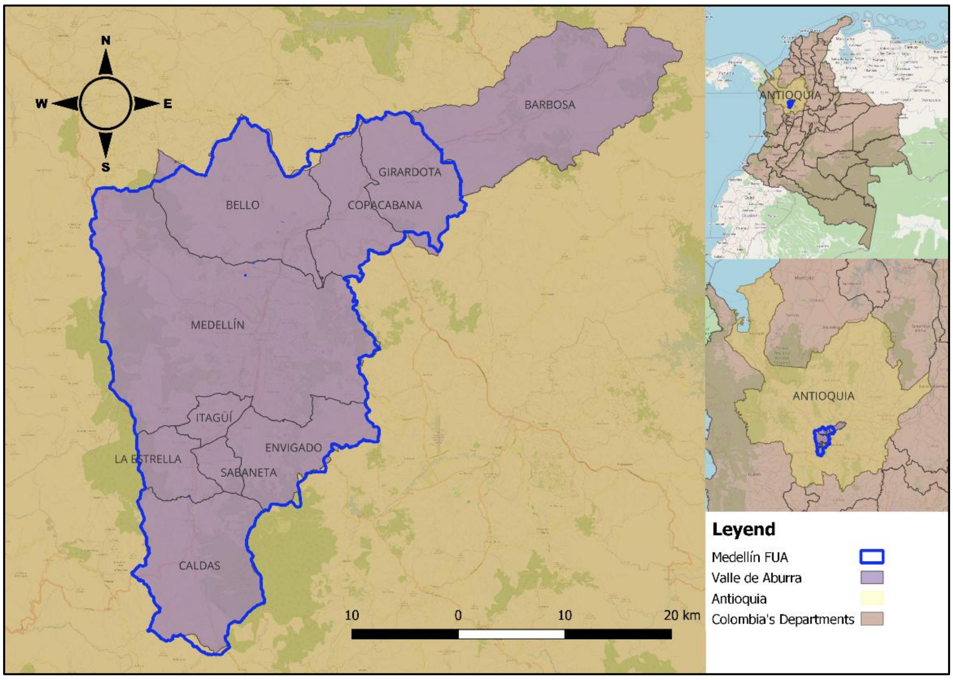
These international organizations have already delineated FUAs for several regions, including the case study areas examined in this thesis: Turin (Italy) and Valle de Aburrá and Cúcuta (Colombia). The FUAs for each are presented in the Figure 5, Figure 6 and Figure 7:

Figure 5
Map of the Metropolitan Area of Turin including its Functional Urban Area



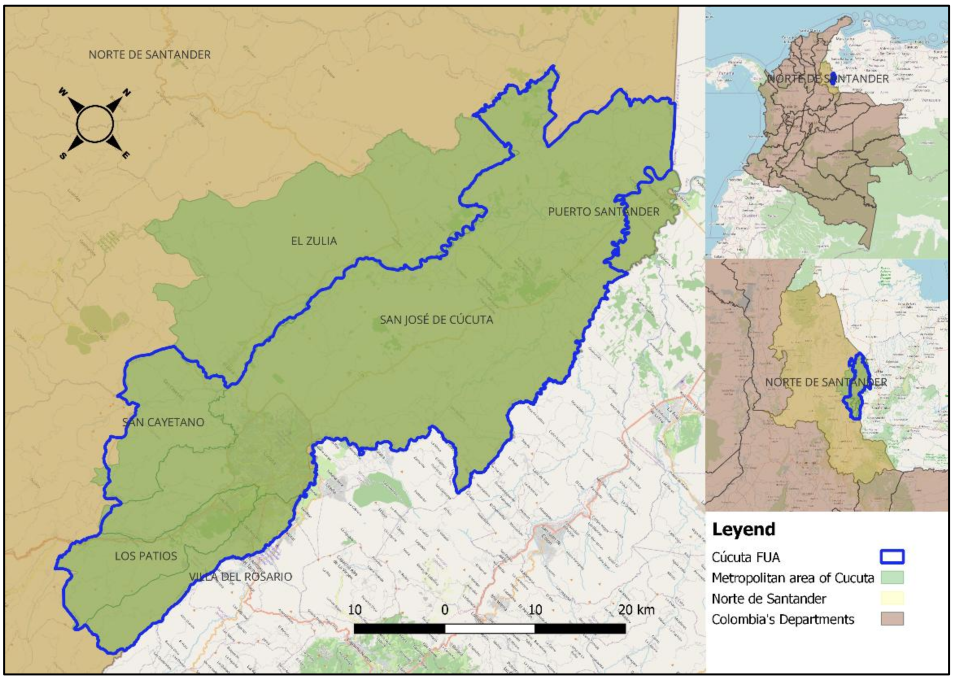
Source: (51)

Figure 6
Map of Metropolitan Area of Valle de Aburrá including its Functional Urban Area



Source: (51)

Figure 7
Map of Metropolitan Area of Cúcuta including its Functional Urban Area



Source: (51)

Table 11 presents the demographic and geographic characteristics of three Functional Urban Areas:

Table 11
Comparison of the Functional Urban Areas

Functional Urban Area	Total Population	Total Surface (km2) (51)	Population Density (inhabitants/km2)	% Urban Surface
Turin	1,752,301 (2016) (52)	1,702.194	1,029.44	7%
Medellin	3,770,965 (2016)	952.682	3,958.26	18%
Cúcuta	880,330 (2022)	1,493.000	589.68	7%

Based on Table 9, Table 11 and maps (Figure 5, Figure 6, and Figure 7), the comparison between each metropolitan area and the respective FUA is presented below:

Turin: In the document OECD Regional Development Studies – Regional Innovation in Piedmont published in 2021 (53 p. 64), was specified that the FUA of Turin includes the city and commuting zone composed of 87 municipalities of 312 that comprises the metropolitan area. In terms of surface area, the FUA represents 26.7% of the metropolitan territory, and it concentrates 77.9% of the metropolitan population.

Valle de Aburrá: In 2016, OECD published Functional Urban Areas in Colombia (54 pp. 23-28), where some Functional Areas where presented. Comparing the FUA with the metropolitan area, the following characteristics were found:

- Barbosa municipality is excluded from the metropolitan area.
- FUA accounts for 81.6% of the total metropolitan territory.
- The inhabitants of the FUA represent 98.7% of the total metropolitan population.

Cúcuta: The FUA differs from the official metropolitan area by excluding El Zulia and Puerto Santander. In terms of surface area, the FUA represents 73.6% of the metropolitan territory, and it concentrates 96.9% of the metropolitan population.

Although comparisons show that a Functional Urban Area does not corresponds to the same territory as a Metropolitan Urban Area, this thesis adopts the simplifying assumption that the Functional Urban Area can be considered equivalent to the Metropolitan Area. Indeed, doing something different would prevent us from using SUMPs data, reports and results that are available.

As noted in Chapter V, the methodology for Urban Mobility Indicators (UMI) is designed to measure mobility within FUA. However, for the purposes of this study, which focuses on the evaluation of SUMPs at the metropolitan scale, UMI indicators will be applied using metropolitan data. This approach ensures consistent and comparable analysis across the three case studies, as the UMI fiches provide quantitative variables that capture the state and progress of SUMPs.

3.2 Sustainable Urban Mobility Plan of Metropolitan Area of Turin

The Turin SUMP presents an organizational framework based on European guidelines, which includes different strategies such as integration of transportation systems, development of collective mobility, promotion of pedestrian and bicycle systems, introduction of shared mobility systems, renewal of the fleet with low-polluting vehicles, reorganization of logistics areas, and increasing mobility safety. These strategies were developed according to appropriate model simulations that represent scenarios where it is possible to evaluate the evolution of each strategy. All aimed at reducing traffic congestion, air pollution and promoting more sustainable modes of transportation.

3.2.1 Structure of the plan

The Table 12 presents the structure of the plan:

Table 12
Structure of the Sustainable Urban Mobility Plans

Section	Description
Introduction	Framework of the PUMS and description of the strategies and actions, and description of the analysis and simulation tools.
Topics and Direction of the Plan	Terms and directions for the development of plan strategies.
Knowledge Framework	Analysis of socio-economic characteristics, demand and supply of transport system, reconstruction of the current scenario.
Plan Strategies and Scenarios	Reference Scenario and First-Generation Scenario (Proximity scenario, Cooperative Scenario and Interactive Scenario).
Interventions of the Plan	Plan Scenario, intervention plan, timetable, and financial plan of interventions.

Source: (55)

3.2.2 Current Situation

3.2.2.1 Supply

The transport supply of the metropolitan city of Turin is composed of:

1. Within the metropolitan borders, the motorway network was extended for a total of 316 km, of which about 60 km was represented by the Ring Road and the ordinary network covered about 5,600 km. The network was subdivided by their functional classification highways, main, secondary, complementary and local roads. The urban network of the capital could count on multiple systems of road axes arranged tangentially, which ensured internal connections and distribution between the various neighborhoods (41 p. 70).
2. In October 2019, the available parking spaces were 14,800, concentrated in the most central areas of the city, the distribution in other areas was sparser, with two car parks in the north with 880 spaces, and only one in the west with approximately 900 spaces (41 p. 71).
3. At the end of 2019, the size of the circulating vehicle fleet registered in the territory of the CMTO amounted to about 1.91 million units, including 1.48 million cars, over 220,000 motorcycles, about 140,000 trucks and over 3,000 buses (41 p. 74).
4. Pedestrian areas in the capital had a total extension of just over 500,000 m2, and 350 km of cycling routes (41 pp. 75-78).
5. The main public transport network in the Metropolitan City of Turin included (41 pp. 79-84):
    - Railway: Long-distances services, regional services and metropolitan services.
    - One subway line, 8 tram lines.
    - 92 daytime bus lines, 6 school lines, 14 special lines for industrial plants, 10-night bus lines.
    - 177 bus lines for extra-urban services under the responsibility of Piedmont Mobility Agency.
    - 22 lines belonging to the neighboring basins, including 4 extra-provincial lines (from Turin to Milan, Biella, Varallo Sesia) and 22 suburban lines (from the capital to outside the metropolitan belt).

6. Regarding bike sharing, Turin had two types of services: a station-based system (ToBike) and a free-floating system (Mobike). The two systems offered a total of just over 3,000 bicycles with 94.000 register users, the total number of rentals exceeded 2.3 million (41 p. 85).
7. On the other hand, for car sharing, three types of services were active in Turin in 2019: two were free-floating (Drive Now and Enjoy) and one station-based (Blue Torino), with a fleet of 1,118 vehicles, with annual rentals of 1.7 million (41 p. 86).
8. There were two large logistics areas located in the North (S. Mauro/Settimo T.se) and the South (Moncalieri/Trofarello) of Turin. Interports logistics were located at Orbassano railway station and the SITO interport Agri-Food Center (CAAT). The second fundamental attraction pole of Turin was Pescarito, in the municipality of S. Mauro T.se (41 pp. 87-88).

3.2.2.2 Demand

The study of the demand was based on the following sources available for the analysis:

ISTAT CENSUS (41 pp. 90-98)**:**
- ✓ The census was conducted in the years 1991, 2001 and 2011.
- ✓ The number of systematic journeys within the metropolitan area of Turin was around 1.17 million trips/day.
- ✓ The modal split for home-school and work-home trips used individual motorized vehicles.

IMQ SURVEY (41 pp. 99-100)**:**
- ✓ Residents in the metropolitan city area were interviewed.
- ✓ The number of trips made by residents of the metropolitan area was 4.4 million trips/day in 2013 of which 1.89 million trips/day only in Turin city.
- ✓ The principal mode of transport used was individual motorization.

TELEPHONE DATA (41 pp. 105-106)**:**
- ✓ The use of the TIM/Olivetti Big Data Platform divided data into 5 categories of users: workers, students, non-residents, foreigners. Allowed to reconstruct the O/D matrices of movements associated with the GPS tracks, showing a total of 969,000 displacements, with pronounced morning and afternoon peaks at 7:00 am and 6:00 pm respectively.

TOURIST MOVEMENT (41 pp. 107-108)**:**
- ✓ ISTAT data on tourist movements (2008-2017): The metropolitan city of Turin had 2.3 million arrivals/year, with an average length of stay of 2.6 nights/arrival.
- ✓ Data from the National Tourism Observatory (1997-2019): The accommodation mainly consisted of hotels and hospitality with relatives and friends. The survey also confirmed a strong concentration of foreign tourists in the city of Turin.

3.2.2.3 Analysis of traffic flows

The description of traffic flows analysis is presented for each mode:

PEDESTRIAN AND CYCLING:
- Turin was equipped with 7-monitory stations, presenting a daily average of transit in September 2019 exceeding 2,000 units in Corso Castelfidardo. The total units for the same month were 266,806 (41 pp. 112-113).

PRIVATE VEHICLE:
- The statistics for principal motorways were reported as: A4: 40,000 veh/d, A5: 18,000 veh/d, A6: 26,000 veh/d, A21: 33,000 veh/d, A32: 13.000 veh/d, A55 (Ring Road): 76.000 veh/d (41 p. 117).

- Another relevant source of information on Average Daily Traffic on the motorized network came from the various sensor systems and the Regional Mobility Center stations, both managed by 5T. Below were some representative records obtained at specific measurement points: Ponte Carlo Emanuele I Corso Novara): 21,370 veh/d, Lungo Dora Agrigento:6,029 veh/d, Regina Margherita (via Pietro Cossa); 53,620 veh/d (41 p. 122).
- Vehicle parking in 2019 had a supply of 14,000 and a demand of 6,000 (daily average 2019). For on-street parking, almost 49,000 tickets were available (41 p. 123).

RAIL:

- **"Turin Metropolitan Railway Service" SFM:** A survey conducted in March 2019 reported an average in a weekday of 76,000 passengers boarding the train of 8 lines on the metropolitan railway service (41 p. 125).
- **"Regional Railway Service" SFR:** On the average weekday in 2019, the passengers were 150,000, of which 51,000 stopping in the metropolitan city of Turin. The two main stations of Turin (Porta Nuova and Porta Susa) exceed 15,000 passengers/day (41 p. 128).

METRO:

- Data from monitoring access to Metro stops (weekday in 2017): Porta Nuova reported: 25,000 passenger boarding/day, XVIII Dicembre: 15,000 passengers boarding/day, Porta Susa, Lingotto and Fermi: 10,000 passenger boarding/day, all other stops between 4,000 to 8,000 passenger boarding/day (41 p. 130).

URBAN:

- Data provided by GTT "Gruppo Torinese Trasporti" reported for the entire 2019, the following transport reports: Metro: 43,000 passengers/year, Tram: 53,000 passenger/year, Bus: 189,000 passenger/year (41 p. 130).
- For extra urban lines, the 2018 survey by the Piedmont Agency reported the number of passengers boarding per day for some lines, the following: Pinerolo: 14,000 passengers boarding/day, Valli Susa and Sangone: 11,000 passengers boarding/day, Ivrea: 10,000 passenger boarding/day (41 p. 131).

FREIGHT:

- From the ELTIS-Transtools matrix, in 2010, originated a flow of 138.7 million tones/year and attracted 138.9 million tones/year (41 p. 135).

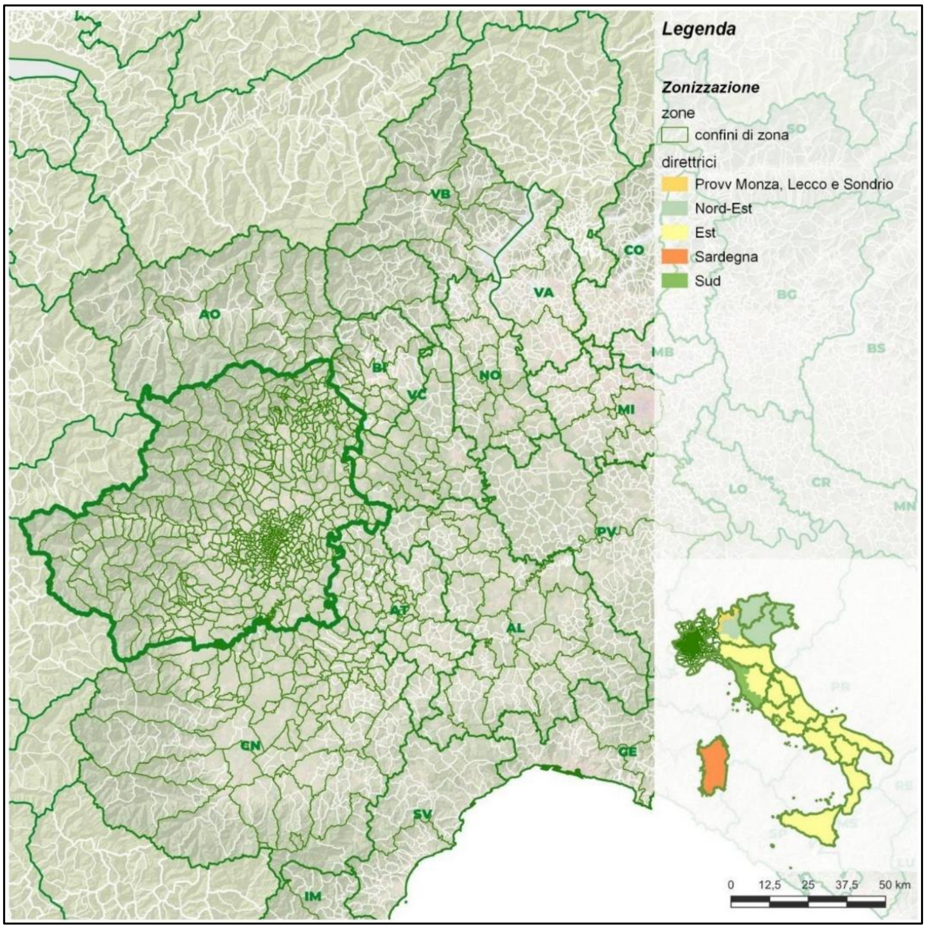
3.2.3 Model Report

General architecture is a multimodal and multiscale model of the i-TraM national system developed by META studio (56 p. 7).

ZONING:

- The characteristics of the model included 734 defined zones of which 595 are in the metropolitan city of Turin, subdivided into 130 in the city of Turin, 146 are homogeneous areas, and the remaining 319 zones and 5 external directions that represented the rest of the national territory and 10 border crossings, that could affect mobility. The Image 1 shows the distribution of zoning with external areas (56 pp. 11-12).

Image 1
Overall and external Zones



Source: (56 p. 12)

SUPPLY MODEL (S):

- It was used three categories for the individual macro-modalities of transport, which were non-motorized, individual motorized, and collective motorized mobility. Each of these categories had its own characteristics in terms of time and cost, these factors contribute to the definition of generalized cost function (56 pp. 15-34).
- The offer for individual motorized mobility consisted of a road graph with 40,000 nodes and 90,000 arcs divided into five distinct functional classes (56 p. 17).
- For collective motorized mobility, the railway graph included 5,500 and 6,000 directional edges, and the public transport services were composed of 333 public transport lines (56 p. 25).

DEMAND MODEL (D)

- The socio-economic data was subdivided into 56 categories, considering gender, age, main activity and specific position (56 pp. 35-36).
- The generation considered a rigid demand hypothesis (56 p. 37).
- The Distribution was an elastic distribution (home-school and home-work) and occasional trips (business, personal and leisure) (56 p. 38).
- The modal split was based on a logit-type algorithm and applied to the 3 macro-modalities. The model was characterized on the comparison between the estimated travel cost, on each O/D pair for individual modal choice (56 pp. 35-48).
- In the modal constants considered attributable to travel comfort and time penalty attributed to waiting time or time spend boarding the vehicles (56 pp. 35-48).

FLOW ASSIGNMENTS (F)

- The assignment of O/D matrices was conducted in the CUBE Voyager environment, using an incremental deterministic method with 25 iterations. The assignment of the O/D matrices was expressed as equivalent vehicle/day, minimizing for each component the generalized travel cost function (56 pp. 49-50).
- The calibration of the model was made using a large set of traffic surveys and systematization of the existing data (56 pp. 49-50).

ENVIRONMENTAL MODEL (A)

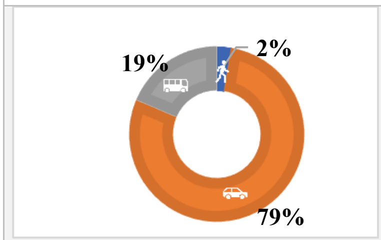
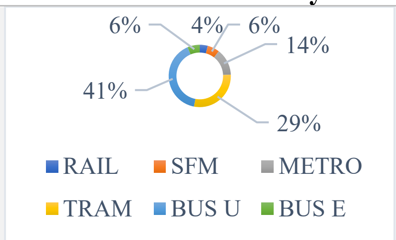
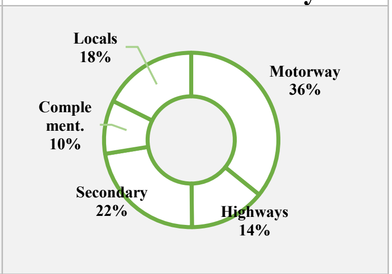
- Evaluation of the expected impacts by transport system.

3.2.4 Planning scenarios

The selection of strategies, programs and goals set up in the SUMPs were based on the appropriate model simulations that allowed to evaluate them according to the expected results. In the case of the metropolitan area of Turin, the following simulations were developed:

- The current scenario corresponded to the reconstruction of the current situation of the goods and passengers demand, including all main transport modes, referring to the current year 2019 (41 pp. 136-142). The results of the model were presented in Table 13:

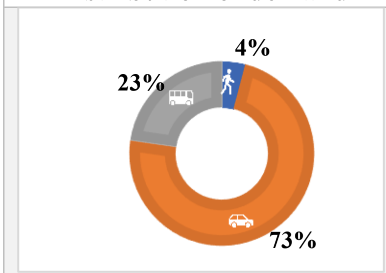
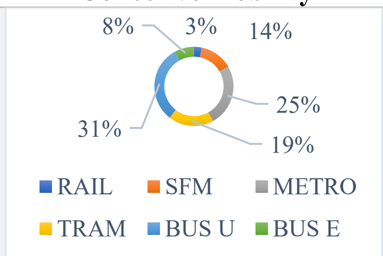
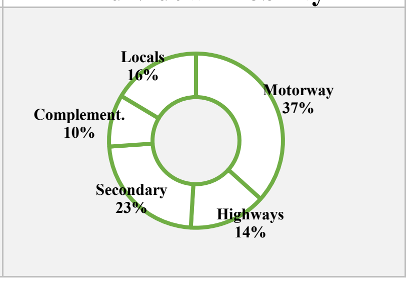
Table 13
Results of Current Scenario

Distribution of demand	Collective mobility	Individual Mobility
		

Source: (41)

- The reference scenario "RIF" corresponded to expected evolution of the system in the absence of specific plan action. This must be referred to 3 times horizon: Short Intervention: 2025, Medium Intervention: 2030 and Long Intervention: 2050 (41 pp. 169-190). The results of the model are presented in the Table 14:

Table 14
Results of Reference Scenario

Distribution of demand	Collective mobility	Individual Mobility
		

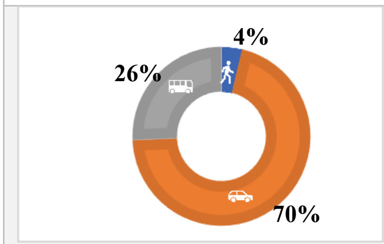
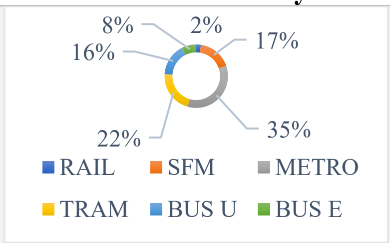
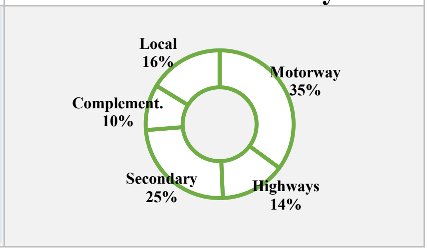
Source: (41)

- The first-generation scenario was an alternative scenario of the plan scenario obtained by adopting the 3 pillars of the "ASI" (Avoid-Shift-Interactive) strategy (41 pp. 199-238).

- Avoid – Proximity Scenario: Promoted non-motorized mobility, the simulation model was based on modifying behavioral parameters.
- Shift – Cooperative Scenario: Transfer demand from individual to collective motorized mobility, characterized by a large set of interventions to strengthen the local public transport offer.
- Interactive scenario had the aim to achieve the plan's objectives by acting the currently dominant mode "individual motorized mobility".

- The plan scenario was the result of combining the most effective actions included in the first-generation scenario (41 pp. 271-285). The results of the model are presented in the Table 15:

Table 15
Results of the Plan Scenario

Distribution of demand	Collective mobility	Individual Mobility
		

Source: (41)

3.2.5 Plan Interventions

Some specific strategies and goals are presented in the plan, among which the following are mentioned (41 p. 12):

- The integration among transportation systems, including rapid transport systems of mass, where economically and financially feasible.
- The development of collective mobility to improve service quality and raise the commercial speed of public transportation.
- The development of pedestrian and bicycle mobility systems to consider travel bicycle and pedestrian travel as an integral and fundamental part of urban mobility.
- The introduction of shared motorized mobility systems, such as car-sharing, bike-sharing, van-sharing, car-pooling.
- The renewal of the fleet with the introduction of vehicles with low polluting impact and high efficiency energy efficiency.
- The rationalization of urban logistics in order to balance the needs of supply of goods needed to increase the vitality of the economy of urban centers.
- The dissemination of the culture related to mobility safety, with actions that aim to accident risk reduction and others whose purpose is to reduce risk exposure (protection of weak users, mitigation of the consequences of accidents).

3.3 Sustainable Urban Mobility Plan of Metropolitan Area Valle de Aburrá

The sustainable urban mobility plan is a management instrument aimed at establishing a sustainable and safe mobility model through the definition of short, medium and long-term actions with a horizon of 2030. These actions are supported by five programs and various objectives, strategies and projects.

3.3.1 Structure of Plan

The Table 16 presents the structure of the plan:

Table 16
Structure of the plan

Section	Description
Introduction	Presentation of the plan, including the normative framework.
Diagnostic Report	Presentation of the current mobility situation in the metropolitan area and the identification of the central problem of mobility in the study area.
Vision of the Plan	Description of the strategic component of the plan.
Formulation of the Plan	List of each strategy, plan and project, focused on achieving each objective.

Source: (55)

3.3.2 Diagnostics

3.3.2.1 Supply

The transport supply of the metropolitan area of Valle de Aburrá is composed of (43):

1. According to the Land Use Planning in 2017, the road infrastructure totalized 5,458.8 km, categorized as follows: 4.89% regional roads, 4.79% principal roads, 2.36% minor principal roads, 6.89% secondary roads, 28.44% local roads and 52.64% unclassified roads (57).
2. In the metropolitan area, 1.38 million vehicles were registered, whit 58% motorbikes and 42% cars (58 p. 160).
3. The bikeway infrastructure in 2018 is composed of 88 km of bikeways in the metropolitan area. The average public space indicator for pedestrians was 3.68 m^2 per inhabitant, with a pedestrian road of 1.78 m2 per inhabitant, totaling 16,569 m^2 (58 pp. 166-167).
4. SITVA "Valle de Aburrá Integrated transport system" was made by (59):
    - The Metro system spanned 31.3 km with two lines and 27 stops, serving six municipalities with a total of 80 trains. The system was supported by 33 feeder services with 370 vehicles.
    - Cable Metro: A gondola lift system with 14.62 km distributed over six lines and 499 gondolas.
    - Tramline: An exclusive carriageway of 4.2 km with nine stops on a single line.
    - Metroplus: An exclusive carriageway of 22.5 km, divided into three lines, with a fleet of 47 articulated buses and 64 standard buses.
5. Collective Transport Services: As of 2018, the total fleet consisted of 3,628 buses with 71.8 km of exclusive carriageway (58 pp. 164-166).
6. Individual Public Transport: By 2013, it was estimated that 22,000 taxis were registered by 34 companies in Medellín (58 pp. 166-167).

3.3.2.2 Demand

The study of the demand was based on the following sources available for the analysis:

HOUSEHOLD SURVEY ORIGIN/DESTINATION:

- ✓ In 2017, household surveys were conducted in the metropolitan area, resulting in 16,340 responses with a minimum confidence interval of 90%. The total number of daily trips made was 6.13 million, with 9% being pedestrian and cyclist trips, 45% using public transport services and 26% using private transport (60).

COUNTING VEHICLES:

- ✓ Additional to the 54 interception surveys stations, seven more stations were used for counting vehicles, identifying peak hours from 5:30 to 8:30 am and 3:45 and 6:45 pm. A total of 219,206 vehicles were registered during the morning peak hour and 213,000 in the afternoon peak hour across all the stations (43 pp. 37-41).

OTHER STUDIES:

- ✓ An additional 112,000 interception surveys were conducted for public and private transport across 54 stations in the metropolitan area (43 pp. 37-41).
- ✓ Frequency and occupation visual survey: 25 sections were selected to check capacity in the public and private transport service (43 pp. 37-41).

3.3.2.3 Analysis of traffic flow

The description of traffic flows analysis is described for each mode (61):

PEDESTRIAN AND CYCLING:

- Pedestrian: 1.72 million daily trips were registered, with an average travel time of 20 minutes and a travel distance of 1.8 km (60).
- Bicycles: 53,100 daily trips were observed, with an average distance of 5.1 km and travel time of 31 minutes (60).

PUBLIC TRANSPORT:

- Daily trips of 2.78 million were reported, subdivided into the Integrated transport system (35%), collective transport system (39%) and taxi use (14%). The peak hours are divided into morning (6:30 to 7:30 am) and afternoon (5:30 to 6:30 pm). The average travel time and the distance were: Metro (61 min, 13,7km); Metroplus (50 min, 7.9 km); Tram (45 min, 5.3 km); collective transport (45 min, 8.2 km) and taxi (30 min, 5.6 km) (60).

PRIVATE VEHICLES

Total daily trips of 1.58 million (52% cars and 26% motorcycles) were presented with the average travel time and the distance of cars (35 min, 7.8km) and motorcycles (32 min, 8.9 km) (60).

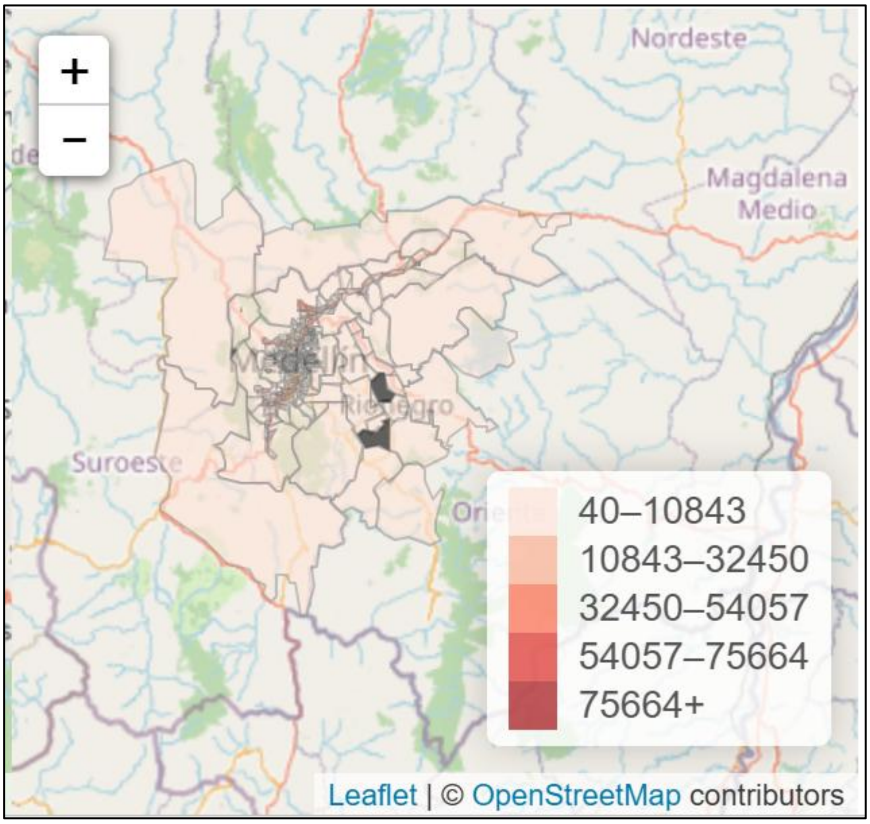
3.3.3 Model Report

The model represented trips in the study area for a typical morning day in 2017. It was developed using EMME software (43 p. 107).

ZONING:

- Composed of a zoning where 536 Transport System zones were integrated (513 within the metropolitan area, 23 external zones) and 13 zones represented the rest of the country affecting the area's mobility. The Image 2 shows the distribution of transport System Zones (43 p. 110).

Image 2
Transport System Zones



Source: (62)

SUPPLY MODULE:

- The supply network: The model integrated the public network transport system and road infrastructure, comprising 17,084 links and 4,943 nodes. Input data included travel speeds, vehicle flow from the counting study and road infrastructure information (43 p. 114).

DEMAND MODULE:

- Model periods were 6:00 to 8:00 am and 4:45 to 6:45 pm corresponding to the peak hours.
- Demand segmentation: Two modes of public and private transport.
- The household matrix was obtained from the travel hierarchy by principal mode and trip pattern. Once classified, the average travel time and the standard deviation were calculated per mode. The interception matrix was derived from the interception survey for each mode of transport including motorcycle, private vehicle, taxi, collective public transport and Integrated transport system (43 p. 129).
- Finally, the two matrices were combined to obtain a single matrix per mode and period, resulting in a 549x549 matrix (43 p. 139).

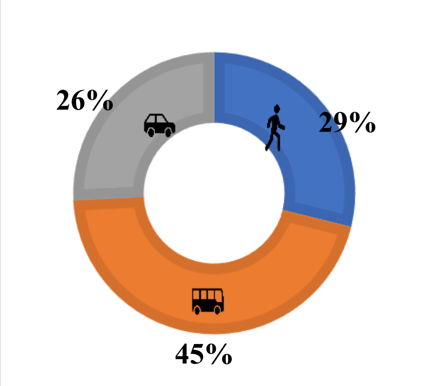
FLOW ASSIGNMENT

- The assignment of transport matrices was based on a generalized cost function, including variables like travel time, walking time, interchange time and monetary charger. The maximum likelihood method was used for calibration, adjusting observed to simulated flows with minimal modification to the principal matrix (43 p. 147).

3.3.4 Scenarios

In the plan, the base scenario was presented so that the current mobility distribution was described identifying potential problems for future improvements. Regarding the evaluation of the strategies, the plan talks about expected results, but does not detail the development of different scenarios, only the milestones in three terms, short, medium and long. In the Table 17, the results in terms of active mobility and public transport system are presented:

Table 17
Expected results from the plan implementation

Distribution of the current demand	Expected results		
	**VISION**	**BASE SCENARIO**	**SCENARIO 2030**
	Increase the use of bicycle and pedestrian trips as daily transportation modes.	29%	34%
	Increase the utilization of the Integrated Transport System (SITVA).	35%	>35%

Source: (55)

3.3.5 Plan Interventions

The strategic component of the plan was based on specific objectives, programs and strategies that defined the path to implementing sustainable and safe mobility by 2030 in the metropolitan area. The plan was based on five core programs (55):

- Safe, friendly and inclusive region for active mobility. (E.g. Consolidation of the cycle network infrastructure and creation of calm traffic zones).
- Public transport, an option for everyone. (E.g. Implementation of sustainable mobility corridors in the metropolitan area)
- A competitive and connected region. (E.g. Implementation of infrastructure to strengthen internal and external connection of the metropolitan area)
- An equitable infrastructure for all. (E.g. Definition and implementation of restrictive measures for the private vehicles use, such as congestion charging and contamination rates)
  We respect life. (E.g. Improvement of road safety in road infrastructure)

3.4 Sustainable Urban Mobility Plan of Metropolitan Area of Cúcuta

The Sustainable Urban Mobility Plan sets 9 objectives to achieve by 2035 a mobility system structured by and for citizens of the Metropolitan Area, characterized as organized, sustainable, safety, modern and connected with territorial dynamics.

3.4.1 Structure of the plan

The Table 18 presents the structure of the plan:

Table 18
Structure of the plan

SECTION	DESCRIPTION
INTRODUCTION	What is the Sustainability and Safe Mobility Plan?
DIAGNOSTIC REPORT	Description of the current mobility situation in the metropolitan area and the identification of the central problem of mobility in the study area.

SECTION	DESCRIPTION
VISION OF THE PLAN	Description of the strategic component of the plan.
FORMULATION OF THE PLAN	Description of each strategy, plan and project, focused on achieving each objective.

Source: (63)

3.4.2 Diagnostic

3.4.2.1 Supply

The transport supply of the metropolitan area of Cúcuta is composed of:

1. As of 2019, the urban network consisted of 1,272 km of arterial, zonal and neighborhood roads, with 1,193 km paved and 79 km unpaved. The second and third order rural networks comprised 918 km of roads, ensuring connectivity between the city and the surrounding municipalities (64 p. 107).
2. Almost 370,000 vehicles were registered in 2021, of which 250,000 were motorbikes. Only 100 hybrid and electric vehicles were listening in 2021 (64 p. 184).
3. A total of 8,427 taxis (74,6% in San Jose de Cúcuta) were operated by 17 companies. Most vehicles were old, and the diagnostic identified 20 routes for this type of transport system (64 p. 168).
4. The bikeway infrastructure included 8 different sections, 6 of which were in San Jose de Cúcuta, totaling 13 km. The bikeways were bidirectional and located over the sidewalks (64 p. 85).
5. There were 114 public transport routes operated by 11 companies, with a total of 2013 vehicles subdivided into: 63% minibus, 3% vans, 27% buses and 7% others. The longer distances routes were classified as short (4 routes), too long (56 routes with some buses empty, causing congestion and slow speeds), medium (30 routes) and long (24 routes), the average route frequency is 13 minutes, and the average travel speed was 16 km/h due to congestion (64 pp. 129-141).
6. The central terminal was a principal passenger terminal in San Jose de Cúcuta, was the major trip attractor and generator, with 26 transport companies operating there (64 p. 122).
7. Private vehicles were often parked on roads and sidewalks throughout the city. Additionally, the downtown area had 40 parking spaces available for 505vehicles (322 cars and 183 motorbikes). There were 140 off-road parking spaces accommodating 10,588 vehicles, with only 15% available for bicycles (64 p. 288).
8. The freight infrastructure included the Cúcuta free zone, east industrial park, Cúcuta industrial zone and Boconó industrial park, with significant industrial factories nearby. San Jose de Cúcuta was a principal freight generator in the region, surrounded by the western and eastern beltways that connect directly county’s main highways without entering the city (64 p. 388).

3.4.2.2 Demand

The study of the demand was based on the following sources available for the analysis:

HOUSEHOLD SURVEY ORIGIN/DESTINATION

- ✓ In 2022, 16,340 households were surveyed in the metropolitan area. The daily total trips were 1.07 million, broken down as: pedestrian and bicycle: 18%; public transport system: 30%; private transport system: 52% (private car, motorbike, school bus, taxi, truck, bike – taxis and others) (57 pp. 14-15).

ORIGIN/DESTINATION OF INTERCEPTION SURVEY

- ✓ A total of 2,147 passenger surveys were conducted at 11 points from 6:00 to 10:00 am to understand the socioeconomic characteristics and origin/destination of public transport passengers (64 p. 37).
- ✓ A total of 4,181 private transport surveys were conducted in 11 points from 6:00 to 9:00 am on a weekday (64 p. 41).

OTHER STUDIES

- ✓ Vehicle counts: 50 stations were used to capture traffic information throughout the metropolitan area (64 pp. 33-34).
- ✓ Support: Videos located along the road infrastructure were analyzed (64 p. 36).
- ✓ Frequency and occupation visual survey: 16 points were selected to check the nominal (number of chairs) and total capacity (standing and setting passengers) of the public transport service (64 pp. 42-43).

3.4.2.3 Analysis of the traffic flow

The description of traffic flows analysis is described for each mode:

PEDESTRIANS AND CYCLISTS

- A total of 161,318 daily walking trips longer than 10 minutes in the metropolitan area, of these 50.7% were trips to return home, 18.9% to study, 17.2% to work. There were 32,544 daily bicycle trips, mainly for returning home (49.7%) and work (44.3%), with high concentration in the city center and distribution along of the city (57 pp. 14-15).

PUBLIC COLLECTIVE TRANSPORT

- The total daily trips were 317,714. The predominant reason for this type of trip was work, on the other hand recreation and shopping had the lowest participation rates. During peak demand 24,977 passengers boarded buses accounting for an average travel time of 30 minutes (57 pp. 14-15).

INDIVIDUAL COLLECTIVE TRANSPORT

- A total of 80 maximum daily passengers were counted. The most frequent reasons for travelling by individual collective transport were returning home (49%), and health issues (31%) (57 pp. 14-15).

PRIVATE TRANSPORT

- The demand for private transport was 560,178 daily trips. The dynamics of mobility in the city center had vehicle flows of 2,000 vehicles per hour, making it the primary trip attraction. The travel speed in the center ranged from 4 to 20 km/h, causing congestion. Surrounding roads had higher flows of approximately 3,000 vehicles per hour, with speeds of 15 to 20 km/h. In general terms private transport had two principal destinations, the city center and east center (57 pp. 14-15).

LOGISTIC AND FREIGHT TRANSPORT:

- The metropolitan area of Cúcuta generated 83% of the freight load of the North Santander department, with 5,645,902 tons generated and attracted annually. During peak demand (6:30 to 8:30 am) approximately 3,600 tones were mobilized (64 pp. 248-249).

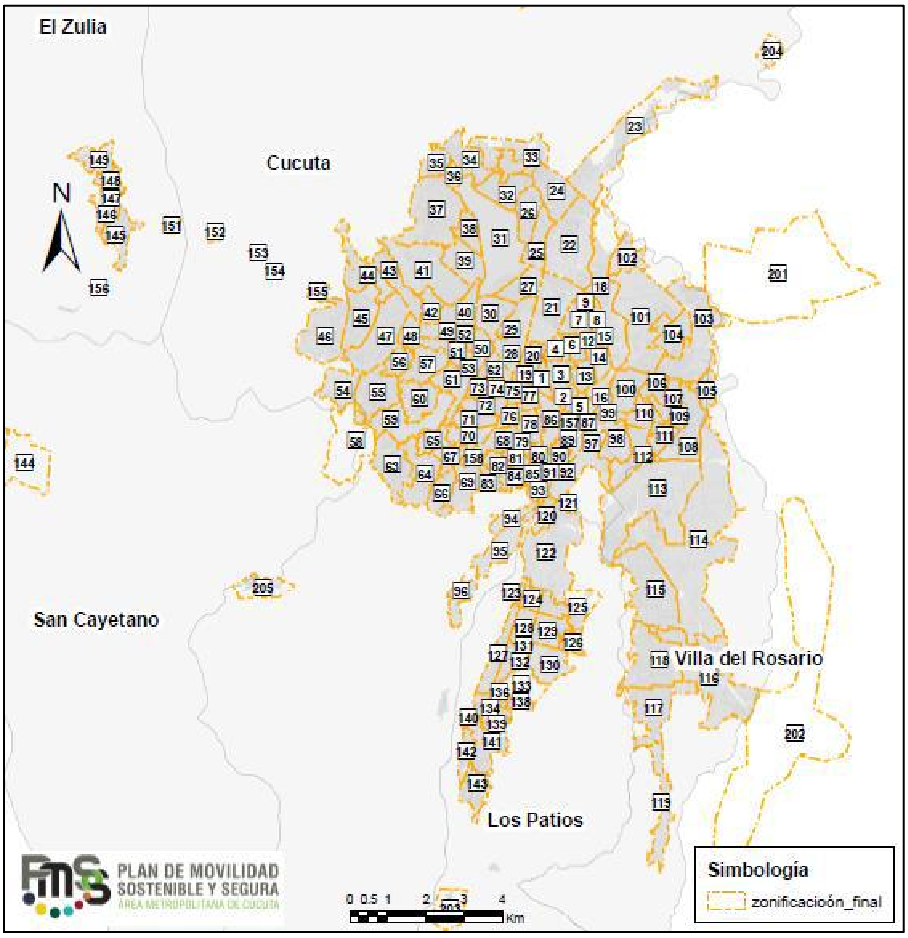
3.4.3 Model Report

The model represented trips in the study area for a typical morning in 2022, developed using VISUM software (63 p. 15).

ZONING:

- The zoning was derived from the census survey (DANE 2018), identifying 155 zones distributed across the metropolitan area, with 6 as trip generators and attractors, and 7 external zones (64 p. 49). The Image 3 shows the distribution of Traffic Analysis Zones:

Image 3
Traffic Analysis Zones



Source: (64 p. 49)

SUPPLY MODEL

- The Metropolitan Road network included the public transport routes, principal, secondary and residential routes, composed by 1,739 links and 1,149 nodes with attributes such as free flow speed, capacity, length and transport mode (64 p. 51).

DEMAND MODEL

- **Generation and attractions model:** The model considered three factors: land use, the socioeconomic characteristics, and the transport system evaluating accessibility. Predicted trips were presented in the O/D matrix. Multiple regression, category analysis, logit ordinal (LO) and growing factor models were used to estimate the number of trips produced in each zone (64 pp. 44-46).
- **The segmentation of the demand:** The model included 2 modes of transport, 2 vehicles ownership categories and 3 activities (work, study and other). Five trip purposes were identified: home-shopping, home – work, home-study, home-other reasons and non-based home (64 p. 54).
- **Distribution:** The model estimated the number of trips during a specific period in the zones, using a gravitational model (aggregated) and the logit model (disaggregated), with an exponential cost function considered (64 pp. 57-58).

- The logit model served as the basis of the modal split, predicting trips by each mode of transportation. Two modes of transport were defined (private transport – car, motorbike, taxi) and public transport (bus, informal transport) (64 pp. 58-60).

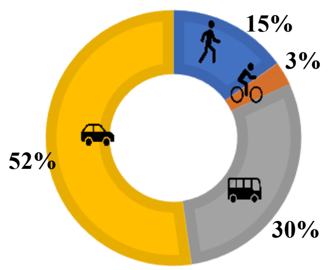
ASSIGNMENT

- The assignment determined trip demand in the different zones, number of trips by zone and the transport mode. Volume – delay functions were used to analyze vehicular transit behavior under congestion conditions, such as the Bureau of Public Roads (BPR) function (64 pp. 60-64).

3.4.4 Scenarios

In the plan the base scenario was presented where the current mobility distribution was described, identifying potential problems for future improvements. Regarding the evaluation of the strategies, the plan talked about expected results, but did not detail the development of different scenarios, only the milestones in three terms, short, medium and long. In the results in terms of active mobility and public transport system are presented in the Table 19:

Table 19
Expected results from the plan implementation

Distribution of the current demand	Expected results		
	VISION	BASE SCENARIO	SCENARIO 2030
	Expanding the bikeway infrastructure in the metropolitan area. (152,8 km segregated bikeway and 41,2 km sport bikeway)	13 km	197.8 km
	Adopting and implementing a strategic public transport system "SETP"	114 routes different operator.	71 routes integrated

Source: (63)

3.4.5 Plan Intervention

The plan comprises 9 general objectives, 50 specific objectives, 6 strategic lines, 25 programs and 54 projects focused on achieving a sustainable, safe, modern and connected transportation system in the metropolitan area (63).

- Sustainable mobility in the whole metropolitan area. (E.g.: Guarantee new, safe, connected bikeway infrastructure to promote bicycle use as a sustainable transport mode.)
- Intelligent transport system. (E.g.: Increase the efficiency of the public transport system through the design and implementation of public transportation operations in the metropolitan area.)
- Mobility management. (E.g.: Implement the Road Plan for the metropolitan area.)
- Institutionality support for mobility (E.g.: Design and implement the metropolitan mobility observatory.)
- Behavior, civic culture and education of the road actors. (E.g.: Formulate and implement strategies for "Free and safe mobility")
- Strengthening logistics and intermodal transport. (E.g.: Formulate and implement plans for loading and unloading zones.)

3.5 Comparison between the three case studies

Based on the Sustainable Urban Mobility Plans (SUMPs) for the metropolitan areas of Turin (Italy), Valle de Aburrá (Colombia) and Cúcuta (Colombia), the Table 20 presents a comparative analysis focuses on key aspects of the urban mobility areas. This comparison provides critical insight into zone characteristics, data sources, planning strategies among these territories in relation to the metropolitan context and planning strategies.

Table 20
Comparison between the three case studies

	METROPOLITAN AREAS		
	TURIN	**VALLE DE ABÚRRA**	**CÚCUTA**
Key Objectives	Reduce traffic congestion and emissions by 2030, promote modal shift through integrated multimodal transport systems	Promote sustainable and safe mobility by2030, strength SITVA "Integrated Transport System", and active transport, improving regional connectivity.	Modernize public transport by 2035, promote active mobility with new infrastructure that promotes safety and civic behavior.
Planning focus	**Active Mobility**		
	Increase the active trips by 4% in 2030.	Increase the active modes as daily transportation mode to 34% in 2030.	Expand bikeways infrastructure from 13 km to 198 km in 2035, increasing the demand in 13%.
	Public Transport		
	Increasing public transport modes to 23% by 2030.	Strengthen SITVA, increasing more than 35% of the modal split participation.	Implement an Integrated Transport System to organize public routes.
	Private Vehicle		
	Reduce car use to 73% by 2030.	Introduce restrictive measures like congestion charges to limit car use.	Limit vehicle congestion in different zones, improve parking regulation and reduce downtown traffic.
	Environmental Improving		
	Reduce air pollution and GHC emissions, promoting low-emission transport modes	Improve air quality, promote public and active transport with low-emission vehicles.	Mitigate air pollution from motorbikes, expand sustainable transport modes.
Current Behavior	Travel behavior is car-dominant, with marginal public transport use in outer areas.	Reasonably balanced mode use with strong use of SITVA.	Extremely high reliance on motorbikes. The public transport system is based on informality.
Daily Trips	4.4 million trips (2013)	6.14 million trips (2017)	1.07 million trips (2022)
Zoning	734 zones (130 in Turin City), 5 external and 10 borders.	536 zones distributed in 10 municipalities and 23 external zones.	155 zones distributed in 5 municipalities and 7 external zones.
Average area and population of each zone	4.19 km^2 5,034 inhabitants. (ANNEX B – Table 70)	5.02 km^2 7,135 inhabitants (ANNEX B – Table 71)	9.44 km2 9,072 inhabitants (ANNEX B – Table 72)

	METROPOLITAN AREAS		
	TURIN	**VALLE DE ABÚRRA**	**CÚCUTA**
Data sources	ISTAT census, mobile data, household survey 2013.	Household survey 2017, visual and intercept surveys.	Household survey 2022, visual and intercept surveys.
Demand model	Based on a logit-type algorithm applied in 3 macro-modalities, with a rigid demand hypothesis and elastic distribution.	Mode/purpose split into 2 principal modes and focused on the peak hour period.	Regression and logit models, with 2 principal modes and 5 purposes.
Supply network	40,000 nodes, 90,000 arcs, 333 public transport lines, full modal integration.	17,084 links and 4,943 nodes, which integrate SITVA on the road network.	1,739 links and 1,149 nodes, limited modal integration.
Planning scenarios	4 scenarios: current scenario, first generation scenarios "ASI" and planning scenario with multimodal simulation.	2 scenarios: base and 2030 vision, limited simulations.	Base and 2035 vision scenarios, limited simulations.
Modeling Software	CUBE Voyager	EMME	VISUM

The SUMPs, show contrasting priorities in line with each region's stage of development. The Turin SUMP is aligned with the European standard planning bases that are focused on modal integration, decongestion and environmental impact reduction through activities and strategies. Regarding the plan of Valle de Aburrá, it emphasizes equity, inclusion and safety framing mobility as a social right and focuses on active and public transport improvements in a regional context. And Cúcuta takes a citizen-centered and modernization approach, aligning transportation restructuring with intelligent systems and infrastructure investments to improve transport service quality.

Zonal definitions vary considerably, affecting the ability of the models to reflect the urban context. Turin uses a highly detailed disaggregated structure with 734 zones, including 595 within the metropolitan area aggregated in 11 homogenous areas, including a subdivision into 130 zones just for the city of Turin, and 5 external zones that represent the rest of the national territory and 10 border crossings, allowing for accurate spatial modeling. Valle de Aburrá uses a moderately disaggregated structure of 536 zones in 10 municipalities, and Cúcuta, on the other hand, adopts a more simplified aggregated model of 155 zones, of which 7 are external.

In terms of transport model, Turin uses a multiscale and multimodal modal with logit-based demand model with elastic distribution and 56 socio-demographic categories. Its behavior-based approach integrates different travel purposes, macro-modalities of transport, time and travel cost across scenarios. The Valle de Aburrá plan models demand well within peak hours, but the model is segmented in two principal modes, and finally Cúcuta, although it employs several modeling techniques such as regression and logit, applies them to a very aggregated zonal structure, the segmentation of the demand in two principal transport modes, and 5 purposes of trips. This limits spatial detail and the representation of the population behaviors. The aggregation of demand reduces the ability to model diverse travel behavior.

The complexity of the supply model reflects the availability of data and the complexity of the network. The Turin network includes 40,000 nodes and 90,000 arcs, with 33 public transport lines and intermodal dynamics. The Valle de Aburrá network is composed of 17,084 links and 4,943 nodes includes SITVA "Integrated Transport System of Valle de Aburrá" integration, but lacks Turin multimodal details. The simplified Cúcuta network, with 1,739 links and 1,149 nodes, captures basic route frequency and congestion, but not fine-scale modal interaction, which affects its ability to modal realistic scenarios.

Concerning the scenario modeling, Turin explores four scenarios: current scenario, the reference scenario where is the expected evolution of the system in the absence of any strategy, first generation scenario including the ("Avoid, Shift and Improve") and finally the plan scenario included all the effective actions, each simulated and evaluated using multimodal allocations. This allows for data-strategy selection and robust policy testing. Turin is the most methodologically rigorous plan. Valle de Aburrá contrasts a baseline with a 2030 vision, like Cúcuta outlines a 2035 vision but, both focusing on modal but lacks intermediate simulation. This limits its capacity for planning or managing uncertainty.

In conclusion, this comparative analysis shows how variation in zonal subdivision, data quality and model sophistication reflect the complexity of each SUMP in the metropolitan areas. These differences underscore the crucial role of mobility planning in transforming objectives into viable and sustainable strategies and interventions.

IV. DESCRIPTION OF DATASETS FROM HOUSEHOLD SURVEYS

In this chapter, the structure of the household surveys conducted in the metropolitan areas subject to study is explained, considering that these surveys constitute one of the main sources of information needed to compute Urban Mobility Indicators (UMI).

As a first stage, it will be briefly described how the data was collected and all variables considered within the survey are going to be listed with their corresponding variable description for each of the metropolitan areas. In a second step, a univariate statistical analysis will be performed to the most relevant variables, finalizing with the presentation of consideration of the bivariate statistical analysis necessary to evaluate the whole survey in terms of mobility.

Considering the above, a household survey is a type of data collection technique that gathers information on household socio-economic characteristics, the factors that influence decision making about their mobility and the trip characteristics that the interviewer makes. Commonly, the survey is applied based on a questionnaire with questions about:

- Trip diary: A list of all trips that the interviewed people made 24 hours preceding the interview. This includes details such as mode of transport, origin and destination locations and trip purpose. (65 p. 162)
- Socio demographics characteristics: Questions regarding age, education level, gender and other relevant attributes. (65 p. 173)

The household surveys may have many variables that depend on the design of the survey and the desired scope. Each variable consists of multiple observations that depend on the sample size. Thus, a set of univariate data is composed of observations from a single variable (66 p. 3)

These variables can be classified into two types (66 p. 3):

1. Categorical variables where their value corresponds to a classification are normally fixed. E.g. the gender of the people normally is described by two categories: Female and Male.
2. Continuous variable where its dominant characteristic is that the value is a number. E.g. the age of a person is represented by a number.

Lastly, for the univariate and bivariate analysis descriptive statistics were used to summarize, classify and analyze a single variable of the survey data, through graphical methods such as the bars diagrams, pie diagrams, histograms, and the computation of central tendency, dispersion, shape and location. Thanks to this analysis, a general overview of the socio-economic characteristics and mobility state in the surveyed city can be obtained, which are the grounds for further assessment.

4.1 Variable Description

4.1.1 Metropolitan Area of Turin

The IMQ mobility survey is one of the most important sources of information on demand data for transport in the metropolitan area, carried out periodically initially carried out from 1991 until 2004 by ATM and GTT. Subsequently, the responsibility was taken over by the Agency for Metropolitan and Reginal Mobility (Italian Agenzia Mobilità Piemontese AMP) with the collaboration of the

Socioeconomic Research Institute of Piedmont (Istituto di Ricerche Economico Sociali del Piemonte IRES Piedmont). The aim is to obtain a picture of the current condition of the mobility in quantitative and qualitative condition of the means of transport systems perceived by the residents of the metropolitan area aged over 10 years.

One of the resources used in the estimation of the multimodal passengers and freight origin and destination matrices which served as the basis for the elaboration of the Sustainable Urban Mobility Plan published in 2022 (the document under analysis in this thesis) were the IMQ matrices derived from the survey made up in 2013 (41 p. 99). More recently, between November 2021 and May 2022, the twelfth edition of household survey was conducted. As in 2013 edition, this was extended to the entire Piedmont region, involved the participation of approximately 51,000 interviews, and was conducted through the same methodology "telephone interviews" (67).

During the survey, was made the telephone interviews were randomly selected from a list of telephone numbers in the districts of the Piedmont Region, in 1991, 1996, 2000, 2004 and 2008 the survey had a large sample with 25 to 30 thousand interviews, and smaller samples with 5 to 7 thousand of samples in the years 1994, 1998, 2002, 2006 and 2010, in the case of 2013 the sample was extended from the Turin to the entire Piedmont Region with more of 50,000 interviews (41 p. 22). The interviews started in April 2013 and were conducted exclusively by telephone between Tuesday and Saturday from 9:30 AM to 9:30 PM. Some information was asked about the trips made during the day before the interview such as the time, place of departure and arrival, the reason for the trip, the means of transport used, among others. This information was essential to understand mobility needs in order to create intervention strategies for transportation systems. In December 2013, the interview phase was concluded, but the verification and completion of the database containing the collected information was not finished until November (68).|

The recorded interview corresponds a homogeneous stratified sample, the variables considered were sex with two classes, age with four intervals, and area of residence (Turin and the other areas in the Piedmont Region). The sample size was calculated by adopting a sampling rate of 3% in the Turin belt (31 municipalities) and 1% the rest of the area, with a minimum of 60 interval per area, for each sample strata the sampling rate was different (69).

A total of 52,199 valid surveys were conducted, of which 16% were conducted in Turin city, 34% in the belt of Turin, which consists of 31 communes, 38% in the rest of Piedmont Region (Vercelli, Novara, Cuneo, Asti, Alessandria, Biella y Verbano-Cusio-Ossola) and the 13% of the surveys were carried out in the rest of the Province of Turin.

According to table No. 1 "*Universo e campione dell'indagine IMQ2013"* of the survey report, the population over 10 years in the study area in 2013 were 3,992,491 (70).Subdivided in the following way presented in the Table 21:

Table 21
Distribution of the population in the Metropolitan Area

Area	Population Over 10 Years	SURVEY		Distribution of the Population %
		Number of Valid Survey	% of the sample	
Turin City	827,471	8,240	1.00%	21%
Belt	578,384	17,500	3.03%	14%
Resto of Province of Turin	665,191	6,720	1.01%	17%
Rest of Piedmont Region	1,921,445	19,659	1.02%	48%
Total	3,992,491	52,119	1.31%	

Source: (70)

The survey variables relating to the interviews can be listed as follows:

SOCIO-ECONOMIC VARIABLES

The objective of this group of variables is to obtain general information and socio-economic characteristics of the households. The module is composed of 17 fields (columns) and 52,120 records (rows), the fields are described in the Table 22:

Table 22
Socio-economic Survey Variables for the Metropolitan Area of Turin

SOCIO-ECONOMIC VARIABLES	
1. ID_INT	Code of Interviewee
2. GIORNO	Day of Interview
3. COD_ZONA_RES	Residential code zone 3.1 C002 – C071/ E025 – E047/Q001 – Q023 Zone in Turin 3.2 R200 – R213 Zone in Vercelli 3.3 R300 – R313 Zone in Novara 3.4 R400 – R433 Zone in Cuneo 3.5 R500 – R512 Zone in Asti 3.6 R600 – R621 Zone in Alessandria 3.7 R700 – R707 Zone in Biella 3.8 R800 – R810 Zone in Verbano-Cusio-Ossola 3.9 T000 Torino Whole Municipality
4. RESIDENZA	Place of the interviewee 4.1 Belt 4.2 Rest of Piedmont 4.3 Rest of Province 4.4 Turin
5. SESSO	Sex of interviewee 5.1 (1) Male 5.2 (2) Female
6. FASCIA_ETA	Range of age of the interviewee 6.1 (1) Between 11 and 19 years old 6.2 (2) Between 20 and 40 years old 6.3 (3) Between 50 and 64 years old 6.4 (4) 65 and older
7. TRASP	Professional activity consists of the transportation of people or things. 7.1 (1) Yes 7.2 (2) No
8. Q_USC	Total number of times the interviewee leaves home during the day (1 to 5 and blanks).
9. N_SPOST	Total number of trips made during the day (1 to 10 and blanks).
10. N_AUTO	Number of cars available in the family (0 to 9 and blanks).
11. ATTIVITA	Professional activity or status 11.1 (1) Entrepreneur/Freelancer 11.2 (2) Official/Manager 11.3 (3) Clerk/Sales Assistant 11.4 (4) Operator 11.5 (5) Teacher 11.6 (6) Sales Representative 11.7 (7) Artisan/Business Owner 11.8 (8) Student 11.9 (9) Housewife 11.10 (10) Retired 11.11 (11) Waiting for 1st job 11.12 (12) Unemployed 11.13 (13) Other 11.14 (99) 11.15 Blanks
12. TIPO_STUD	Type of school attended (only for students) 12.1 (1) Lower Secondary School 12.2 (2) Higher education (high school, technical and professional institutes, etc.) 12.3 (3) Extracurricular courses in the Region 12.4 (4) Other extracurricular courses

SOCIO-ECONOMIC VARIABLES	
	12.5 (5) University/Polytechnic 12.6 (6) Post-graduate specialization courses 12.7 Blank=Not a student
13. LAVORA	Active worker 13.1 (1) Yes, the interviewee works. 13.2 (2) No, the interviewee does not work. 13.3 Blank=The interviewee is not an employee.
14. SETTORE_LAV	Sector of activity 14.1 (1) Agriculture. 14.2 (2) Industry. 14.3 (3) Trade/Crafts. 14.4 (4) Services. 14.5 (5) Public Administration. 14.6 (6) Other 14.7 Blank= Not a worker
15. TITOLO_STUDIO	Educational Qualification 15.1 (1) No educational qualifications. 15.2 (2) Elementary school certificate 15.3 (3) Lower secondary school diploma 15.4 (4) High school diploma/diploma 15.5 (5) Degree 15.6 (6) Post-graduate specialization courses 15.7
16. RESID_ANAGR	Registered residence 16.1 (1) At the home from which you are responding. 16.2 (2) In another address of the same Municipality. 16.3 (3) In another municipality of the Piedmont region. 16.4 (4) Elsewhere
17. TASSO_CAMP	Sampling rate percentage of the stratum to which the respondent belongs

Source: (69)

MOBILITY VARIABLES

The objective of this module is to obtain detailed information about the trips made by the households, the module is composed by 27 fields (columns) and 105,099 records (rows), the fields are described in the Table 23:

Table 23
Mobility Survey Variables for the Metropolitan Area of Turin

MOBILITY VARIABLES	
1. ID_INT	Code of Interviewee
2. PROGR_USC	Progressive number of the exit in the interview (1 to 5/Blank)
3. PROGR_SPOST	Progressive number of trips in the exit (1 to 10/Blank)
4. SESSO	Sex of interviewee 4.1 (1) Male 4.2 (2) Female
5. FASCIA_ETA	Range of age of the interviewee 5.1 (1) Between 11 and 19 years old 5.2 (2) Between 20 and 49 years old 5.3 (3) Between 50 and 64 years old 5.4 (4) 65 and older
6. COD_ZONA_RES	Residential code zone 6.1 C002 – C071/ E025 – E047/Q001 – Q023 Zone in Turin 6.2 R200 – R213 Zone in Vercelli 6.3 R300 – R313 Zone in Novara 6.4 R400 – R433 Zone in Cuneo 6.5 R500 – R512 Zone in Asti 6.6 R600 – R621 Zone in Alessandria 6.7 R700 – R707 Zone in Biella 6.8 R800 – R810 Zone in Verbano-Cusio-Ossola T000 Torino Whole Municipality Blank=Out of Piedmont Region

MOBILITY VARIABLES	
7. SCOPO	Purpose of trips 7.1 (1) Going to work 7.2 (2) Work reasons 7.3 (3) Study 7.4 (4) Purchasing/Commissions 7.5 (5) Accompaniment 7.6 (6) Medical care/Visits 7.7 (7) Sport/Leisure 7.8 (8) Returning home 7.9 (9) Visits to relatives/Friends 7.10 (10) Other 7.11 (11) Returning home on interview day
8. COD_ZONA_PAR	Departure Zone 8.1 C002 – C071/ E025 – E047/Q001 – Q023 Zone in Turin 8.2 R200 – R213 Zone in Vercelli 8.3 R300 – R313 Zone in Novara 8.4 R400 – R433 Zone in Cuneo 8.5 R500 – R512 Zone in Asti 8.6 R600 – R621 Zone in Alessandria 8.7 R700 – R707 Zone in Biella 8.8 R800 – R810 Zone in Verbano-Cusio-Ossola T000 Torino Whole Municipality Blank=Out of Piedmont Region
9. PROV_PAR	Province/Foreign State of Departure 001 Torino, 002 Vercelli, 003 Novara, 004 Cuneo, 005 Asti, 006 Alessandria, 007 Valle d'Aosta/Vallée d'Aoste, 008 Imperia, 009 Savona, 010 Genova, 011 La Spezia, 012 Varese, 013 Como, 014 Sondrio, 015 Milano, 016 Bergamo, 017 Brescia, 018 Pavia, 019 Cremona, 020 Mantova, 022 Trento, 023 Verona, 024 Vicenza, 028 Padova, 030 Udine, 033 Piacenza, 034 Parma, 035 Reggio nell'Emilia, 036 Modena, 037 Bologna, 038 Ferrara, 040 Forlì-Cesena, 041 Pesaro e Urbino, 048 Firenze, 052 Siena, 054 Perugia, 058 Roma, 096 Biella, 098 Lodi, 099 Rimini, 100 Prato, 103 Verbano-Cusio-Ossola, 108 Monza e della Brianza, Francia, Principato di Monaco, Svizzera.
10. ORA_PAR	Departure time (hh:mm)
11. COD_ZONA_ARR	Arrival zone 11.1 C002 – C071/ E025 – E047/Q001 – Q023 Zone in Turin 11.2 R200 – R213 Zone in Vercelli 11.3 R300 – R313 Zone in Novara 11.4 R400 – R433 Zone in Cuneo 11.5 R500 – R512 Zone in Asti 11.6 R600 – R621 Zone in Alessandria 11.7 R700 – R707 Zone in Biella 11.8 R800 – R810 Zone in Verbano-Cusio-Ossola T000 Torino Whole Municipality Blank=Out of Piedmont Region
12. PROV_ARR	Province/Foreign State of Arrival 001 Torino, 002 Vercelli, 003 Novara, 004 Cuneo, 005 Asti, 006 Alessandria, 007 Valle d'Aosta/Vallée d'Aoste, 008 Imperia, 009 Savona, 010 Genova, 011 La Spezia, 012 Varese, 013 Como, 014 Sondrio, 015 Milano, 016 Bergamo, 017 Brescia, 018 Pavia, 019 Cremona, 020 Mantova, 022 Trento, 023 Verona, 024 Vicenza, 028 Padova, 030 Udine, 033 Piacenza, 034 Parma, 035 Reggio nell'Emilia, 036 Modena, 037 Bologna, 038 Ferrara, 040 Forlì-Cesena, 041 Pesaro e Urbino, 048 Firenze, 052 Siena, 054 Perugia, 058 Roma, 096 Biella, 098 Lodi, 099 Rimini, 100 Prato, 103 Verbano-Cusio-Ossola, 108 Monza e della Brianza, Francia, Principato di Monaco, Svizzera.
13. ORA_ARR	Arrival time (hh:mm)
14. USO_MEZZ	Use of means of transport when moving 14.1 (1) Yes 14.2 (2) No
15. MEZZO 1 **16. MEZZO 2** **17. MEZZO 3**	1st, 2nd, 3rd type of means used in the journey (1) By feet – Other (2) Motorcycle – Other (3) Car as driver – Private (4) Car as a passenger – Private (5) Taxi – Other (6) Suburban city bus and/or GTT Tram (TO and beltway) – Public (7) GTT suburban bus – Private

MOBILITY VARIABLES	
	(8) Urban transport (bus, trolleybus, tram, subway) of other municipalities and other cities than Turin – Public (9) Extra-urban bus other company – Public (10) Corporate bus – Public (11) School bus – Public (12) Trenitalia railway – Public (13) GTT Railway (Canavesana, TO - Ceres TO - Chieri) – Public (15) Other (16) Personal bicycle – Other (20) Bike Sharing system bicycle – Other (19) GTT automatic subway – Public (21) Car Sharing system vehicle as driver – Private (22) Rail other companies (TRENORD, SSIF, FART, SBB-CFF-FFS, SNCF, BLS) – Public (23) Other overland public transportation (funicular, cable car) – Public (24) Other public transportation on water (boat, hydrofoil) – Public
18. PAX_AUTO	Number of passengers in car (0 to 6/Blank=not using car as driver)
19. NUM_LIN_URB	Number of GTT urban/suburban lines used in the Turin area (1 to 4/Blank)
20. COD_ALTROURB	ISTAT code of the Municipality in which an urban/suburban TPL system different from that of the Turin area was used. 001030 Borgofranco D'ivrea, 001059 Carmagnola, 001078 Chieri, 001082 Chivasso, 001152 Mezzenile, 001156 Moncalieri, 001164 Nichelino, 001171 Orbassano, 001189 Pianezza, 001191 Pinerolo, 001209 Quassolo, 001219 Rivoli, 001229 Rubiana, 001249 San Mauro Torinese, 001265 Settimo Torinese, 002158 Vercelli, 003068 Galliate, 003106 Novara, 003131 Romentino, 004003 Alba, 004022 Bernezzo, 004025 Borgo San Dalmazzo, 004029 Bra, 004034 Busca, 004064 Cervasca, 004078 Cuneo, 004130 Mondovi, 004203 Saluzzo, 005005 Asti, 006001 Acqui Terme, 006003 Alessandria, 006039 Casale Monferrato, 006114 Novi Ligure, 006174 Tortona, 15146, 096004 Biella, 103028 Domodossola, 103072 Verbania
21. COD_ZONA_2M	Zone where the 2nd type of vehicle was taken. 21.1 C002 – C071/ E025 – E047/Q001 – Q023 Zone in Turin 21.2 R200 – R213 Zone in Vercelli 21.3 R300 – R313 Zone in Novara 21.4 R400 – R433 Zone in Cuneo 21.5 R500 – R512 Zone in Asti 21.6 R600 – R621 Zone in Alessandria 21.7 R700 – R707 Zone in Biella 21.8 R800 – R810 Zone in Verbano-Cusio-Ossola T000 Torino Whole Municipality Blank=Out of Piedmont Region
22. PROV_2M	Province where the 2nd type of vehicle was taken. 001 Torino, 002 Vercelli, 003 Novara, 004 Cuneo, 005 Asti, 006 Alessandria, 007 Valle d'Aosta/Vallée d'Aoste, 010 Genova, 015 Milano, 018 Pavia, 96 Biella, 103 Verbano-Cusio-Ossola.
23. ORA_2MEZZO	Time at which the 2nd type of vehicle was taken (hh:mm)
24. COD_ZONA_3M	Area where the 3rd type of vehicle was taken 24.1 C002 – C071/ E025 – E047/Q001 – Q023 Zone in Turin 24.2 R200 – R213 Zone in Vercelli 24.3 R300 – R313 Zone in Novara 24.4 R400 – R433 Zone in Cuneo 24.5 R500 – R512 Zone in Asti 24.6 R600 – R621 Zone in Alessandria 24.7 R700 – R707 Zone in Biella 24.8 R800 – R810 Zone in Verbano-Cusio-Ossola T000 Torino Whole Municipality Blank=Out of Piedmont Region
25. PROV_3M	Province where the 3rd type of vehicle was taken 001 Torino, 002 Vercelli, 003 Novara, 004 Cuneo, 005 Asti, 006 Alessandria, 015 Milano, 096 Biella
26. ORA_3MEZZO	Time at which the 3rd type of medium was taken (hh:mm)
27. TASSO_CAMP	Sampling rate percentage of the stratum to which the respondent belongs

Source: (69)

4.1.2 Metropolitan Area of Valle de Aburrá

The Valle de Aburrá Household Mobility Survey was made between March 21 and June 16, 2017. With the results of the survey, it was possible to build a comprehensive view of how people move, identified the modes of transportation used, and analyzed the distribution of trips, these insights are essential for planning and investment in the infrastructure and transportation. The survey was conducted by the Metropolitan Area of Valle de Aburrá, with support from consultant firms TPD Ingeniería and EPYS.

The survey was conducted through household visits to 16,340 randomly selected households, equivalent to 1.3% of the total 1,202,258 households in the metropolitan area. The whole members in the household were interviewed (43 pp. 21-22).

According to the survey report, the population in 2016 was 3,821,797, of which 65% were concentrated in the Medellín City, while the rest of the population were distributed in the remaining 9 municipalities in the metropolitan area (43 p. 18)

The distribution of households and inhabitants by municipality within the Metropolitan Area in 2016 was as follows presented in the Table 24:

Table 24
Distribution of the Population in the Survey in the Metropolitan Area of Valle de Aburrá

Area	Households	Inhabitants	% of population	Survey	
				No. of Valid Survey	% of surveys
Medellín	809,833	2,486,723	65%	8,038	1.0%
Envigado	63,259	227,599	6%	1,810	2.9%
Bello	134,135	464,560	12%	2,908	2.2%
Itagüi	82,838	270,920	7%	1,460	1.8%
Barbosa	15,323	50,832	1%	726	4.7%
Caldas	21,373	78,762	2%	311	1.5%
Copacabana	23,078	71,033	2%	347	1.5%
Girardota	14,498	55,477	1%	278	1.9%
La Estrella	17,971	63,332	2%	213	1.2%
Sabaneta	19,951	52,559	1%	249	1.2%
Total	1,202,258	3,821,797		16,340	

Source: (43 p. 18)

Interviewers filled out a questionnaire consisting of three modules, with the responses of the households interviewed. The first module collected general information of the survey household, the second recorded socioeconomic data about the household members, and the third documented the trips made during the last 24 hours (the previous day and night) by each member of the household (43 pp. 26-31). The variables included in each module are as follows:

Module 1: Household Data
The module is composed of 72 fields (columns) and 16,341 records (rows), the fields are described in the Table 25:

Table 25
Household Survey Variables for the Metropolitan Area of Valle de Aburrá

HOUSEHOLD VARIABLES	
1. FECHA_ENCUESTA	Day of Interview
2. ID_HOGAR	Code of the household

HOUSEHOLD VARIABLES	
3. ID_MUNICIPIO **4. NOM_MUNICIPIO**	Municipality code 001 Medellín, 079 Barbosa, 088 Bello, 129 Caldas, 212 Copacabana, 266 Envigado, 308 Girardota, 360 Itagüi, 380 La Estrella, 631 Sabaneta
5. ID_MACROZONA **6. NOM_MACROZONA**	Code and name of each macrozone
7. ID_BARRIO **8. NOM_BARRIO**	Code and name of each neighborhood
9. ESTRATO_EPM	Range of socioeconomic strata • Stratum 1 • Stratum 2 • Stratum 3 • Stratum 4 • Stratum 5 • Stratum 6
10. ID_SIT **11. NOM_SIT**	Number and name of Integrated Transport System (SIT)
12. HOGARES EN VIVIENDA	Number of households are in the house (1 to 8)
13. MIEMBROS HOGAR	Number of household members (1 to 10)
14. MIEMBROS PRESENTES	Number of household members present at the interview (1 to 10)
15. TIPO VIVIENDA **16. DESCRIPCIÓN TIPO VIVIENDA**	Type of house • 1 House • 2 Flat • 3 Other
17. VIVIENDA ES **18. DESC VIVIENDA ES**	Description of the type of household • 1 Homeownership • 2 Rented Housing • 3 Provided by others • Does not respond
19. # CELDA PARQUEADERO	Number of parking spaces in the household (1 to 10)
20. CELDA PROPIA **21. CELDA ALQUILADA** **22. CELDA OTRO TIPO**	Type of parking spaces in the household (False/True)
23. VEH EN HOGAR	Number of cars in the household (1 to 11)
24. TIPO VEH 1,2,3,4,5,6,7 **25. DES TIPO VEH 1,2,3,4,5,6,7**	Description of vehicle type 01 Compact car < 1300cc 02 Medium car 1300-1800cc 03 Pickup truck (<1.5 Ton) 04 Small truck (1.5 - 3.5 Ton) 05 2-stroke motorcycle 06 4-stroke motorcycle 07 Motor tricycle 08 Taxi 09 Non-motorized bicycle 10 Motorized bicycle 11 Other
26. MODELO VEH 1,2,3,4,5,6,7 **27. MATRICULA AMVA VEH 1,2,3,4,5,6,7** **28. DIGITO_PYP 1,2,3,4,5,6,7**	Car model and license plate number
29. TIPO COMBUSTIBLE 1,2,3,4,5,6,7 **30. DES TIPO COMBUSTIBLE 1,2,3,4,5,6,7**	Type and description of fuel • A Natural Gas • D Diesel • E Electric • G Gasoline • No response

Module 2: Household Residents Data

The module is composed of 83 fields (columns) and 52,470 records (rows), the fields are described in the Table 26:

Table 26
Residents Survey Variables for the Metropolitan Area of Valle de Aburrá

RESIDENTS VARIABLES	
1. ID_HOGAR	Code of the household
2. ORDEN MORADOR **3. MORADOR PRESENTE**	No. of the resident
4. PARENTESCO **5. DESC-PARETESCO**	Type of relationship of household members 1 Boss 2 Spouse or partner 3 Son/Daughter 4 Relative 5 Live-in employee 6 Visitor 7 Tenant 8 Grandparent 9 Other
6. EDAD	Age of the interviewee
7. GENERO	Sex of interviewee 1 Male 2 Female
8. ESCOLARIDAD **9. DESC ESCOLARIDAD MAX**	Level of education 1 None 2 Primary School 3 Night Grade 4 High School Diploma 5 Non-formal Education 6 Technical Education 7 Technologist Education 8 University Degree 9 Postgraduate Degree No response
10. OCUPACIÓN **11. DESC OCUPACIÓN**	Interviewee's occupation 01 Homemaker 02 Retired 03 Student 04 Self-employed worker 05 Employee (dependent worker) 06 Unemployed 07 Retired and student 08 Retired and worker 09 Homemaker and student 10 Worker and student 11 None No response
12. DEDICACIÓN LABORAL **13. DES DEDICACIÓN LABORAL**	Work dedication 1 Full-time 2 Part-time 3 Volunteer or unpaid No response
14. SECTOR LABORAL **15. DESC SECTOR LABORAL**	Description of the labor sector 01 Agriculture-Fishing-Mining 02 Manufacturing 03 Construction 04 Education 05 Finance 06 Healthcare 07 Transportation 08 Hotels and Restaurants 09 Commerce 10 Government 11 Other Services No response
16. NIVEL LABORAL **17. DESC NIVEL LABORAL**	Occupational rank 1 Managerial 2 Support Staff

RESIDENTS VARIABLES	
	3 Operational 4 Other No response
18. LUGAR LABORA **19. DESC LUGAR LABORA**	Place of work 1 Home 2 Office 3 Home and Office 4 On the street 5 Visitor 6 On the car 7 Other No response
20. HORA LABORA CASA	Number of hours working at home
21. HORA LABORA OFICINA	Number of hours working in the office
22. HORA OFICIAL INICIO LABORAL	Start time of the working day
23. DISCAPACIDAD **24. DESC DISCAPACIDAD**	Description of disability 0 None 1 Sense of sight 2 Sense of sound 3 Sense of Taste 4 Mobility 5 Sense of Touch 6 Mental 7 Sense of Sight and Talk No response
25. DISCAPACIDAD ES **26. DES DISCAPACIDAD ES**	Degree of disability 1 Permanent 2 Temporary No response
27. REQUIERE AYUDA **28. DESC REQUIERE AYUDA**	Description of the help needed 1 Wheelchair 2 Crutch 3 Cane 4 Walking frame 5 Caregiver 6 None 7 Other No response
29. DIFICULTAD ACCESO 2,3,4,5,6 **30. DESC DIFICULTAD ACCESO 2,3,4,5,6**	Description of the difficulty of access 01 Bicycle 02 Taxi 03 Bus 04 Subway 05 Metroplus 06 Car 07 Motorcycle 08 Tram 09 Gondola Lift 10 All 11 None No response
31. REALIZO VIAJE **32. DESC REALIZO VIAJES**	Made any trip in the last 24 hours 1 Traveled 2 Did not travel
33. RAZON NO VIAJO **34. DESC RAZON NO VIAJO**	If the trip did not take place, indicate the reason 1 Was sick 2 Was waiting for someone to arrive or call 3 Had to take care of someone 4 Had to work at home 5 Did not want/need to go out 6 Because of the weather 7 Did not have money for transportation 8 Pico y Placa (traffic restriction system)

RESIDENTS VARIABLES	
	9 None
35. **MODO USA POR PYP AM** 36. **DESC MODO USA POR PYP AM** 37. **MODO USA POR PYP PM** 38. **DESC MODO USA POR PYP PM**	Mode of travel used by Pico y Placa (traffic restriction system) 01 Car before and after Pico y Placa 02 Metro 06 Bus 09 Walking 10 Not Traveling No response
39. **RAZON NO USA AUTO 2,3,4.** 40. **DESC RAZON NO USAR AUTO 2,3,4.**	Reason for not using a car 1 Pico y Placa (traffic restriction system) 2 Parking Problems 3 Is expensive 4 Traffic congestion 5 The public transport is faster 6 The car is damaged 7 Environmental Reason 8 Other No response
41. **REGISTRO VEH APP TRABAJAR** 42. **DESC REGISTRO VEH APP TRABAJAR**	The vehicle is registered in an application 1 Yes 2 No
43. **INGRESO HOGAR** 44. **DESC INGRESO HOGAR**	Range of income 1 Lower than $738.000 (COP) 2 Between $738.001-$1.500.000 (COP) 3 Between $1.500.001-$2.250.000 (COP) 4 Between $2.250.001-$3.500.000 (COP) 5 Between $3.500.001-$5.000.000 (COP) 6 Between $5.000.001-$7.000.000 (COP) 7 More than $7.000.000 (COP)

Module 3: Mobility Data

The module is composed of 43 fields (columns) and 87,614 records (rows), the fields are described in the Table 27:

Table 27
Mobility Survey Variables for the Metropolitan Area of Valle de Aburrá

MOBILITY VARIABLES	
1. **ID_HOGAR**	Code of the household
2. **ID_MORADOR**	Code of the interviewee
3. **ID MUNICIPIO O** 4. **MUNICIPIO O**	Origin of each trip – Municipality 001 Medellín, 079 Barbosa, 088 Bello, 129 Caldas, 148 Carmen de Vivoral, 212 Copacabana, 266 Envigado, 308 Girardota, 318 Guarne, 360 Itagüi, 376 La Ceja, 380 La Estrella, 400 La Unión, 440 Marinilla, 541 Guatape Peñol, 607 El Retiro, 615 Rionegro, 631 Sabaneta, Another municipiality of Colombia.
5. **ID COMUNA O** 6. **COMUNA O**	Origin of each trip – Commune
7. **ID BARRIO O** 8. **BARRIO O**	Origin of each trip – Neighborhood
9. **SIT O**	Origin in the Integrated Transport System (SIT)
10. **HORA O**	Start time of each trip (hr-min)
11. **ID MUNICIPIO D** 12. **MUNICIPIO D**	Destination of each trip – Municipality 001-002 Medellín, 079 Barbosa, 088 Bello, 129 Caldas, 148 Carmen de Vivoral, 212 Copacabana, 266 Envigado, 308 Girardota, 318 Guarne, 360 Itagüi, 376 La Ceja, 380 La Estrella, 400 La Unión, 440 Marinilla, 541 Guatape Peñol, 607 El Retiro, 615 Rionegro, 631 Sabaneta, Another municipiality of Colombia.
13. **ID COMUNA D** 14. **COMUNA D**	Destination of each trip – Commune
15. **ID BARRIO D** 16. **BARRIO D**	Destination of each trip – Neighborhood

MOBILITY VARIABLES	
17. SIT O	Destination in the Integrated Transport System (SIT)
18. HORA D	Finish time of each trip (hr-min)
19. MOTIVO VIAJE **20. DESC MOTIVO VIAJE**	Reason for each trip 01 Work 02 Study 03 Return home 04 Lunch time 05 Shopping 06 Health 07 Recreation 08 Personal errands 09 Accompany someone 10 Pick up/drop off someone 11 Other
21. MODO TRANSPORTE 1,2,3,4,5,6,7 **22. DESC MODO TRANSPORTE 1,2,3,4,5,6,7**	Type of means used in the trip 1 Urban Bus 2 Suburban Bus 3 Feeder Buses 4 Metro 5 Metroplus 6 Gondola Lift 7 Tram 8 Private Car/driver 9 Private Car/Passenger 10 Motorcycle/driver 11 Motorcycle/Passenger 12 Motorcycle Taxi 13 Motor Tricycle 14 Special Transportation Company 15 School bus 16 Taxi 17 Collective Taxi 18 Suburban Taxi 19 Private vehicles with payment (On street-without platform) 20 Private vehicles with payment (Platform) 21-39 On foot 1 block to 19 blocks or more 40 Own bicycle 41 Public bicycle 42 Flight
23. FREC CANTIDAD **24. ID FREC VIAJE** **25. DESC ID FREC VIAJE**	Travel frequency 1 Diary 2 Weekly 3 Monthly 4 Annual No response
26. COSTO TTE PARQ **27. FORMA PAGO PARQUEADERO** **28. DESC FORMA PAGO PARQUEADERO**	Parking Cost 1 Per minute 2 Per hour 3 Per day 4 Per month 5 Per year No response
29. TIPO PARQUEADERO **30. DESC TIPO PARQUEADERO**	Parking type 1 On the street without payment 2 On the street with payment 3 Building with payment 4 Building without payment 5 Own No response

4.1.3 Metropolitan Area of Cúcuta

The survey was carried out in March 2022 and ended in May of the same year, intending to establish the socioeconomic profile of households and residents of the metropolitan area of Cúcuta, as well as obtaining information to determine mobility patterns for public and private transportation users. The survey targeted households and individuals over the age of 5 years old, it was carried out by the consulting firms CalyMayor and Deloitte with the support of the mayor of Cúcuta.

The sample design incorporated a stratification, dividing the study population into independent groups, considering one variable known as statistical stratum, created from the coverage of public utility services and the criterium defined by the National Planning Department[2]. A total of 6,220 valid surveys were conducted, of which 74% were concentrated in San Jose de Cúcuta city, while 24% in the rest of metropolitan area (La Zulia, Los Patios, Puerto Santander, San Cayetano and Villas del Rosario) (64 p. 358).

According to SUMP diagnostic report No. 5-35 "*Distribución de hogares y personas por municipio dentro del AMC (2022)*", the population were 908,276. Subdivided in the following way presented in the Table 28:

Table 28
Household, Residents and Household Size Distribution in the Metropolitan Area.

Area	**Inhabitants**	**Households**	**% of the population**	**Survey**	
				No. of Valid Survey	**% of survey**
Cúcuta	682,961	211,994	75%	4,752	2.2%
El Zulia	19,416	6,308	2%	175	2.8%
Los Patios	88,013	27,542	10%	545	2.0%
Puerto Santander	8,530	2,633	1%	67	2.5%
San Cayetano	6,384	2,036	1%	36	1.8%
Villa del Rosario	102,972	32,602	11%	644	2.0%
Total	908,276	283,115		6,219	

Source: (64 p. 355)

The survey was conducted in person by trainer interviews who visited selected households and where a structured questionnaire was filled with questions on socioeconomic profile and specific travel details for each household member on a typical workday.

The survey variables were subdivided into three main sections:

MODULE OF HOUSEHOLD VARIABLES
The module is composed of 18 fields (columns) and 6,220 records (rows), the fields are described in the Table 29:

[2] **Stratification:** The socioeconomic stratification in Colombia is a property classification used as a geographic targeting tool for differential billing of public utility services, involving a cross-subsidy system. Six strata are defined historically based on housing and neighborhood characteristics, serving as an indirect indicator of the economic capacity of residents. In this way, housing quality approximates resident's quality of life. https://colaboracion.dnp.gov.co/CDT/Sinergia/Documentos/Evaluacion_Politicas_Publicas_10_Estratificacion_Socioeconomica.pdf

Table 29
Household Survey Variables for the Metropolitan Area of Valle de Cúcuta

HOUSEHOLD VARIABLES	
1. FECHA (ES)	Day of Interview
2. HORA	Hour of Interview
3. MANZANA	Code of Block
4. HOGAR	The sequence of households surveyed
5. MUNICIPIO	Municipality code 5.1 54001 Cúcuta 5.2 54261 El Zulia 5.3 54405 Los Patios 5.4 54553 Puerto Santander 5.5 54673 San Cayetano 5.6 54874 Villa del Rosario
6. BARRIO	Name of neighborhood
7. ESTRATO	Range of socioeconomic strata 7.1 Low 7.2 Middle 7.3 Upper 7.4 Blank- Does Not Respond
8. TIPO DE VIVIENDA	Type of house 8.1 Homeownership 8.2 Family Housing 8.3 Rented Housing 8.4 Other
9. ESTACIONAMIENTO	The house has its own parking space 9.1 Yes 9.2 No
10. INGRESO	Range of income 10.1 (1) The interviewee does not feel comfortable answering 10.2 (2) Less than one minimum wage 10.3 (3) Between 1 and 3 million (COP) 10.4 (4) Between 3 and 5 million (COP) 10.5 (5) Between 5 and 10 million (COP)
11. PERTENECEN AL MISMO HOGAR	The people living in the house belong to the same household. 11.1 Yes 11.2 No 11.3 Blank
12. HOGARES EN VIVIENDA	Number of households are in the house (1 to 8/Blank)
13. PERSONAS POR HOGAR	Number of household members (1 to 9, 20, 23)
14. MAYORES DE 5 AÑOS	Number of people over 5 years old (1 to 9, 16, 22)
15. CABEZA DE HOGAR	The interviewee is the head of the household 15.1 Yes 15.2 No
16. ID_HOGAR	Code of the household
17. ZAT	Number of the Transportation Analysis Zones
18. F.E. HOGAR	

MODULE OF HOUSEHOLD RESIDENT VARIABLES

The module is composed of 24 fields (columns) and 16,880 records (rows), the fields are described in the Table 30:

Table 30
Household Residents Survey Variables for the Metropolitan Area of Valle de Cúcuta

RESIDENTS VARIABLES	
1. ID_HOGAR	Code of the household

RESIDENTS VARIABLES	
2. ID_PERSONA	Code of the person
3. NACIONALIDAD	Nationality of the interviewee 3.1 Colombian 3.2 Venezuelan 3.3 Peruvian 3.4 Brazilian 3.5 Blank
4. EDAD	Range of age of the interviewee 4.1 Between 5 and 10 years old 4.2 Between 10 and 20 years old 4.3 Between 21 and 40 years old 4.4 Between 41 and 60 years old 4.5 61 and older 4.6 Does Not Respond
5. GENERO	Sex of interviewee 5.1 (0) Female 5.2 (1) Male 5.3 Does Not Respond
6. NIVEL ESCOLARIDAD	Level of education 6.1 (1) None 6.2 (2) Elementary School 6.3 (3) High School 6.4 (4) Technician/Technologist 6.5 (5) University 6.6 (6) Post graduated specialization
7. DISCAPACIDAD	The person has a disability 7.1 Yes 7.2 No
8. ESTÁ PRESENTE	The person is present during the interview 8.1 Yes 8.2 No
9. REALIZA VIAJES	The person makes trips 9.1 Yes 9.2 No
10. TIEMPO VIVIENDO AMC	Years living in the metropolitan area of Cúcuta
11. AUTOMOVIL O CAMIONETA ROPIO	Number of cars owned by the interviewee
12. AUTOMOVIL O CAMIONETA DE TERCERO	Number of cars owned by a third party
13. BUS PROPIO	Number of buses owned by the interviewee
14. BUS TERCERO	Number of buses owned by a third party
15. TAXI PROPIO	Number of taxis owned by the interviewee
16. TAXI TERCERO	Number of taxis owned by a third party
17. CAMION PROPIO	Number of trucks owned by the interviewee
18. CAMION TERCERO	Number of trucks owned by a third party
19. MOTOCICLETA PROPIA	Number of motorcycles owned by the interviewee
20. MOTOCICLETA TERCERO	Number of motorcycles owned by a third party
21. BICICLETA ADULTO PROPIA	Number of adult bicycles owned by the interviewee
22. BICICLETA ADULTO TERCERO	Number of adult bicycles owned by a third party
23. BICICLETA ELECTRICA O MONOPATIN PROPIO	Number of electric bicycles or scooters owned by the interviewee
24. BICICLETA ELECTRICA O MONOPATIN TERCERO	Number of electric bicycles or scooters owned by a third party

MODULE OF MOBILITY VARIABLES

The module is composed of 34 fields (columns) and 20,808 records (rows), the fields are described in the Table 31:

Table 31
Mobility Survey Variables for the Metropolitan Area of Valle de Cúcuta

MOBILITY VARIABLES	
1. NUMERO DE VIAJE	Travel diary of the person
2. RAZÓN DE VIAJE	Purpose of trips 2.1 (1) Work 2.2 (2) Study 2.3 (3) Shopping 2.4 (3.1) Personal Shopping 2.5 (3.2) Household Shopping 2.6 (4) Return home 2.7 (4.1) Work 2.8 (4.2) Study 2.9 (4.3) Health 2.10 (4.4) Other 2.11 (5) Personal errands 2.12 (6) Pick up/drop off someone 2.13 (6.1) For work 2.14 (6.2) For study 2.15 (6.3) or health 2.16 (6.4) Other 2.17 (7) Health 2.18 (8) Recreation 2.19 (9) Sports 2.20 (10) Religious Activity 2.21 (11) Visit friends or relatives 2.22 (12) Other (which?)
3. LUGAR COMENZÓ VIAJE	The place where the trip started 3.1 Home 3.2 Where the previous trip ended 3.3 Other
4. MUNICIPIO INICIO	Municipality where the trip started
5. BARRIO O VEREDA INICIO	Neighborhood or Sidewalk where the trip started
6. ZAT_O	Number of the Transportation Analysis Zone where the trip started
7. HORA_SALIDA	The time at which the trip started
8. LUGAR FIN VIAJE	The place where the trip ended 8.1 Home 8.2 Other
9. MUNICIPIO FIN	Municipality where the trip end
10. BARRIO O VEREDA FIN	Neighborhood or Sidewalk where the trip end
11. ZAT_D	Number of the Transportation Analysis Zone where the trip end
12. HORA_LLEGADA	The time at which the trip end
13. VIAJE SOLO A PIE	The trip was only on foot 13.1 Yes 13.2 No
14. TRANSPORTE UTILIZA **15. MODO**	Type of means used in the trip (1) Public transport bus (2) Transport from outside the metropolitan area (3) Taxi (4) Private car (paid service) (5) Shared Taxi (6) Motorcycle Taxi (7) Uber, Indriver, etc (8) Bicycle (9) Motorzed bicycle (10) Electric bicycle

MOBILITY VARIABLES	
	(11) Scooter (12) Private Car/driver (13) Motorcycle/driver (14) Truck/driver (15) Private car/passenger (16) Motorcycle/passenger (17) Truck/passenger (18) Work-provide transport (19) School bus (20) Walkin (on foot) (21) Other
16. OTRO CUAL	Description of other means
17. TIEMPO EN EL VEHICULO	In vehicle travel time (mm)
18. CUADRAS PARA ACCEDER AL BUS	Number of blocks walking to access the bus
19. PAGO DEL SERVICIO	Cost of the service used ($ COP)
20. TIEMPO DE ESPERA	Waiting time for the service
21. RAZON PREFRERIR	Reason to prefer using this transport system 21.1 (1) It is fastest 21.2 (2) No other means are available 21.3 (3) More economical 21.4 (4) Pico y Placa restriction (a traffic restriction system) 21.5 (5) It is the most accessible 21.6 (6) Other reason
22. OTRA RAZON	Description of other reasons to prefer using this transport system
23. PERSONAS EN EL VEHICULO	Number of people in the vehicle
24. GASTO COMBUSTIBLE	Cost of fuel ($ COP)
25. TIPO ESTACIONAMIENTO	Parking type 25.1 (1) Public off-street 25.2 (2) Private off-street 25.3 (3) Bay, on public street 25.4 (4) Public Street 25.5 (5) On the sidewalk 25.6 (6) Own garage 25.7 (7) Rented garage
26. TIEMPO ESTACIONAMIENTO	Parking time
27. COBRO ESTACIONAMIENTO	Parking Cost 27.1 Yes 27.2 No 27.3 Cost of the parking
28. UNIDAD DE TIEMPO DE COBRO	Parking fee unit 28.1 0 28.2 (1) Fraction rate 28.3 (2) Hour 28.4 (3) Day 28.5 (4) Week 28.6 (5) Monthly
29. COBRO UNIDAD	Parking fee unit ($ COP)
30. USO OTRO VEHICULO	Use of another vehicle to complete the trip 30.1 Yes 30.2 No 30.3 Does not Respond
31. CUADRAS CAMINO AL DESTINO	Number of blocks walking to arrive at the destination
32. ID_HOGAR	Code of the household
33. ID_PERSONA	Code of the person

4.1.4 *Comparison of the three metropolitan areas*

In this section presents a comparative analysis of the data variables included in the household survey conducted in metropolitan areas of Turin (Italy), Valle de Aburrá (Colombia) and Cúcuta (Colombia). These datasets are an important tool to understanding urban transport behaviors, and the challenges in terms of infrastructure, mobility and policy planning.

Survey Scope: Each metropolitan area designed its mobility surveys with a common objective: evaluate the current mobility situation. The Turin survey, carried out in 2013, had the primary objective of quantifying and characterizing the demand for multimodal transport thought origin-destination matrices across the whole Piedmont Region. In the case of Valle de Aburrá and Cúcuta surveys, carried out in 2017 and 2022 respectively, their goals emphasized the identification of daily trip patterns, transportation accessibility and social inequalities that need to be improved in terms of mobility focused on metropolitan areas.

Survey Methodology: The Turin survey employed telephone interviews with a stratified sampling based on sex, age, and place of residence, the methodology allowed tracking travel behavior as a function of time and across multiple areas. In contrast, Valle de Aburrá and Cúcuta survey adopted in-person household interviews, which allowed a greater control in the response rates.

Survey Structure: All three surveys subdivided into different modules where were evaluated: the socio-economic characteristics of the households, the residents' profiles and the mobility patterns.

Table 32
Comparison of Survey Structures among the three metropolitan areas

Characteristic	**Turin**	**Valle de Aburrá**	**Cúcuta**
Sample Size	52,199 individuals	16,340 households	6,220 households
Age Threshold	Over 10 years	All individuals of the households	Over 5 years
Modules	Socioeconomic characteristics and Mobility patterns	Household, Residents and Mobility.	Household, Residents and Mobility.
Socioeconomic variables	Sex, age, occupation, education, car ownership, household location.	Socioeconomic strata, education, disability, labour sector, vehicle type.	Income, car ownership, nationally, household composition.
Mobility Variables	Trip purpose, time, zones (departure/arrival), means of transport (up to 3)	Origen/Destination, time, trip frequency, travel mode (up to 7), parking cost.	Trip reasons, travel time, vehicle type, walking distance, parking, fuel, public ticket cost.
Transport modes	24 types including private, public, share, bike, walking trips, etc.	42 types including integrated transport system, walking by blocks, etc.	21 types including share rides, motorbikes, scooters, school/work transport.

In order to complete the description presented in the Table 32, key points are listed:

- **Socioeconomic Variables:** All surveys including age, sex, education level, and employment status. However, Valle de Aburrá and Cúcuta included disability status, which is not explicitly detailed in Turin dataset. Additionally, household vehicle ownership was documented in the three, though Valle de Aburrá and Cúcuta distinguished between ownership by household members or third parties, and Valle de Aburrá extended the information about the characteristics of the vehicles like model, type of fuel, etc.

- **Mobility Variables:** Trips purpose was a common variable across all datasets. Valle de Aburrá and Cúcuta included frequency of trips made by residents, which Turin did not mention explicitly.
  Valle de Aburrá and Cúcuta incorporated transportation cost and parking detailed, reflecting that surveys wanted to focus on affordability and accessibility factors.
  Turin and Valle de Aburrá provide a detailed record of all transport modes used by respondents to complete their trips, offering a comprehensive view of mobility patterns, which is not detailed in the Cúcuta dataset.

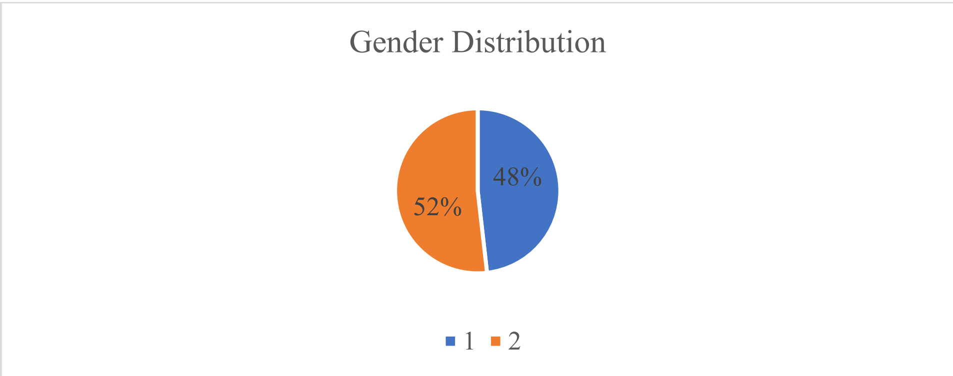
4.2 Univariate Descriptive Analysis

4.2.1 Metropolitan Area of Turin

GENDER

In the Graph 2 it is observed how the gender is distributed in the study area. The class with the highest frequency is the second which corresponds to the women accounting for 52%. Regarding class 1, which represents the men, has in total 48%.

Graph 2
Gender Distribution of Metropolitan Area of Turin



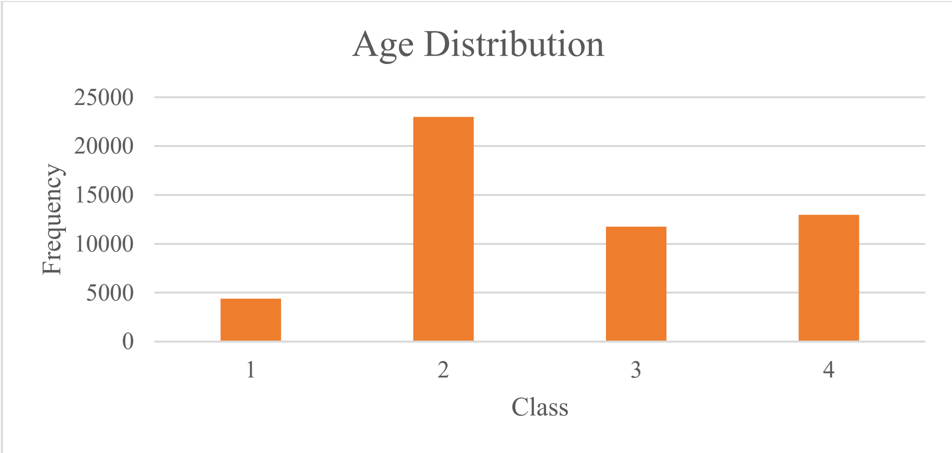
Class	Description	Class	Description
1	Female	**2**	Male

AGE

Graph 3 provides the results of the age distribution. The class with the highest frequency corresponds to the second class with 22,994 people falling between 20 to 40 years, representing 44%. This indicates most of the trips are made by this group of people.

The fourth class is the second in terms of frequency with 12,977 (25%), who are older than 65 years, The third class grouping the ages from 50 to 64 years accounts 23% with 11,761 persons. Finally, the first class counts with 4,387 people between 11 and 19 years corresponding to the 8 %. It is important to mention that the width of the classes is already predefined by the company in charge of the survey.

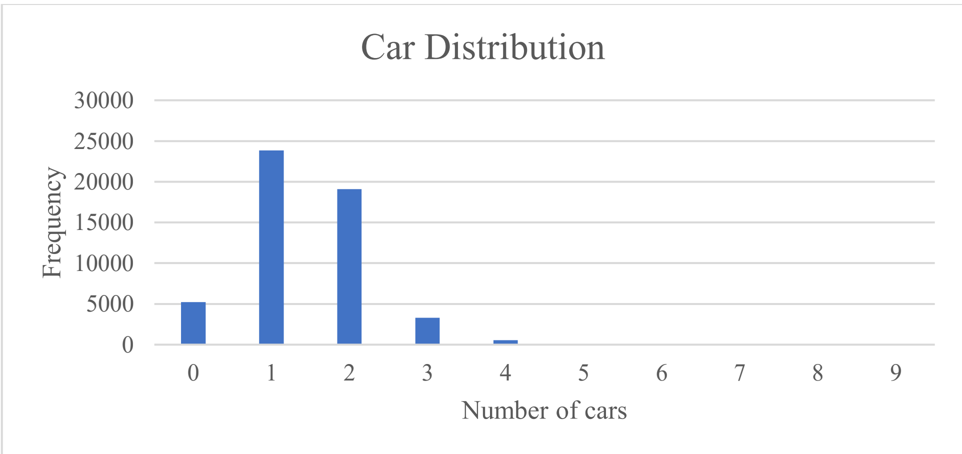
Graph 3
Age Distribution of Metropolitan Area of Turin



Class	Description	Class	Description	Class	Description
1	Between 11 and 19 years	**2**	Between 20 and 49 years	**3**	Between 50 and 64 years
4	65 and older				

NUMBER OF CARS OWNED
The results obtained of the car distribution in the metropolitan area is shown in the Graph 4, the minimum and maximum were 0 and 11 cars per house, respectively. The mean is 1.44 cars, however; the mean is 1, which means at least 50% of the houses have 1 car. The standard deviation is 0.82 which shows a low dispersion and suggests the number of cars prevailing in the household ranges from 1 to 2. Additionally, the variable is positive skewness (0.57), which means the data tends to the left of the distribution, and starting from 4 cars, the cases can be considered outlier.

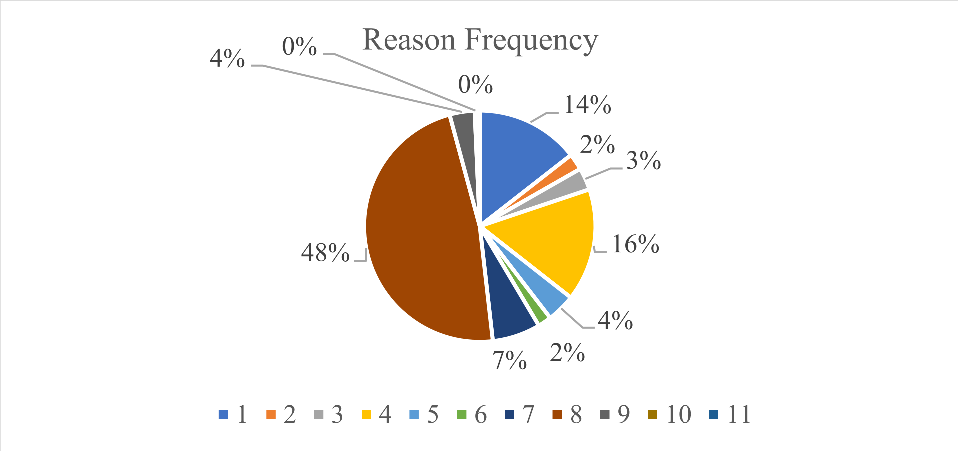
Graph 4
Car Distribution in the Metropolitan Area of Turin



REASON FOR THE TRIPS
As shown in the Graph 5, the class with the highest frequency is number 8 with 50,021 trips made to return home (48%). Class 4 is the second in frequency, accounting for 16,550 trips motivated by personal errands (16%). Class 1 occupies the third position with 15,185 trips (14%), corresponding to trips to go to work. This could imply that after the pandemic many workers are working from home, considering that, according to the age classification, the class with the highest frequency is between 20 to 49 years old, range that groups with most of the working force.

The remaining categories are class 7 (sport/leisure), class 5 (accompaniment), class 3 (study) and class 9 (Visiting friends); all accounting for less than 10%.

Graph 5
Frequency of Reason for Trip in the Metropolitan Area of Turin

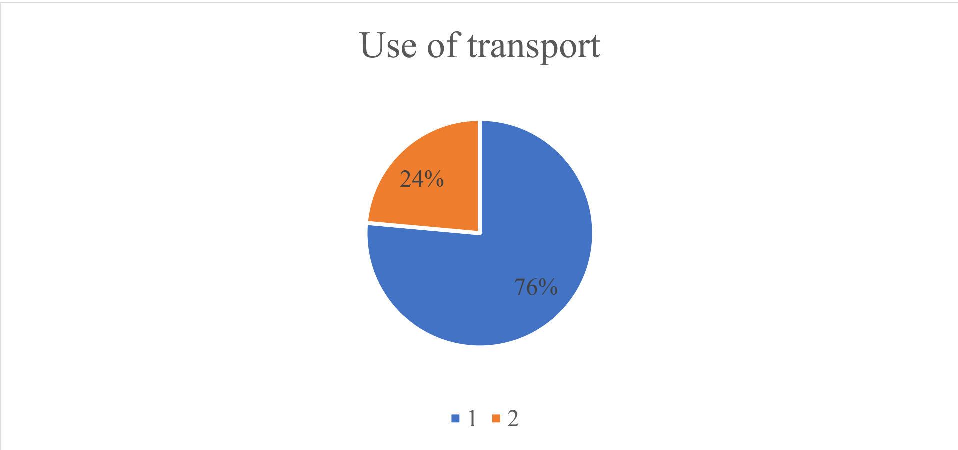


Class	Description	Class	Description	Class	Description
1	Go to work	2	Work reasons	3	Study
4	Purchasing/Commissions	5	Accompaniment	6	Medical care/Visits
7	Sport/Leisure	8	Returning home	9	Visits to relatives/Friends
10	Other	11	Returning home on interview day		

TRANSPORT MODE
First of all, the survey considered the people who make their trips using any means of transport or walking. It is observed from the Graph 6 that class 1 has a frequency of 80,336 corresponding to 76% which means the majority of the people take any means of transport for their trips. On the other hand, class 2 registered 24,762 observations equivalent to the 24% accounting for the trips made by walking.

It can be concluded that there is a strong preference for the means of transport, likely determined by factors such as the involved distance or the availability of services routed to the desired destination.

Graph 6
Use of Transport Distribution in the Metropolitan Area of Turin



Class	Description	Class	Description
1	Different transport mode	2	Only walking trips

Regarding Class 1, which refers to the means of transport used by inhabitants of the study area, the survey categorized trips that involve two or three transport modes, This subdivision was necessary, as in some cases, multiple modes are required to complete a trip. Graph 7 illustrates and lists each transport mode used by inhabitants:

Transport Mode 1: The class with the highest frequency is the number 3 with 56,583 trips made in cars as driver, representing the 71% of the total of the classes. Class 4 is the second in popularity with 7,593 trips in cars as passenger accounting for 9% of the total. Other categories with fewer frequencies are class number 6 (suburban city bus and/or GTT Tram (TO and beltway) registering 5,382 trips (7%) and class 16 (personal bicycle) with 4,369 trips (5%). According to the results, the car is the most predominant mode in the first stage of the trips, either as driver or passenger.

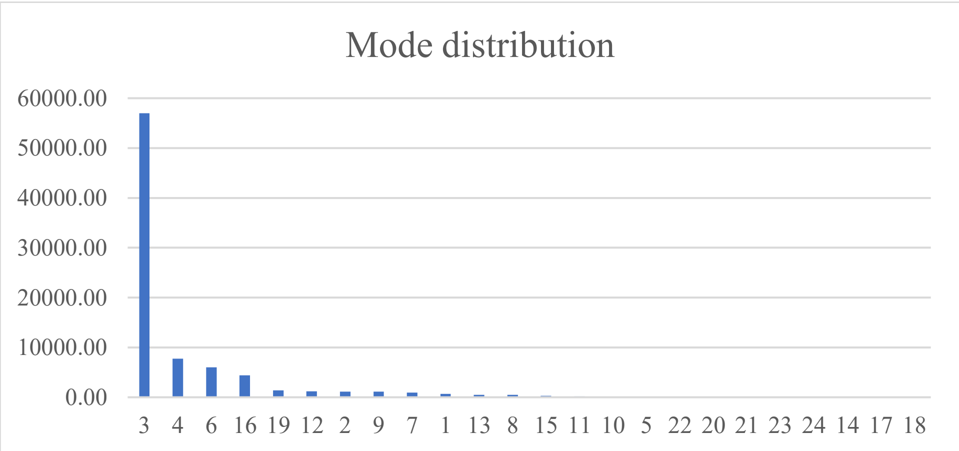
Transport Mode 2: Class 6 (Suburban city bus and/or GTT Tram (TO and beltway)) is the most popular accounting for 509 trips (20%). Metro (Class 19 - GTT automatic subway) and train (Class 12 - Trenitalia railway) trips are the following in order of preference with 488 trips (19%) and 440 trips (17%) respectively. Other categories with less frequency in this list are class 3 (Car as passenger) with 294 trips (12%) and class 1 (Walking) with 231 trips (9%).

The data suggest a big portion of the trips were started by car and completed by public transport at a later stage, which may indicate the trips come from the outskirts or municipalities within the metropolitan area, whereas their destination is found within the city itself.

Transport Mode 3: Class 1 is the one with the highest frequency with 114 trips (28%) which corresponds to walking. Class 6 (suburban city bus and/or GTT Tram (TO and beltway)) with 104 trips (25%) is the next in order of preference. Class 3 (Car as driver registered 81 trips (20%) and classes with frequencies lower than 10% are class 19 (GTT automatic subway) with 33 trips (8%) and class 4 (Car as passenger) with 28 trips (7).

The Graph 7 represents the sum of the frequencies observed in the above-mentioned three transport modes to complete the trips within the area of study:

Graph 7
Transport Mode Distribution in the Metropolitan Area of Turin



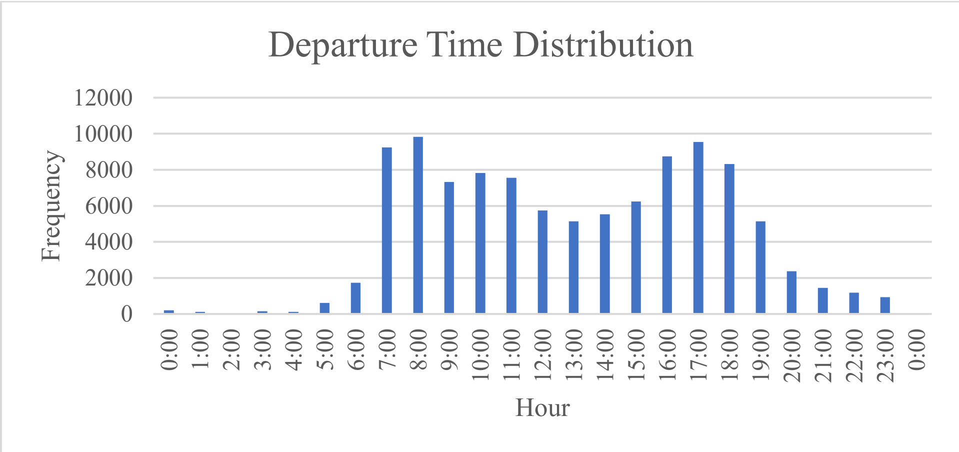
Class	Description	Class	Description	Class	Description
1	By feet	**2**	Motorcycle	**3**	Car as driver
4	Car as a passenger	**5**	Taxi	**6**	Suburban city bus and/or GTT Tram (TO and beltway)
7	GTT suburban bus	**8**	Urban transport (bus, trolleybus, tram, subway) of other municipalities and other cities than Turin	**9**	Extra-urban bus other company
10	Corporate bus	**11**	School bus	**12**	Trenitalia railway
13	GTT Railway (Canavesana, TO - Ceres TO - Chieri)	**15**	Other	**16**	Personal bicycle
20	Bike Sharing system bicycle	**19**	GTT automatic subway	**21**	Car Sharing system vehicle as driver

Class	Description	Class	Description	Class	Description
22	Rail other companies (TRENORD, SSIF, FART, SBB-CFF-FFS, SNCF, BLS)	**23**	Other overland public transportation (funicular, cable car)	**24**	Other public transportation on water (boat, hydrofoil)

DEPARTURE TIME

From the Graph 8, it is apparent that the hour with highest frequency is 8:00 am with nearly 10,000 coincidences which is related to the beginning of daily activities like work and study. Regarding the frequency distribution, it can be stated that the trips start between 7:00 and 10:00 when 35% of the trips occur. Another important peak is found within the range between 16:00 to 18:00 related to the return trips of the people. After 19:00 mobility is continuously reduced, finding the lowest frequencies during night

Graph 8
Departure Time Distribution in the Metropolitan Area of Turin

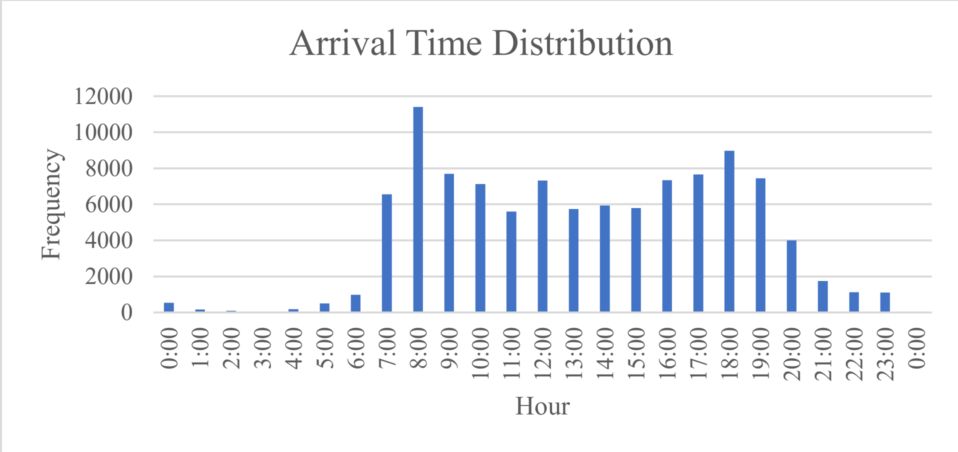


ARRIVAL TIME

The behavior of this variable (Graph 9) is like the departure time, however, the following differences stand out:

- The arrival time of trips peaks around 8:00, accounting for 11% of trips. This suggests that the trip duration is less than 1 hour, considering that most of the trips start at the same time at 8:00.
- Regarding the frequency distribution, it can be confirmed that trips finish at 8:00, where about 20% of the arrival trips have been made. Another significant peak is seen from 6:00 pm to 19:00, which may be related to the end of the daily activity. After 20:00, the mobility drops, showing a reduction in the night-time trips.

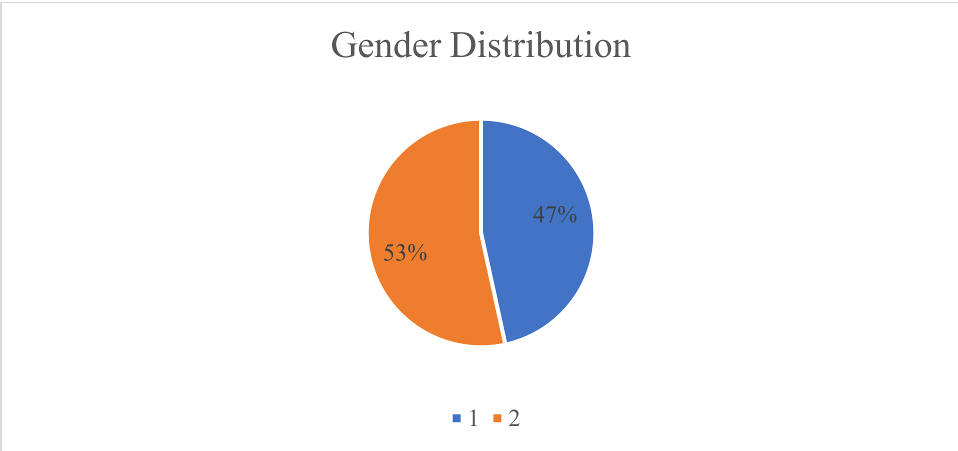
Graph 9
Arrival Time Distribution in the Metropolitan Area of Turin



4.2.2 Metropolitan Area of Valle de Aburrá

GENDER
In the Graph 10 it is observed how the gender is distributed in the metropolitan area. The class with the highest frequency is the number 2 where 53% of the total interviewed people are women. As far as class 1 presents a percentage of 47% that corresponds to man.

Graph 10
Gender Distribution in the Metropolitan Area of Valle de Aburrá

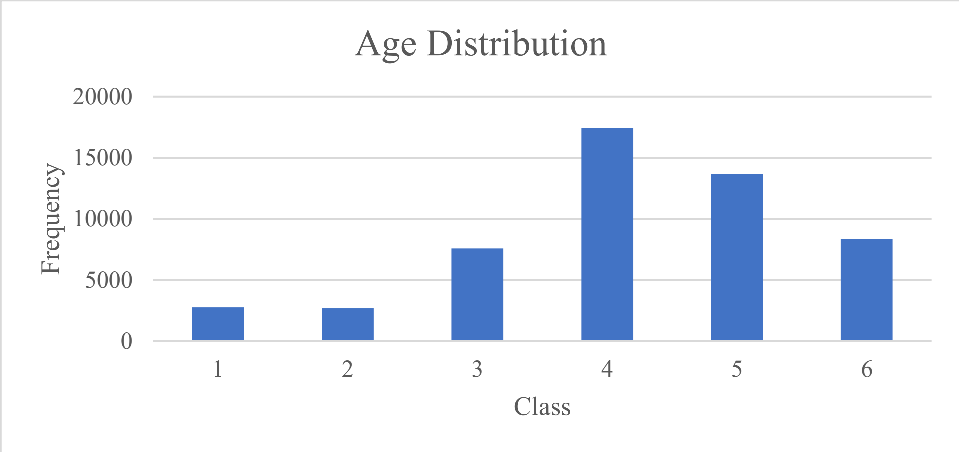


Class	Description	Class	Description
1	Famele	**2**	Male

AGE
Graph 11 provides the result of the age distribution. The average age of the interviewees was approximately 37 years, the median is 35 years, indicating at least 50% of people are 37 years or younger. The most frequent age is 30 years. Based on the presented measures of central tendency, it could be possible to conclude that the population is composed primarily of young adults. This is confirmed by the frequency distribution, which is concentrated between 20 and 60 years, ages considered economically and productive active and from 61 years the frequency declines.

The variance is 445.25, reflecting a considerable separation around the mean, the standard deviation is equal to 21.21 years, indicating that ages are well distributed in a high range equivalent to 107 years (1 to 108 years) and show diversity across different age groups. Additionally, the frequency distribution has a slight positive skewness of 0.29, which suggests a small accumulation towards young ages values. The kurtosis is -0.74 indicates that the distribution has low peaks and uniform dispersion.

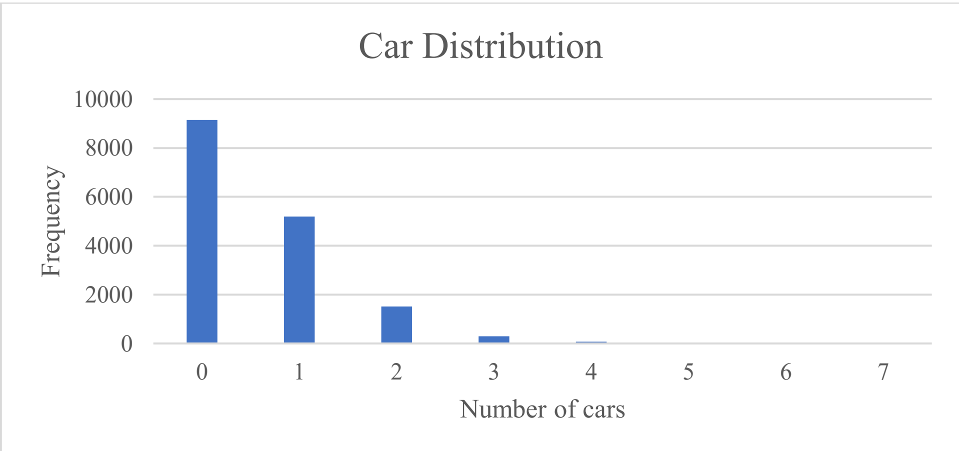
Graph 11
Age Distribution in the Metropolitan Area of Valle de Aburrá



Class	Description	Class	Description	Class	Description
1	Between 0 and 5 years	**2**	Between 6 and 10 years	**3**	Between 11 and 20 years
4	Between 21 and 40 years	**5**	Between 41 and 60 years	**6**	61 and older

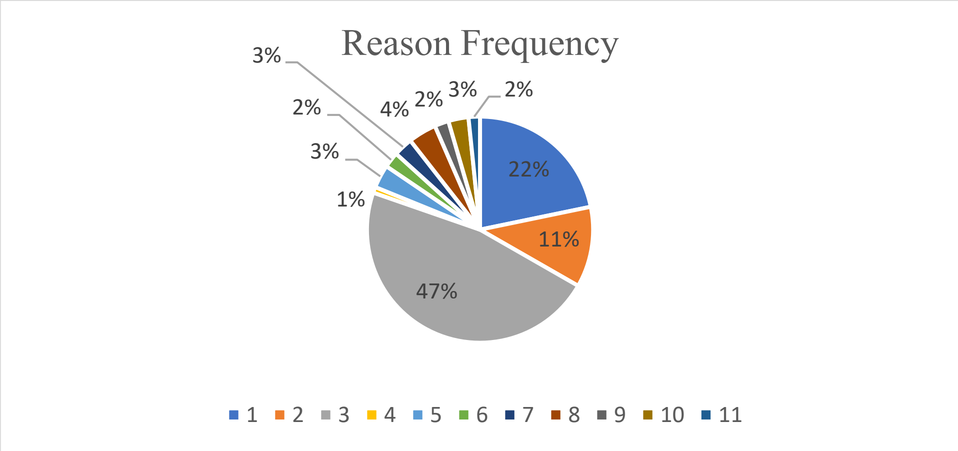
NUMBER OF CARS OWNED
The results obtained of the car distribution is shown in the Graph 12. The means are 0.58 cars, the median and mode is 0, which allow us to infer that at least 50% of the houses in the metropolitan area do not have a car at home. With respect to the standard deviation is 0.69, and the variance is 0.62, which suggests that the data dispersion is low, and these are concentrated from 0 to 1 car per home. Frequency distribution shows a positive skewness (1.52) and kurtosis (3.11), indicating that the data are concentrated to the left of the distribution and starting from 3 cars or more per home is considered an outlier.

Graph 12
Car Distribution in the Metropolitan Area of Valle de Aburrá



REASON FOR THE TRIP
As shown in the Graph 13, the class with the highest frequency corresponds to class 3, with 41,206 trips made to return home, representing 47% of the total. Class 1 is the second most frequent, with 19,061 trips (22%) motivated to work. The third position in the frequency is class 2, with 10,097 trips (12%) for study. Class 8 (personal errands) and class 5 (shopping) have a frequency lower of 5%. The data indicates that most of the population's trips in the area are within productive age.

Graph 13
Frequency of Reason for Trip in the Metropolitan Area of Valle de Aburrá



Class	Description	Class	Description	Class	Description
1	Work	**2**	Study	**3**	Return home
4	Lunch time	**5**	Shopping	**6**	Health
7	Recreation	**8**	Personal errands	**9**	Accompany someone
10	Pick up/drop off someone	**11**	Other		

TRANSPORT MODE

The survey is subdivided into 7 transport modes that were used by residents in the metropolitan area in order to complete their journeys.

Transport Mode 1: The class with the highest frequency is class 21 with 11,964 walking trips for 1 block representing 14% of the total, class 22 (walking for 2 blocks) is the second most frequent with 8,414 trips (10%). Class 10 (motorcycle as driver) has the third highest frequency with 7,939 trips (9%), followed by class 8 (car as driver) with 7,187 trips (8%). These results reflect the residents primarily starting their trips on foot possibly to access the next mode of transport, as also the motorized means have an important portion in the mobility of the metropolitan area.

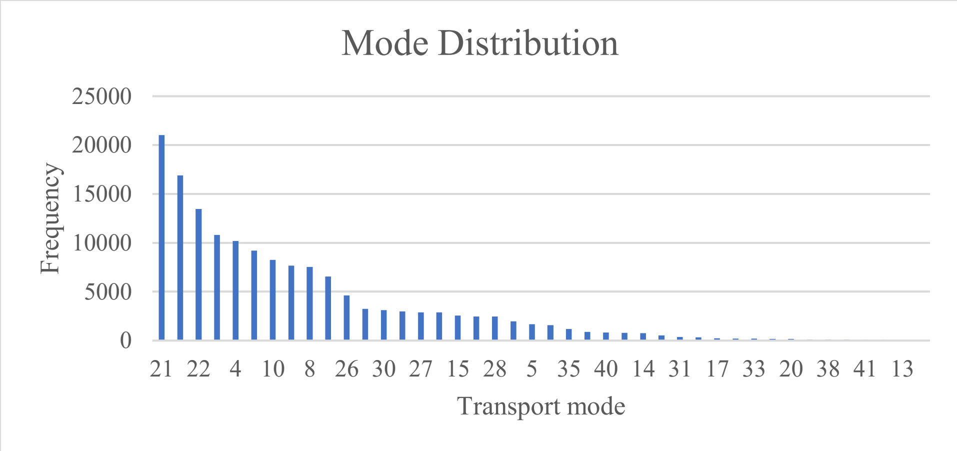
Transport Mode 2: Class 1 (Urban bus trips) is the most frequent with 10,728 trips (36%), the second most frequently is class 4 (Metro) with 6,354 trips (21%) and class 3 (Feeder Bus) with 4,189 trips (14%). This data suggests that some residents that started their trips on foot continued their trips using the available urban transportation system.

Transport Mode 3: The most frequent class is class 21 with 4,968 walking trips for 1 block (22%), followed by class 4 (metro) with 3,434 trips (15%) and the third place is class 3 (feeder bus) registered 2,599 trips (12%). This indicates that the public transport system continues to play a significant role in this mode.

Other modes: The predominant mode in these modes was walking trips for 1 to 3 blocks corresponding to classes 21 to 23, respectively, followed by class 4 (metro) with 8,348 trips and class 5 (metroplus) with 2,257 trips.

The Graph 14 presents the sum of the observed frequencies across the seven modes. In conclusion, the most significant modes of transportation within the metropolitan area are walking trips (especially for distances of 1 to 6 blocks), and public transportation. These play an important role in the way people make their trips.

Graph 14
Mode of Transportation Distribution in the Metropolitan Area of Valle de Aburrá



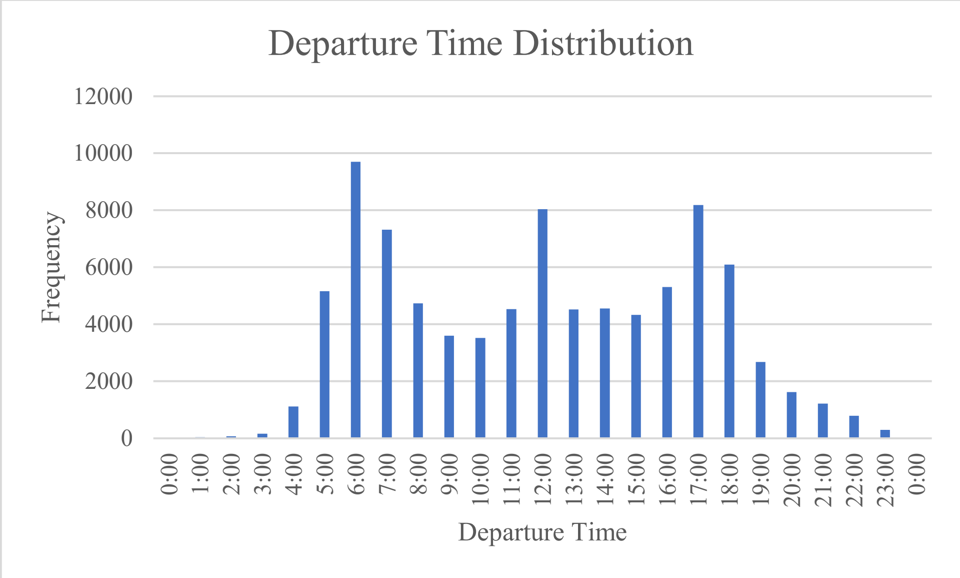
Class	Description	Class	Description	Class	Description
1	Urban Bus	**2**	Suburban Bus	**3**	Feeder Buses
4	Metro	**5**	Metroplus	**6**	Gondola Lift
7	Tram	**8**	Private Car/driver	**9**	Private Car/Passenger
10	Motorcycle/driver	**11**	Motorcycle/Passenger	**12**	Motorcycle Taxi
13	Motor Tricycle	**14**	Special Transportation Company	**15**	School bus
16	Taxi	**17**	Collective Taxi	**18**	Suburban Taxi
19	Private vehicles with payment (On street-without platform)	**20**	Private vehicles with payment (Platform)	**21-39**	On foot 1 block to 19 blocks or more
40	Own bicycle	**41**	Public bicycle	**42**	Flight

DEPARTURE TIME
From the Graph 15, it is apparent that, the most frequent departure time is 6:00, with about 9,700 trips (11%). Regarding the frequency distribution throughout the day, it can be observed 31% of the total of the trips take place between 5:00 to 8:00 representing the first peak hour of the day. Around noon 8,044 trips were registered (8%) associated with lunch time. Finally, the last peak hour falls from 17:00 to 18:00, concentrating on about 8% of daily trips.

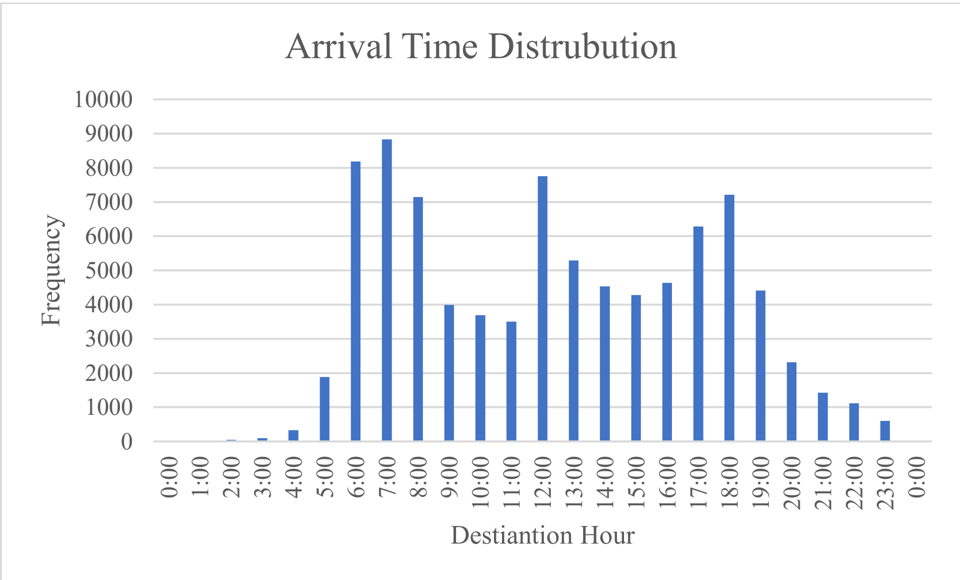
ARRIVAL TIME
The behavior of this variable (Graph 16) is like the departure time; however, the following differences stand out:

- The arrival time of trips peaks around 7:00, accounting for 11% of trips. This suggests that the trip duration is about 1 hour, considering that most of the trips start at 6:00.
- Regarding the frequency distribution, it can be confirmed that trips finish at 8:00 am, where about 30% of the arrival trips have been made. Another significant peak is seen from 6:00 pm to 7:00 pm, which may be related to the end of the daily activity. After 9:00 pm, the mobility drops, indicating a reduction in the night-time trips.

Graph 15
Departure Time Distribution in the Metropolitan Area of Valle de Aburrá



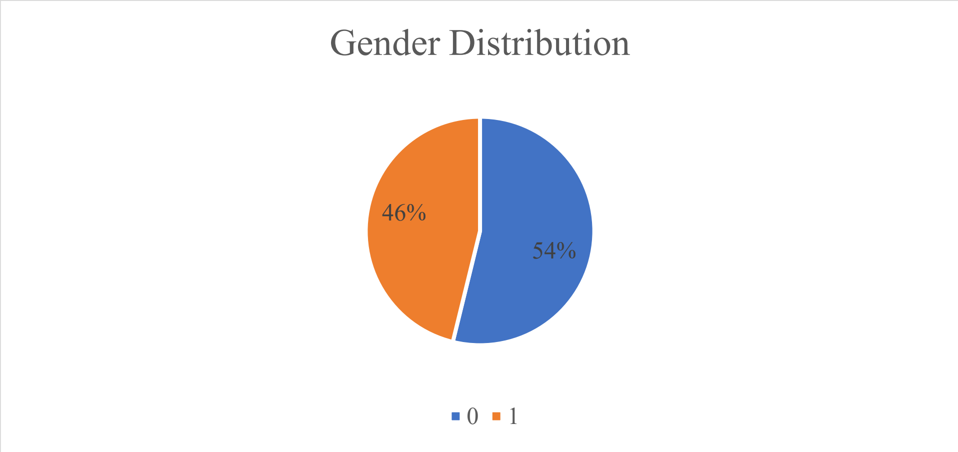
Graph 16
Arrival Time Distribution in the Metropolitan Area of Valle de Aburrá



4.2.3 Metropolitan Area of Cúcuta

GENDER
In the Graph 17 shows the gender distribution in the study area. The class with highest frequency is the class 0 (women) representing 54% of the total of the observations, while class 1 (man) have 46%.

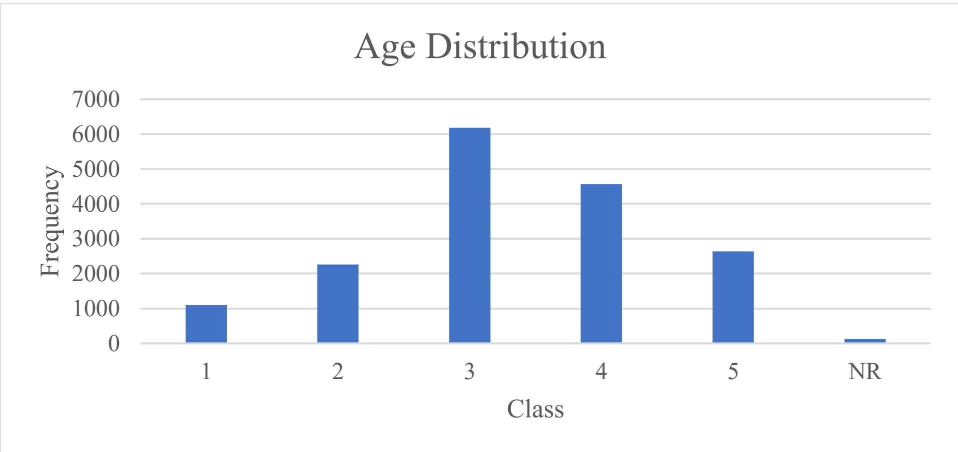
Graph 17
Gender Distribution of Metropolitan Area of Cúcuta



Class	Description	Class	Description
0	Famele	**1**	Male

AGE
Graph 18 provides the result of the age distribution. The most frequent class corresponds to people aged 20 to 40 years with 6,185 observations (37%), the second most frequent class includes people aged 40 to 60 years with 4,572 observations (27%), and the class that representing people aged over 60 years is the third in terms of frequency with (16%). It can be concluded that most of the population falls within the economically active ages and possibly they are the same that make more trips, primarily for work purposes.

Graph 18
Age Distribution of Metropolitan Area of Cúcuta



Class	Description	Class	Description	Class	Description
1	Between 5 and 10 years	**2**	Between 11 and 20 years	**3**	Between 21 and 40 years
4	Between 41 and 60 years	**5**	Between 61 and older	**6**	No response

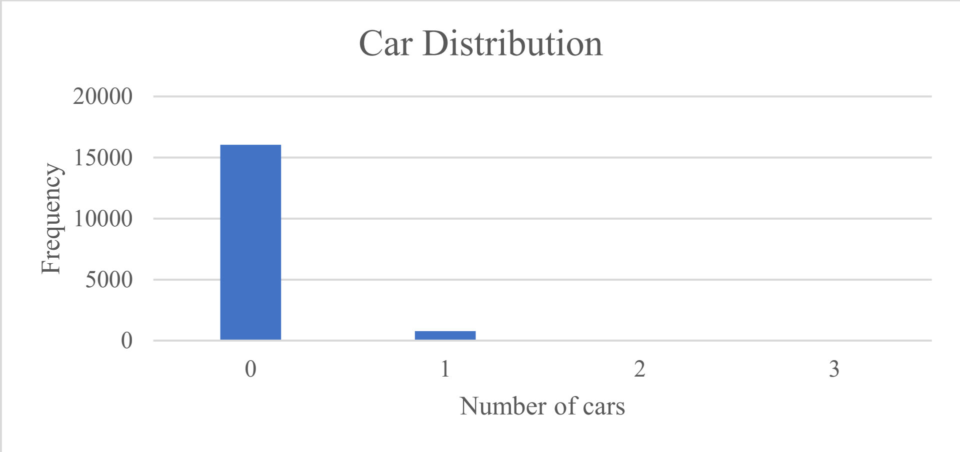
NUMBER OF OWNED VEHICLES
The survey distinguishes the kinds of vehicles owned by the households, in these sections evaluates the owned cars and motorbikes variables, which are the most common vehicles in the metropolitan area

PRIVATELY OWNED CARS OR PICKUP TRUCKS
The results obtained of the private owned car is shown in the Graph 19. The mean is 0.05, the median and mode is 0 car, showing that at least 50% of the households do not have cars. Regarding the standard deviation is 0.23 and variance is 0.053, suggesting a low dispersion of the data, and these are concentrated in 0 cars. The distribution of the frequency shows a skewness of 4.74 and kurtosis of 24.06,

confirmed that the data are concentrated to the left of the distribution, meaning that owing to 1 or more cars is considered outlier.

Considering that 16,879 people in the households were surveyed, the total number of observations in this variable is relatively low, suggesting that car ownership is limited in the metropolitan area.

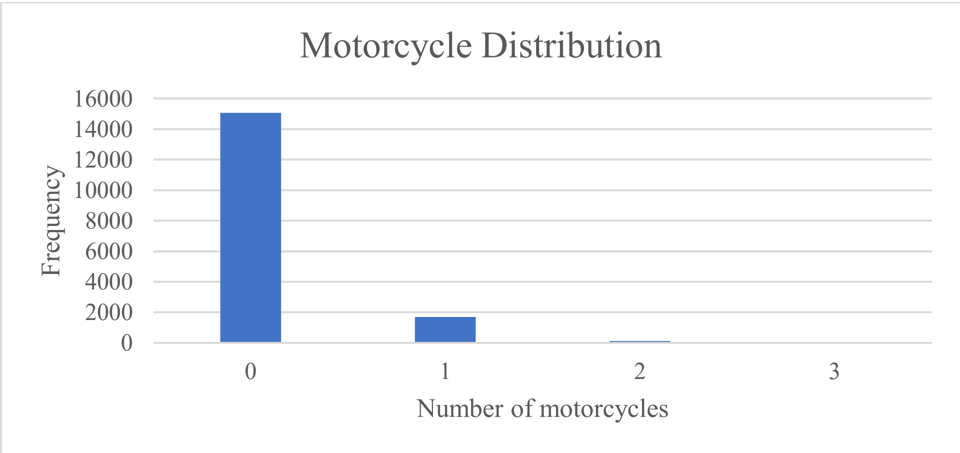
Graph 19
Car Distribution in the Metropolitan Area of Cúcuta



PRIVATELY OWNED MOTORCYCLE
The private owned motorcycle distribution is illustrated in the Graph 20. The mean is 0.12, the median and mode is 0 motorcycle, indicating that at least 50% of the household do not have a motorcycle. The standard deviation is 0.342 and variance is 0.117, suggesting a low dispersion of the data, and these are concentrated in 0 motorcycles.

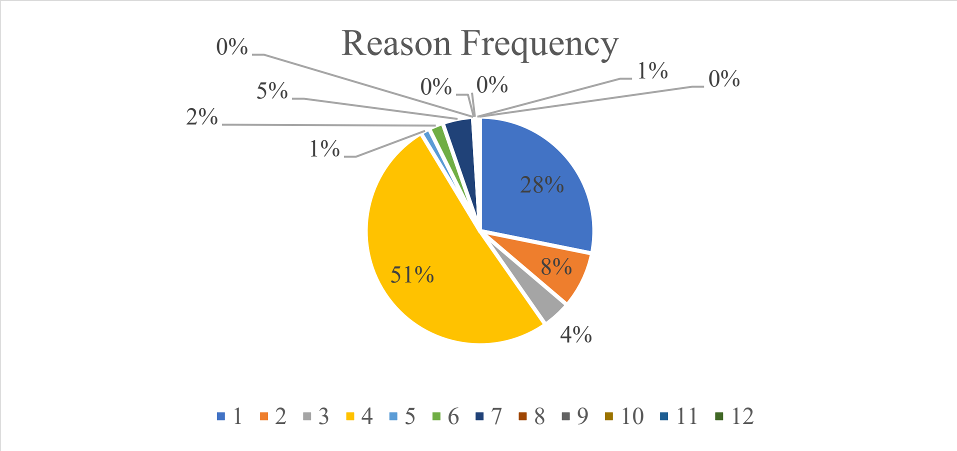
The distribution of the frequency shows a skewness of 3.02 and kurtosis of 9.25, confirmed that the data are concentrated to the left of the distribution, meaning that owing to 1 or more motorcycles are considered outlier.

Graph 20
Motorcycle Distribution in the Metropolitan Area of Cúcuta



REASON FOR THE TRIP
As shown in Graph 21. The class with the highest frequency corresponds to class 4, with 10,623 trips made to return home, representing 51% of the total. Class 1 is the second most frequent, with 5,859 trips (28%) motivated to work. The third position in the frequency is class 2, with 1,677 trips (8%) for study. Class 7 (health) and class 3 (shopping) have a frequency equal of 4%.

Graph 21
Frequency of Reason of Trip in the Metropolitan Area of Cúcuta

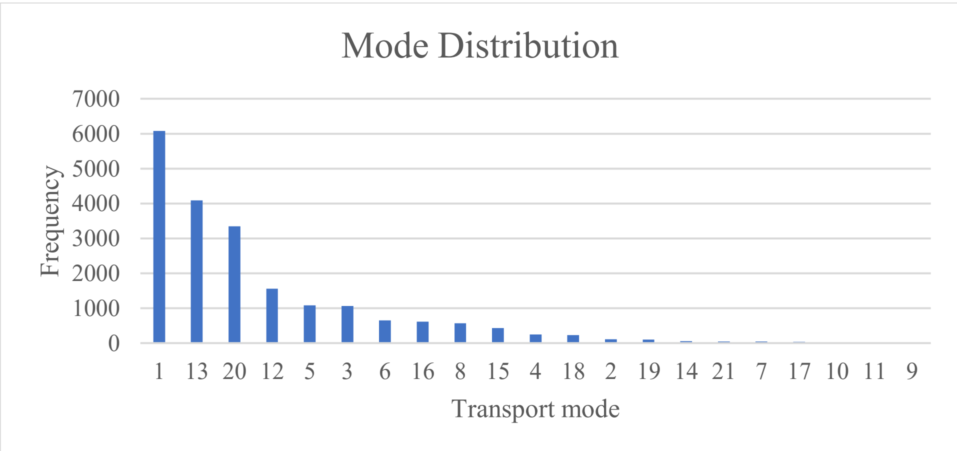


Class	Description	Class	Description	Class	Description
1	Work	2	Study	3	Shopping
4	Return home	5	Personal errands	6	Pick up/drop off someone
7	Health	8	Recreation	9	Sports
10	Religious Activity	11	Visit friends or relatives	12	Other

TRANSPORT MODE

The Graph 22 below illustrates that the class with the highest frequency is class 1 with 6,078 public transport trips representing 30% of the total, class 13 (motorcycle as driver) is the second most frequent with 4,085 trips (20%). Other classes with lower frequency are class 20 (walking trip) which registered 3,347 trips (16%) and class 12 (car as driver) had 1,559 trips (8%). The obtained results show that the public transportation system plays a fundamental role in mobility in the metropolitan area, followed by motorized modes, especially motorcycle trips and the walking trips also have an important leading role although their frequency was lower.

Graph 22
Transport Mode Distribution in the Metropolitan Area of Cúcuta



Class	Description	Class	Description	Class	Description
1	Public transport bus	2	Transport from outside the metropolitan area	3	Taxi
4	Private car (paid service)	5	Shared Taxi	6	Motorcycle Taxi
7	Uber, Indriver, etc	8	Bicycle	9	Motorzed bicycle
10	Electric bicycle	11	Scooter	12	Private Car/driver
13	Motorcycle/driver	14	Truck/driver	15	Private car/passenger
16	Motorcycle/passenger	17	Truck/passenger	18	Work-provide transport
19	School bus	20	Walkin (on foot)	21	Other

DEPARTURE TIME

From the Graph 23, it is apparent that the most frequent departure time is 7:00, with about 2,615 observed trips (11%). Regarding the frequency distribution, it can be observed that:

- 35% of the trips begin before 7:00.
- Approximately half of the trips start before 11:00.
- 75% of the trips begin before 16:00, indicating that most of the journeys occur before the late afternoon.
- After 20:00 the mobility decreases significantly.

ARRIVAL TIME

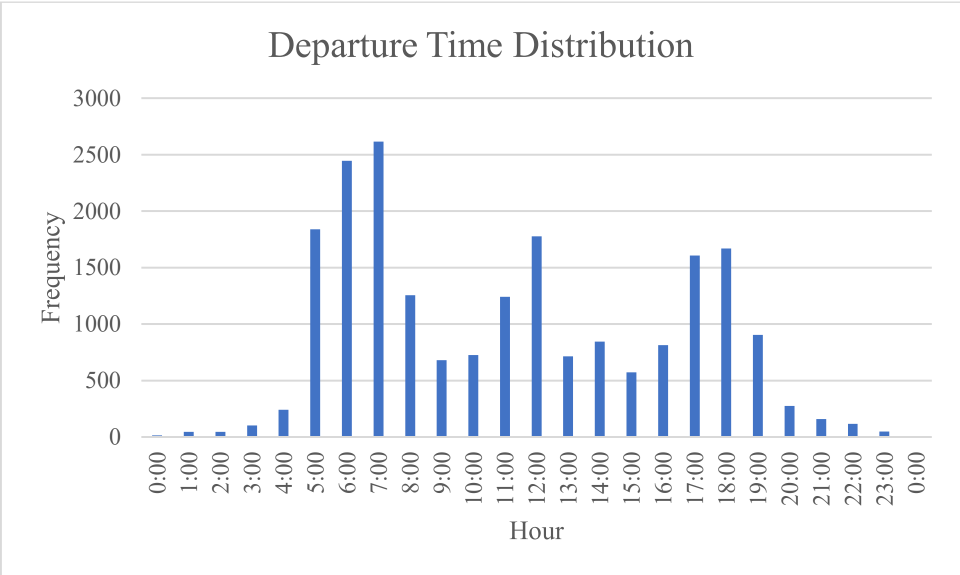
The most frequent arrival time is 7:00, with about 2,853 observed, this suggests that the trip duration is less than 1 hour, considering that most of the trips start at 7:00.

. Regarding the frequency distribution (Graph 24), it can be observed that:

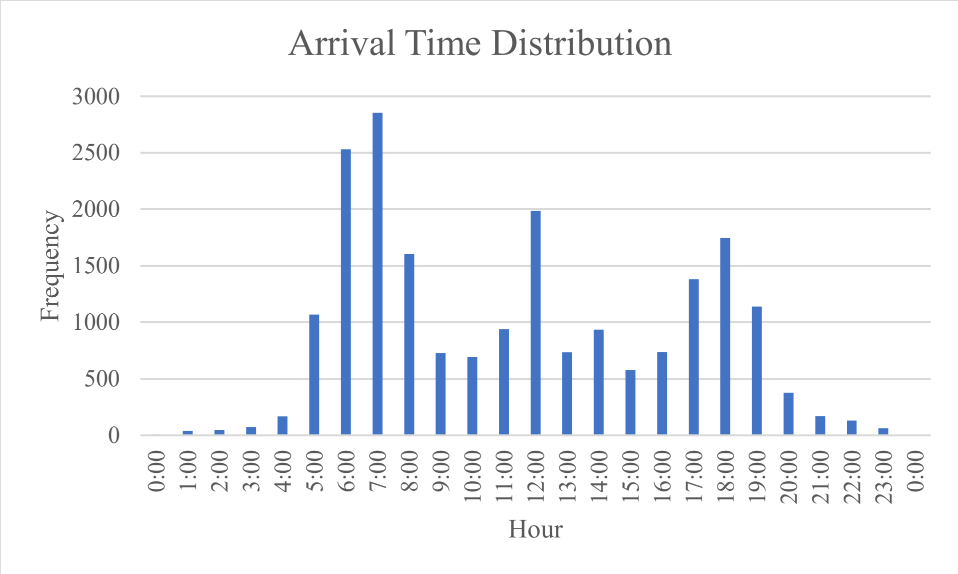
- 40% of the trips begin before 8:00.
- Approximately half of the trips start before 11:00.
- 75% of the trips begin before 16:00, indicating that most of the journeys occur before the late afternoon.
- After 21:00 the mobility decreases significantly.

Graph 23

Departure Time Distribution in the Metropolitan Area of Cúcuta



Graph 24
Arrival Time Distribution in the Metropolitan Area of Cúcuta



4.2.4 Comparison of the three Metropolitan Areas

A comparative summary of the univariate descriptive analysis of the three datasets of the metropolitan areas is provided below:

1. **Demographics (Gender and Age):**
   a. All metropolitan areas present higher percentage of women.
   b. The largest active travel population are in the 20-49 years old (Turin – Italy) and 20-60 years old (Valle de Aburrá and Cúcuta – Colombia), where the working age population dominates, indicating mobility patterns possible could be influenced by economic activity.
   c. The population of Valle de Aburrá is significantly younger, while Turin has an elderly population is significantly more active in the mobility with 25% over 65 years.

2. **Vehicle Ownership:**
   a. Turin has the highest car ownership (with an average of 1.44 cars per household), indicating a greater car dependency.
   b. Colombian metropolitan areas demonstrate low car dependency but high motorcycle ownership especially in Cúcuta, reflecting socioeconomic characteristics.
   c. Non-motorized and public transport alternatives are important in the Colombian metropolitan areas due to the lower private vehicle access.

3. **Purpose of Trips:**
   a. Across all metropolitan areas, "Returning Home" is the dominant trip purpose around 48% to 51%.
   b. Work related trips are more frequent in Valle de Aburrá and Cúcuta metropolitan areas than in Turin, likely influenced by trends like work from home.

4. **Transport Mode:**
   a. In Turin a strong preference for private car use is evident, but walking still accounts for approximately a quarter of the total trips.
   b. Valle de Aburrá shows a multimodal mobility being walking and public transport trips dominant.
   c. In Cúcuta there is high reliance on motorbikes and public transport, with walking trips also important but less prevalent.

d. The dependency on public transport is strong in the Colombian metropolitan areas, while in Turin, private car usage is dominant, reflecting differences needs in urban transport planning.

5. **Departure and Arrival times:**

a. All metropolitan areas exhibit bimodal travel peaks: early morning and late afternoon. Peaks align with work trips, emphasizing the importance of finding transport solutions in urban planning.

b. Colombian metropolitan areas have earlier start times approximately at 6 to 7 AM, due to work culture and limitation infrastructure.

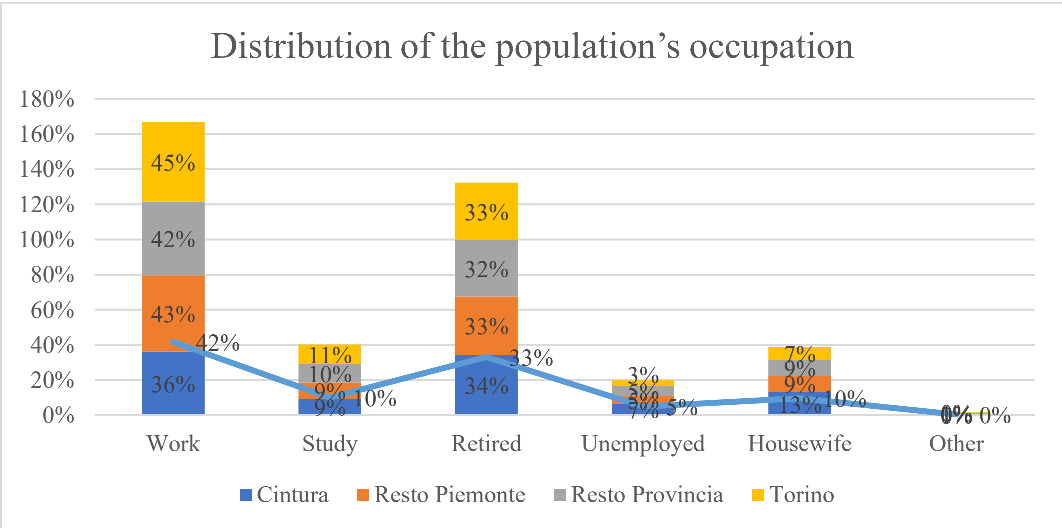
In conclusion, the univariate analyses provide a baseline for the planning solutions in terms of mobility, the results reveal that the metropolitan area of Turin requires targeted strategies to promote modal shift away from private car use toward sustainable options. In the case of the metropolitan area of Valle de Aburrá is necessary to enhance the integration and quality of all transport modes in order to support the existing multimodal system. Meanwhile, in the metropolitan area of Cúcuta high motorcycle use indicates a need to improve infrastructure that facilitates non-motorized and formal collective transport travel.

4.3 Key Bivariate Statistics

4.3.1 Metropolitan Area of Turin

One of the most influential factors in the mobility pattern is the occupation type. Generally, individuals who work or study tend to travel with a high frequency to carry out their activities. In the Graph 25 is described the distribution of population occupation in the study area: 42% of the people work, 33% were retired and 10% were students. In Turin City and the rest of the Piedmont Region the highest proportion of workers were concentrated, whereas in Turin Belt shows a lower proportion of workers and students. However, the Torino Belt has a higher proportion of retired individuals, unemployed and housewife, which may indicate a tendency thought population redistribution outside of the Turin City, but with the principal economical activities concentrated in the city.

Graph 25
Distribution of the population's occupation in the Metropolitan Area of Turin



A total of 105,098 trips on a typical workday were registered in the survey. Approximately 62% of these trips originated in the Province of Turin, distributed as: 28% in the Turin Belt, 22% in the Turin City and 13% in the rest of the province. Meanwhile, 37% of trips originated in the rest of the Piedmont Region. In the Table 33 provides details of the number of trips by each area:

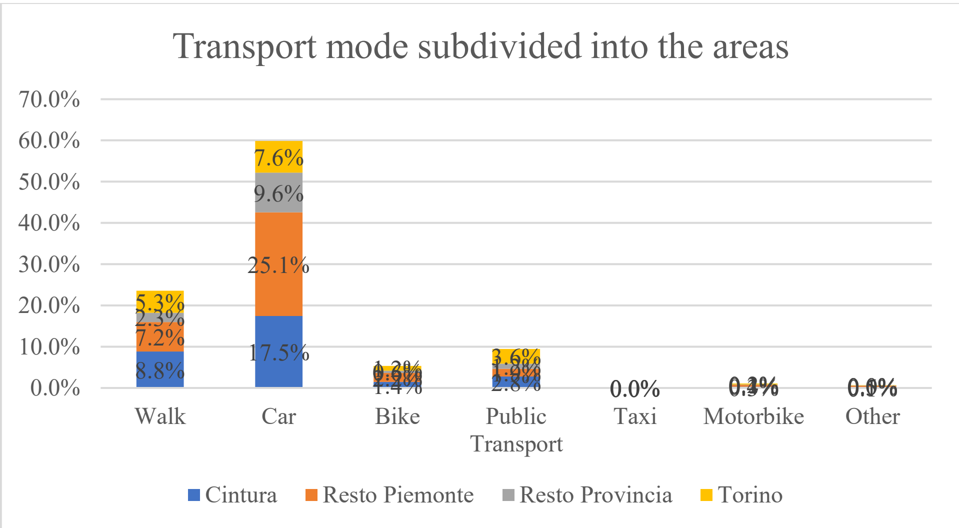
Table 33
Number of Trips reported in the Interview in the Metropolitan Area of Turin

AREA	PROVINCE	# TRIPS REPORTED IN THE INTERVIEW	%
Belt	Torino	29,072	28%
Rest of Piedmont Region	Torino	38,675	37%
Rest of Province of Turin	(Vercelli, Novara, Cuneo, Asti, Alessandria, Biella y Verbano-Cusio-Ossola)	13,628	13%
Turin City	Torino	22,919	22%
Out of Region		804	1%

In the Graph 26 it is possible to evaluate the percentage of each transport mode subdivided into the areas where it is possible to identify:

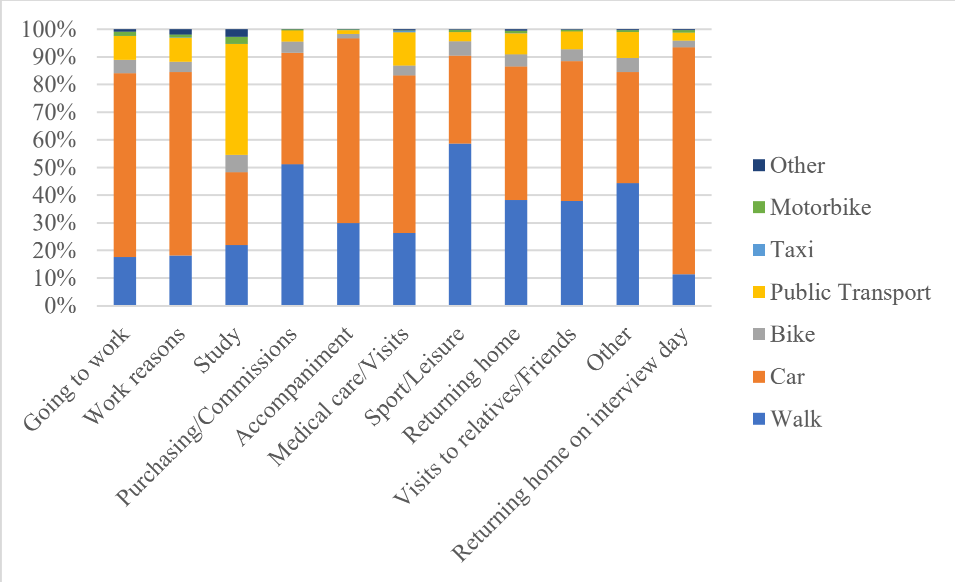
- The use of the car is highest in the Rest of Piedmont with 25% of the trips, and lower in Turin City with 8% of trips, indicating more dependency on cars in rural areas.
- Walking trips are the most common in the Belt with 9% of the trips, and less common in the Rest of Province (2%), possibly in the Belt some destinations are easily accessible walking.
- Public transport use is relatively low in the four areas; however, Turin City presents the highest percentage of trips with 4%, showing that in the urban areas it is more relevant.
- Bike trips remain constant with 1 to 2% in all zones.
- The use of Taxi, Motorbike and Other mode shows a lower percentage of 0.5% in the whole area.

Graph 26
Percentage of Transport mode subdivided into the Metropolitan Area of Turin



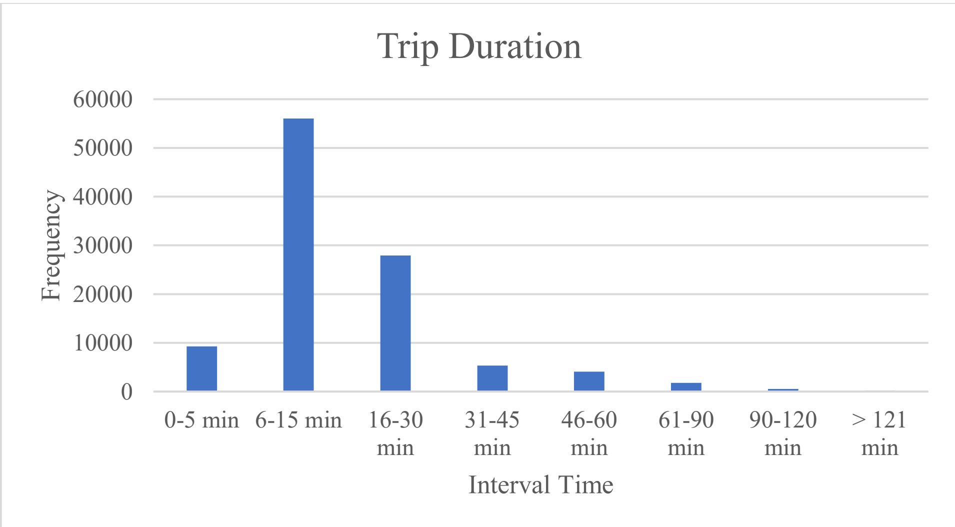
Analyzing the modal split and trip purpose represented in the Graph 27, it is evident that cars are the most used transport mode for different purposes in the study area. Regarding public transport, a significant portion of the residents choose it to travel to their place of study. On the other hand, in active mobility, the walking trips are mostly made for the purpose of shopping or sport/leisure activities, and bicycles have a small percentage of trips in the study area.

Graph 27
Transport Mode vs. Trip Purpose in the Metropolitan Area of Turin



The average travel time was calculated as the difference between the arrival and departure time in each trip reported in the survey. The average trip duration is 20 minutes, the standard deviation is 18 minutes, indicating that most trips fall in a range of 2 to 39 minutes. The Graph 28 shows that the interval of 6 to 15 minutes accounts for many trips, suggesting that short distance travel, possibly of good accessibility to destination like workplaces, schools, universities or shopping centers. In the 16 to 30 minutes intervals also have a significative trip duration, while trips exceeding 31 minutes are less frequent, indicating that these are exceptional travel cases.

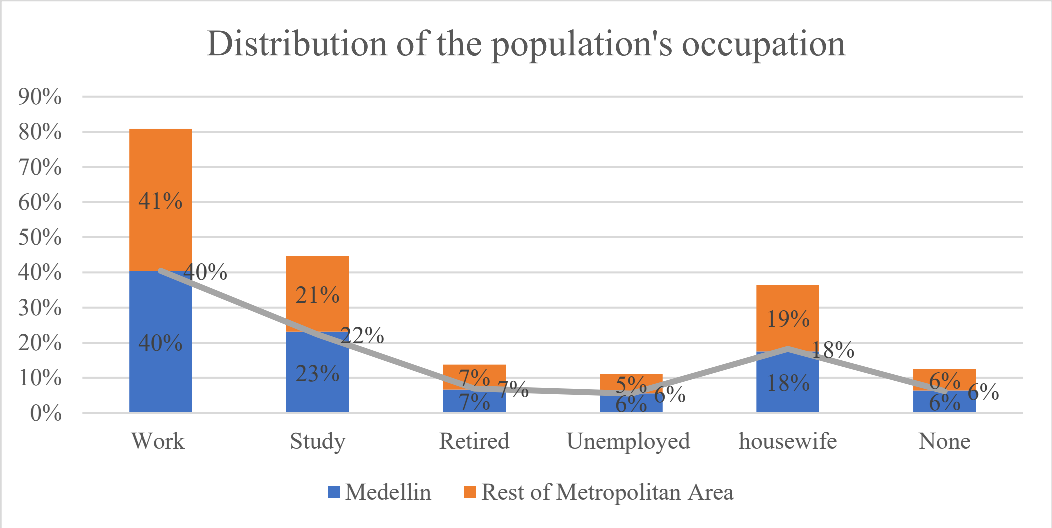
Graph 28
Trip Duration in the Metropolitan Area of Turin



4.3.2 ***Metropolitan Area of Valle de Aburrá***

Graph 29 presents the distribution of population occupation in the study area, on average, 40% of people work, 22% were students, 18% were housewife and 7% were retired, regarding the distribution of the occupation in Medellín and the other municipalities within the metropolitan area remain constant in each occupation, indicating a uniform distribution across the metropolitan area.

Graph 29
Distribution of the population's occupation in the Metropolitan Area of Valle de Aburrá



A total of 87,613 trips on a typical workday were registered in the survey. Approximately 57% of these trips originated in Medellín City, followed by 42% from the rest of municipalities of the Metropolitan Area and 1% have their origin outside the area. The number of trips broken down by the metropolitan area is detailed in the Table 34:

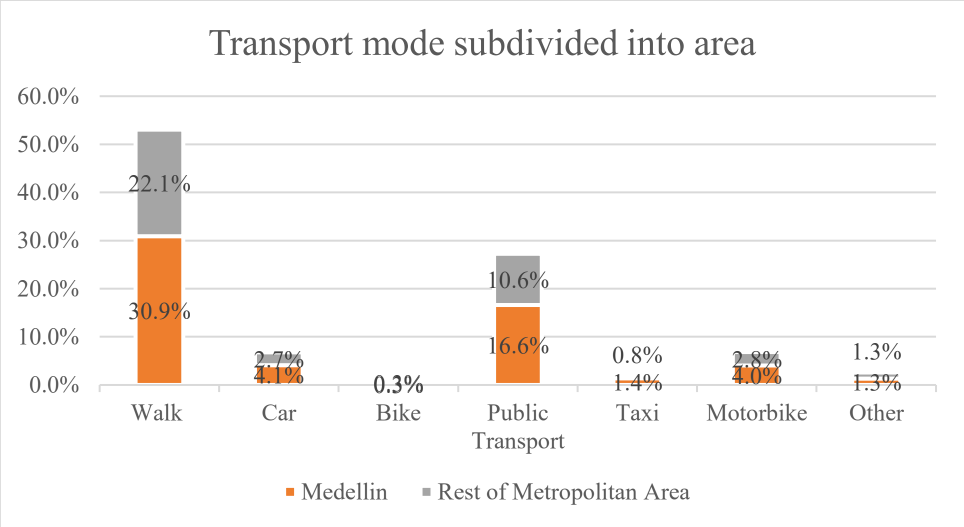
Table 34
Number of Trips reported in the Interview in the Metropolitan Area of Valle de Aburrá

Area	Municipalities	No. of trips observed in the interview	%
Medellín		50,136	57%
Rest of the Metropolitan Area	Barbosa, Bello, Caldas, Copacabana, Envigado, Girardota, Itagüí, La Estrella, Sabaneta	36,935	42%
Out of the metropolitan area		542	1%

In the Graph 30 it is possible to evaluate the percentage share of each transport mode subdivided into the areas. It could be noticed that:

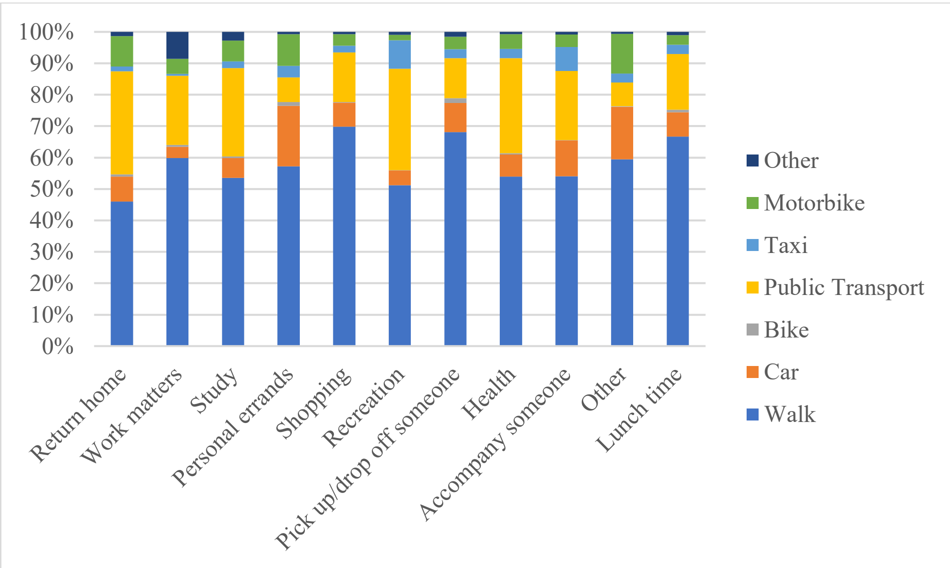
- Car usage represents a small portion of the total trips. In Medellín 4.1% of the trips are made by car, while in the rest of the metropolitan area, the share drops to 2.7%.
- Walking trips include all trips from 1 to 19 blocks. In Medellín 30.9% of the trips are made on foot, whereas in the rest of the metropolitan area it declines to 22.1%.
- The public transport system is more commonly used in Medellín, where it accounts for nearly 17% of the trips, its usage is lower in the rest of the metropolitan area, possibly due to the concentration of the services within the city.
- Bikes' usage remains constantly low in the whole metropolitan area with a marginal percentage of trips.
- The motorbike use follows a pattern similar to the use of Cars.

Graph 30
Percentage of Transport mode subdivided into the Metropolitan Area of Valle de Aburrá



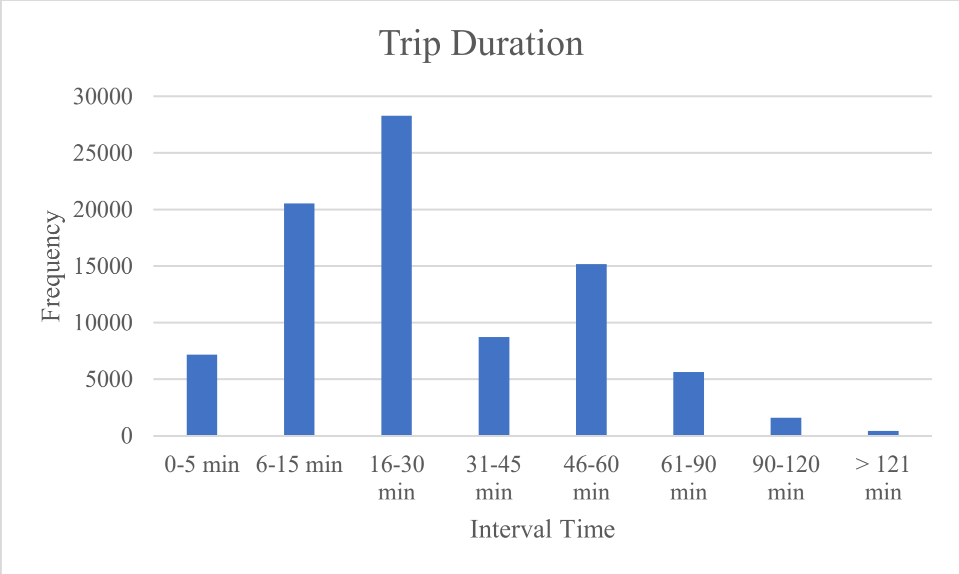
When analyzing the modal split according to the purpose of the trips detailed in Graph 31, as can be seen that the walking trips are the most important mode in order to start and finish the majority of the trips in the metropolitan area, followed by the public transport system that has a greater share of the return home, study, recreation and health trips, as for the private mobility (cars and motorcycle) has more participation in the personal errands and accompany someone.

Graph 31
Transport Mode vs. Trip Purpose in the Metropolitan Area of Valle de Aburrá



The average trip duration is 34 minutes, and the standard deviation is 27 minutes, indicating that most trips fall in a range of 8 to 61 minutes. The Graph 32 shows that the interval of 16 to 30 minutes accounts for many trips, followed by the 6 to 15 minutes intervals, suggesting that workplaces and schools or universities are located not so far from the origin of the trips that are generally the households. Another interval with a considerable number of trips is from 46 to 60 minutes, indicating that people who fall in this interval should travel a greater distance to access their destinations, like possible home locations in the peripheries.

Graph 32
Trip Duration in the Metropolitan Area of Valle de Aburrá



4.3.3 Metropolitan Area of Cúcuta

Compared to the surveys of the Metropolitan Are of Turin and Valle de Aburrá, the description of the occupation of the residents was not taken into account in the survey of the Metropolitan Area of Cúcuta, so it the analysis of this variable is not presented.

A total of 20,808 trips on a typical workday were registered in the survey. Approximately 81% of these trips originated in San José de Cúcuta City, followed by 19% from the rest of municipalities of the Metropolitan Area and 1% have their origin outside the area. The number of trips broken down by the metropolitan area is detailed in the Table 35:

Table 35
Number of Trips reported in the Interview in the Metropolitan Area of Cúcuta

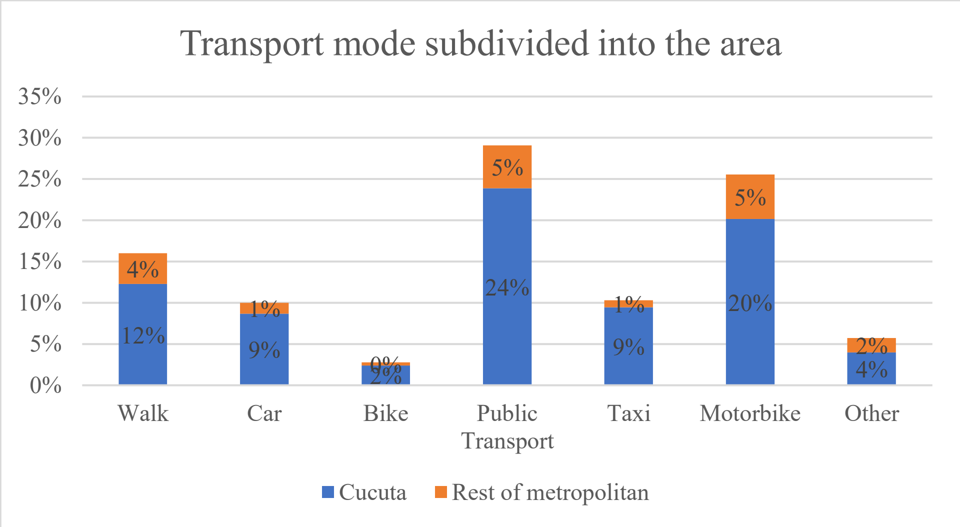
Area	Municipalities	No. of trips observed in the interview	%
Cúcuta		16,805	81%
Rest of metropolitan area	La Zulia, Los Patios, Puerto Santander, San Cayetano and Villas del Rosario	3,873	19%
Out of the metropolitan area		129	1%

In the Graph 33 it is possible to evaluate the percentage share of each transport mode subdivided into the areas. It could be noticed that:

- The public transport system is the most used mode throughout the study area. In Cúcuta it represents 24% of the trips, compared with the rest of the metropolitan area that reported only 5%.
- Motorbike use is highest in the San Jose de Cúcuta with 20% of the trips, and lowest in the rest of the metropolitan area with 5% of trips, indicating more dependency on this mode in urban areas.
- Walking trips are the most common in San Jose de Cúcuta with 12% of the trips, and less common in the rest of the metropolitan area (4%).

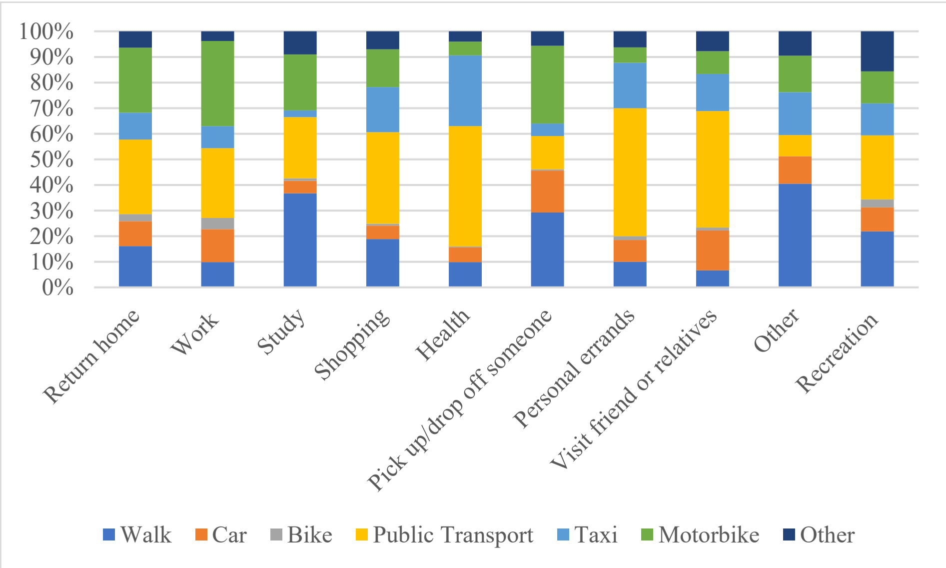
- In conclusion, trips have a general tendency to be concentrated mostly in San Jose de Cúcuta City where the greatest number of trip attractors are located, such as work, and study places.

Graph 33
Percentage of Transport mode subdivided into the Metropolitan Area of Cúcuta



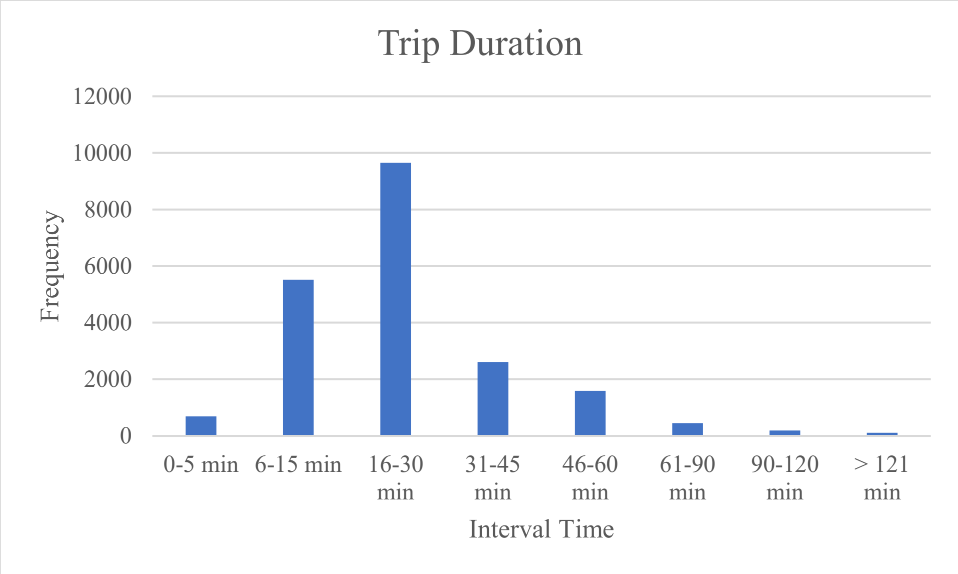
When analyzing the modal split according to the purpose of the trip detailed in Graph 34, as can be seen that walking trips are relevant related to educational and other daily activities, public transport has a higher share in returning home, shopping, healthcare, personal errands and visiting friends and family trips. Car and motorcycle usages are predominantly used for work, visiting friends or relative trips. Other transport modes, such as school buses and ride-hailing services, show significant participation in trips for study, recreation and other purposes.

Graph 34
Transportation Mode vs. Purpose in the Metropolitan Area of Cúcuta



The average trip duration is 29 minutes, and the standard deviation is 28 minutes, indicating that most trips fall in a range of 1 to 57 minutes. The Graph 35 shows that the interval of 16 to 30 minutes accounts for many trips, followed by the 6 to 15 minutes intervals, indicating that a significant portion of trips cover short distances.

Graph 35
Trip Duration in the Metropolitan Area of Cúcuta



4.3.4 Comparison of the three Metropolitan Areas

The results of the Key Bivariate Statistics across the three metropolitan areas (Turin, Valle de Aburrá and Cúcuta) are summarized in Table 36 and these complements the Univariate analysis:

Table 36
Comparison of Key Bivariate Statistics across the three metropolitan areas

1. POPULATION OCCUPATION AND MOBILITY PATTERNS	
Metropolitan Area of Turin	• Workers (42%) and students (10%) have higher trip frequencies, especially concentrated in Turin city. • Retired people (33%) show more localized trips, especially in the Turin Belt, where their proportion is higher.
Metropolitan Area of Valle de Aburrá	• Workers (40%) and students (22%) dominate mobility. • Housewives (18%) have a significant participation in the travel patterns, possibly in midday travel peaks. • Retired people (7%) have a lower mobility rate compared to Turin.
Metropolitan Area of Cúcuta	• Occupational statistics were not recorded. However, mobility patterns suggest that most trips are made by workers.
2. ORIGIN OF TRIPS IN METROPOLITAN AREAS	
Metropolitan Area of Turin	• The majority trips originate in Turin Province (62%), with the rest from Piedmont Region.
Metropolitan Area of Valle de Aburrá	• The majority trips start in Medellín (57%), reinforcing that this city has transport dominance in the metropolitan area, however an exists a regional integration.
Metropolitan Area of Cúcuta	• 81% of trips originate in San Jose de Cúcuta, demonstrating the mobility is concentrated in the urban zone of the metropolitan area.
3. TRANSPORT MODE AND TRIP PURPOSE	
Metropolitan Area of Turin	• Private car dominance is highest in the rural areas with 25% and used across all purposes, the walking trips are highest in the Turin Belt with 9% and the public transport has a peak in Turin city with 4%. • Car dependency is notably higher, especially for work trips and personal errands, whereas travel by public transport is more used in the study trips.

Metropolitan Area of Valle de Aburrá	• Public and active transport are the most significant, because for work related trips public transport leads with 22%, and walking trips are preferred for study purpose and personal errands, this reinforcing the role of pedestrian infrastructure.
Metropolitan Area of Cúcuta	• Public transport dominant in San José de Cúcuta with 24% additional is relevant for study purpose and personal errands. In terms of private motorized mobility, motorbike trips are common in the metropolitan area, special in work-related trips.
4. TRIP DURATION	
Metropolitan Area of Turin	• Short average travel time (20 minutes) suggests good access to destinations. • Long trips are rare.
Metropolitan Area of Valle de Aburrá	• Longer average travel time (34 minutes) suggests greater urban expansion.
Metropolitan Area of Cúcuta	• Moderate average travel time (29 minutes) indicates that in San Jose de Cúcuta are concentrated the trips attractors.

The comparative analysis of the three metropolitan areas highlights how demographic organization; mobility behavior and transport infrastructure can influence the effectiveness of Sustainable Urban Mobility Plans. Turin demonstrates the challenge of reduce car dependency, in Valle de Aburrá show that needs to improve the connectivity and the requirements of Cúcuta in investment in formal and sustainable transport infrastructure. These insights confirm the SUMP goals, such as promoting accessibility, environmental sustainability and social equity.

V. COMPUTING AND ASSESSING THE URBAN MOBILITY INDICATORS

The Urban Mobility Indicators (UMI) developed by the European Commission (31) chosen in this chapter serve to provide an overview of the state of mobility in each metropolitan area and to identify key aspects that require greater attention in the evaluation and monitoring of each Sustainable Urban Mobility Plan (SUMP).The comparison covers aspects of road safety, modal share, environmental impacts, congestion, greenhouse gas emissions, and access to mobility. The following aspects were evaluated in order to select those indicators, ensuring that most of the criteria described below are met, considering also their alignment with the requirements described in the SUMP guidelines (11 pp. 95-102):

1. **Alignment with SUMPs objectives:** The indicators selected are aligned with the principal pillars of the SUMPs of Turin, Valle de Aburrá and Cúcuta. These plans emphasize goals such improving road safety, promoting active mobility and public transport, reducing the environmental impacts, improving accessibility and managing congestion (described in Chapter III). The indicators chosen, covering traffic fatalities and serious injuries, modal share, air and noise pollution, greenhouse gas emissions, congestion and mobility access. This alignment ensures that the monitoring framework is not only technical, but also planning policy sensitive, so that the assessment of the interventions proposed in the plans are achieving their intended objectives.

2. **Data Availability:** A principal consideration in indicator selection was the availability and reliability of input data in each metropolitan area. As far as possible, the indicators were chosen based on their compatibility with existing data sources, according to the analysis developed in Chapter IV dealing with the household travel surveys. This analysis included a univariate statistical description of key travel characteristics such as modal split, trip purpose and peak time of departures and arrivals, as well as, bivariate analysis to establish the relationship the travel behavior with the occupation profile of the population, the most common transport mode in the municipalities of the metropolitan area, and the interaction between transport mode, trip purpose and trip duration. These analyses were fundamental to understand which data are available for the calculation of indicators like crash and injuries and modal share, since input data are directly related to modal split and trip purpose data, in addition the congestion indicator considered the peak hour travel patterns and trip duration ,

   Some official transport statistics, air quality monitoring networks, and information provided in the SUMPs themselves were considered in order to complete the necessary information. This approach helps ensure that monitoring is not only feasible in theory, but also realistic within current institutional and technical capacities, especially in Colombia metropolitan areas where resource constraints may limit new data collection efforts.

3. **Monitoring During Implementation:** Another key selection aspect was the possibility of regular monitoring throughout the implementation of SUMPs. This allows for continuous evaluation of indicator performance and the possibility of having feedback needed for

monitoring planning of the mobility. For example, indicators such as modal split by purpose are especially useful for monitoring behavioral changes in specific users, which can serve as basis for more interventions during the implementation of the plan.

4. **Comparative Analysis Across Metropolitan Areas:** Finally, all indicators selected facilitate a comparative analysis of the three metropolitan areas, taking into account, that one of the central objectives of this thesis is to compare the objectives and expected improvements in terms of sustainable mobility. For this reason, priority was given to standardized indicators in international contexts, in particular those included in the Urban Mobility Indicators (UMI) framework, which allows a structured comparison of performance, planning strategies, and data quality.

5.1 CRASHES AND INJURIES

These indicators are essential for evaluating the SUMPs strategies about road safety and the existing exposure to risk in urban transport environments and the effectiveness of capturing safety performance of the transport infrastructure and highlight the vulnerability of non-motorized users such as pedestrians and cyclists.

For the purpose of understanding some terms of the indicators, here are the definitions provided by the Eurostat Glossary for Transportation Statistics and included in the UMI indicators fiches:

- **Persons Fatally injured:** Any person killed immediately or dying within 30 days as a result of an injury accident, excluding suicides (71 p. 73). This concept is understood in the same way across the three Metropolitan Areas.
- **Person Seriously Injured:** Any person injured who was hospitalized for a period of more than 24 hours (71 p. 75).
    - **Turin Consideration:** Refers to people who have sustained injuries to their bodies as a result of the accident, with no distinction between light or severely injured due to the difficult of defining objectives criteria on the level of injured sustained (72 p. 7).
    - **Valle de Aburrá and Cúcuta Consideration:** Accidents that cause injuries to those involved but not results in fatalities (73).
    - Therefore, in the indicator "seriously injured" only the total number of injuries in each metropolitan area was considered in the calculation of this indicator.

  Although none of the three metropolitan areas explicitly require hospitalization in a period of more than 24 hours to classify in a person seriously injured, it can be inferred that they consider any non-fatal injured resulting from a traffic accident as seriously injured.
- **Functional Urban Area (FUA):** The reader is referred to the assumptions made in section 3.1.4.

The selected indicators of the fiche "Road Crashes and Injuries" (33) were:

1) **R1 – NUMBER OF PERSONS FATALLY INJURED IN ROAD CRASHES WHILE WALKING OR CYCLING IN THE CITY/FUA**

Calculation	$\boldsymbol{R1 = O_{3Walking} + O_{3Cycling}}$ **Where:** • $\boldsymbol{O_{3Walking/Cycling}}$ **Number of persons fatally injured in road crashes per year in the city.**
Unit	Number of Persons
Note	This indicator measures the absolute number of people fatally injured among vulnerable road users (pedestrians and cyclist) during a year.

2) **R2 – NUMBER OF PERSONS INJURED IN ROAD CRASHES WHILE WALKING OR CYCLING IN THE CITY/FUA**

Calculation	$$R2 = O_{4Walking} + O_{4Cycling}$$ **Where:** • $O_{4Walking/Cycling}$ **Number of persons injured in road crashes per year in the city**
Unit	Number of Persons
Note	This indicator measures the absolute number of people injured in a road crash among vulnerable road users (pedestrians and cyclist) during a year.

3) **R3 – NUMBER OF PERSONS FATALLY INJURED IN ROAD CRASHES WHILE WALKING OR CYCLING IN THE CITY/FUA PER MILLION WALKING CYCLING TRIPS PER YEAR**

Calculation	$$R3 = (O_{3Walking} + O_{3Cycling})/(I_3 + I_4) \cdot 10^6$$ **Where:** • $O_{3Walking/cycling}$ **Number of persons fatally injured in road crashes per year in the city.** • I_3 **Number of walking trips per year in the city.** • I_4 **Number of cycling trips per year in the city.**
Unit	Number of Persons per million trips
Note	This indicator measures the number of people fatally injured among vulnerable road users (pedestrians and cyclist) per million of walking and cycling trips.

4) **R4 – NUMBER OF PERSONS INJURED IN ROAD CRASHES WHILE WALKING OR CYCLING IN THE CITY/FUA PER MILLION WALKING CYCLING TRIPS PER YEAR**

Calculation	$$R4 = (O_{4Walking} + O_{4Cycling})/(I_3 + I_4) \cdot 10^6$$ **Where:** • $O_{4Walking/Cycling}$ **Number of persons injured in road crashes per year in the city.** • I_3 **Number of walking trips per year in the city.** • I_4 **Number of cycling trips per year in the city.**
Unit	Number of Persons per million trips
Note	This indicator measures the number of people injured in a traffic road accident among vulnerable road users (pedestrians and cyclist) per million of walking and cycling trips.

5) **R5 – NUMBER OF PERSONS FATALLY INJURED IN ROAD CRASHES IN THE CITY/FUA PER YEAR PER 100 000 INHABITANTS PER YEAR**

Calculation	$$R4 = (O_{3\ sum\ of\ all\ type\ of\ vehicles})/(I_1) \cdot 10^5$$ **Where:** • $O_{3\ sum\ of\ all\ type\ of\ vehicles}$ **Number of persons fatally injured in road crashes per year in the city.** • I_1 **Number of inhabitants.**
Unit	Number of Persons per 100 thousand inhabitants
Note	This indicator measures the people fatally injured among of all type of vehicles per 100 thousand inhabitants.

6) **R9 – NUMBER OF PERSONS INJURED IN ROAD CRASHES IN THE CITY/FUA PER 100 000 INHABITANTS PER YEAR**

Calculation	$$R9 = (O_{3\ sum\ of\ all\ type\ of\ vehicles})/(I_1) \cdot 10^5$$ **Where:** • $O_{3\ sum\ of\ all\ type\ of\ vehicles}$ **Number of persons injured in road crashes per year in the city.**

	• I_1 **Number of inhabitants.**
Unit	Number of Persons per 100 thousand inhabitants
Note	This indicator measures the people injured among of all type of vehicles per 100 thousand inhabitants.

5.1.1 Comparative Analysis

These indicators are related to road safety in the metropolitan areas analysed, paying attention in the most vulnerable road users such as pedestrians and cyclist, the main users of sustainable mobility.

- **Persons Fatally Injured and Injured while walking or cycling per year:**

The results of the indicator R1 "*Number of persons fatally injured in road crashes while walking or cycling in the city/FUA*" and R2 "*Number of persons injured in road crashes while walking and cycling in the city/FUA"* in the three metropolitan areas below are listed the values in the Table 37:

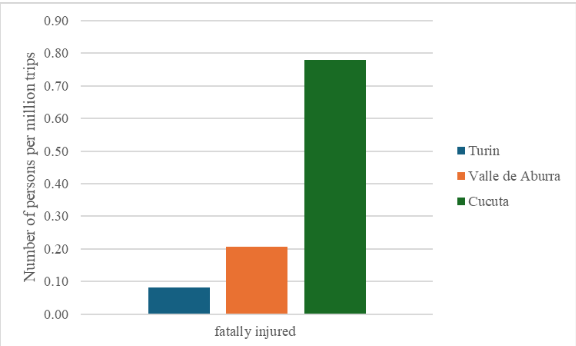
Table 37
Results of indicators R1 "Number of persons fatally injured in road crashes while walking or cycling in the city/FUA" and R2 "Number of persons injured in road crashes while walking and cycling in the city/FUA"

Metropolitan Area	R1-Persons fatally injured per year	R2-Persons injured per year	Fatality per injured
Turin	36	1,434	1 per 40
Valle de Aburrá	143	957	1 per 7
Cúcuta	59	160	1 per 3

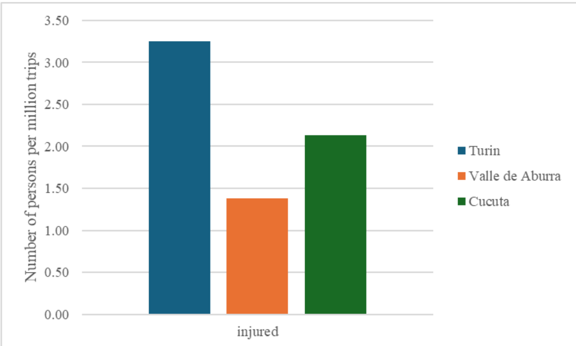
The ratio of fatalities to injuries serves as an approximation of the relative risk that vulnerable road users face in the road network in each metropolitan area. Although Turin records a high number of injuries along with a much lower number of fatalities, resulting in one fatality is reported for every 40 injuries, while Valle de Aburrá and Cúcuta experiences one fatality for every 7 and 3 every injury respectively, which implies a higher severity of crash and accidents. It is worth mentioning that these results are closely linked to the size and total population of each metropolitan area. Therefore, direct comparisons between them are not meaningful.

- **Persons Fatally Injured and Seriously Injured while walking or cycling per million of trips per year:**

Graph 36
R3 "Number of persons fatally injured in road crashes while walking and cycling in the city/FUA per million walking cycling trips per year"



Graph 37
R4 "Number of persons injured in road crashes while walking and cycling in the city/FUA per million walking cycling trips per year"



Graph 36 illustrates the indicator R3 – Number of persons fatally injured in road crashes per million walking or cycling trips per year within the three metropolitan areas. The data show that the Metropolitan Area of Cúcuta exhibits the highest fatality rate, with 0.78 fatalities per million trips, indicating a hazardous environment for non-motorized road users (pedestrians and cyclist). In comparison, Metropolitan Area of Valle de Aburrá reports a lower fatality rate of 0.21 fatalities per million trips, while Turin with only 0.08 fatalities per million trips.

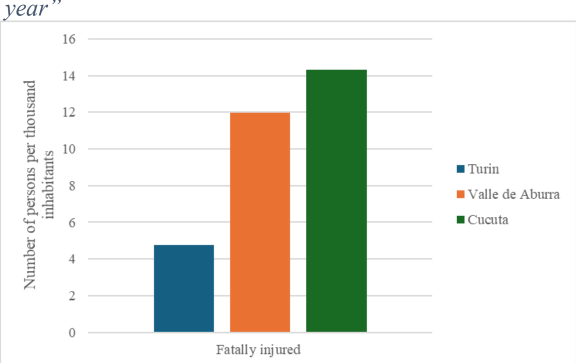
This highest risk in the Metropolitan Area of Cúcuta could be attributed to insufficient safety infrastructure. Cyclists and pedestrians are often forced to share roads designated for motorized vehicles, increasing the exposure to fatality injures. According to the diagnostic document of the SUMP, the lack of dedicated infrastructure, such as bike lanes and pedestrian paths (64 p. 326), represents a key weakness is the Metropolitan Urban mobility strategy. In response, the SUMP presents different projects focused on active the pedestrian and cyclist mobility, improving the pedestrian routes, and expanding and building of a new safe cycling infrastructure (57 p. 50).

Graph 37 shows the indicator R4 – Number of persons injured in road crashes per million walking or cycling trips per year within the three metropolitan areas. Unlike the fatalities injured, the highest number of injuries occurred in the Metropolitan Area of Turin with 1434 injures per million trips, followed by the other metropolitan areas with lower values. This suggests that while fatal injuries are rare, the Metropolitan Area of Turin faces challenges related to non-fatal road injuries. The prevalence of private car use in the metropolitan area, combined with risk of human behavior, such as the distraction caused by excessive use of mobile phones while driving or walking, as (41 p. 34), contributes to number of injuries. Additional issues could be related to the reporting mechanisms of hospitalization and to higher levels of care for an ageing population like the one in Turin.

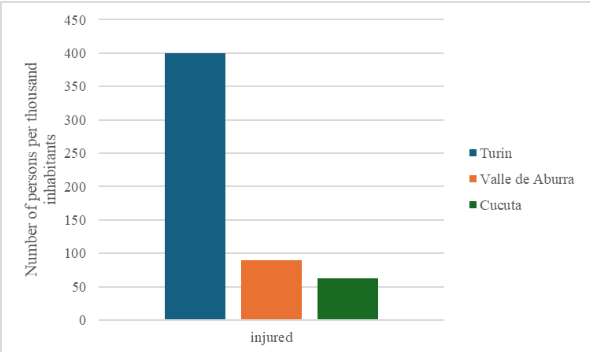
To address this issue, the Turin SUMP highlights the need to strengthen the culture of road safety, not only for drivers but also for pedestrians and cyclists. Educational campaigns, stricter enforcement, and improved infrastructure could all contribute to reducing injuries, or the project being implemented in Turin called "Vision Zero" to reduce the number of accidents victims (injuries and deaths), paying particular attention to vulnerable users (41 p. 184).

- **Fatalities and serious injuries per 100,000 inhabitants**

Graph 38
R5 "Number of persons fatalities injured in road crashes in the city/FUA per year per 100 thousand inhabitants per year"



Graph 39
R9 "Number of persons injured in road crashes in the city/FUA per year per 100 thousand inhabitants per year""



Graph 38 presents the indicator R5 - Number of persons fatalities injured in road crashes in the city/FUA per year per 100 thousand inhabitants per year, including all vehicle type. The data highest significant differences across the metropolitan areas. The Metropolitan Area of Cúcuta records the highest fatality rate (14 deaths per 100,000 inhabitants), which is especially concerning given its relatively small population. This indicates that Cúcuta faces severe road safety challenges.

Graph 39 exhibit the indicator R9 – Number of persons injured in road crashes in the city/FUA per year per 100 thousand inhabitants per year. Turin demonstrates the highest rate 400 (injured per 100,000 inhabitants). This suggests that, while the Metropolitan Area effectively prevents fatalities, the traffic network still results in a frequency of non-fatal injuries, factors like high volumes of traffic or an inadequate protection for all road users contribute to this. In Colombia, the initial recording of crash fatalities and injuries is done by DITRA (Transit and Transport Direction of National Police), followed by monthly accidents reports from the Nacional Road Safety Observatory. If a crash is not attended by the police, particularly in the case of minor incidents, it may go unreported and therefore not included in national statistics (74). This could help explain the significant discrepancies in the numbers of injuries compared to Turin.

Reducing the number of road traffic injuries and fatalities also significantly reduces the associated medical costs. According to World Health Organization (WHO), road traffic crashes cost for most countries a cost equivalent to 3% of their gross domestic product (GDP) (75) due to factors such as medical expenses, loss of productivity or damage to the infrastructure. Reducing this cost represents progress in terms of public health and quality of life but also frees up economic resources that could be reinvested in priority areas like education or sustainable mobility.

5.2 MODAL SHARE

The selected indicators of the fiche called "Modal Share" (34) were:

1) **R1 – SHARE OF CITY/FUA INHABITANT TRIPS DONE BY WALKING, CYCLING OR PUBLIC TRANSPORT**

Calculation	$\boldsymbol{R1 = (O_{1Walking} + O_{1Cycling} + O_{1Public\ Transport})/(O_{1All\ modes})}$ **Where:** • $\boldsymbol{O_{1Walking}}$ **Number of walking trips per year.** • $\boldsymbol{O_{1Cycling}}$**Number of cycling trips per year.** • $\boldsymbol{O_{1Public\ Transport}}$**Number of public transport trips per year.** • $\boldsymbol{O_{1All\ modes}}$**Total trips per year.**
Unit	% of Total Trips
Note	This indicator measures the percentage of the active and public transport mode in the whole mobility patter in the Metropolitan Area.

2) **R2 – SHARE OF MODES IN TOTAL CITY/FUA INHABITANT TRIPS**

Calculation	$\boldsymbol{R2 = O_{1Each\ mode}/O_{1All\ modes}}$ **Where:** • $\boldsymbol{O_{1Each\ Trip}}$ **Number of walking, private car, bicycle, public transport, taxi, motorbike and other mode trips per year.** • $\boldsymbol{O_{1All\ modes}}$**Total trips per year**
Unit	% of trips per each mode
Note	This indicator measures the modal share of the total trips in the Metropolitan Area.

3) **R3 – R4 – R5 – SHARE OF MODES IN CITY/FUA INHABITANT TRIPS TO AND FROM A WORKPLACE, SCHOOL AND SHOP RESPECTIVELY**

Calculation	$\boldsymbol{R2 = O_{2Each\ mode}/O_{2All\ modes}}$ **Where:** • $\boldsymbol{O_{2Each\ Trip}}$ **Number of walking, private car, bicycle, public transport, taxi, motorbike and other mode trips per year for different purposes** • $\boldsymbol{O_{2All\ modes}}$**Total trips per year for work purposes.**
Unit	% of total trips per each mode
Note	This indicator measures the modal share of the total trips in the Metropolitan Area for different purposes. R3 Work purposes/R4 Study purposes/R5 Shopping purposes

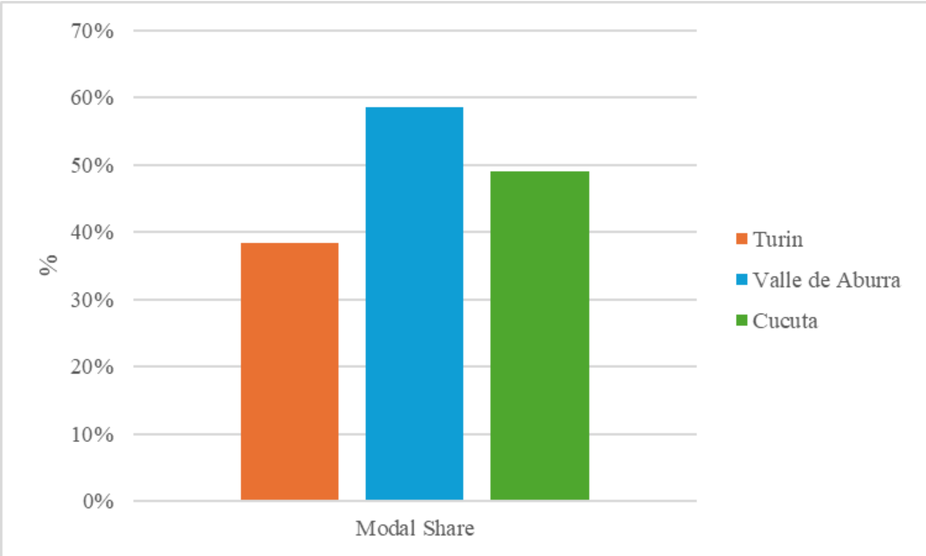
5.2.1 *Comparative Analysis*

These indicators are related understanding the mobility patterns in the metropolitan areas.

- **Share of modes in the metropolitan areas per inhabitant trips done by walking, cycling or public transport**

In the Graph 40 is presented the results the indicator R1 share of trips done by walking, cycling and public transport, representing the active and sustainable modes in the metropolitan areas:

Graph 40
R1 "Share of city/FUA inhabitants trips done by walking, cycling or public transport"

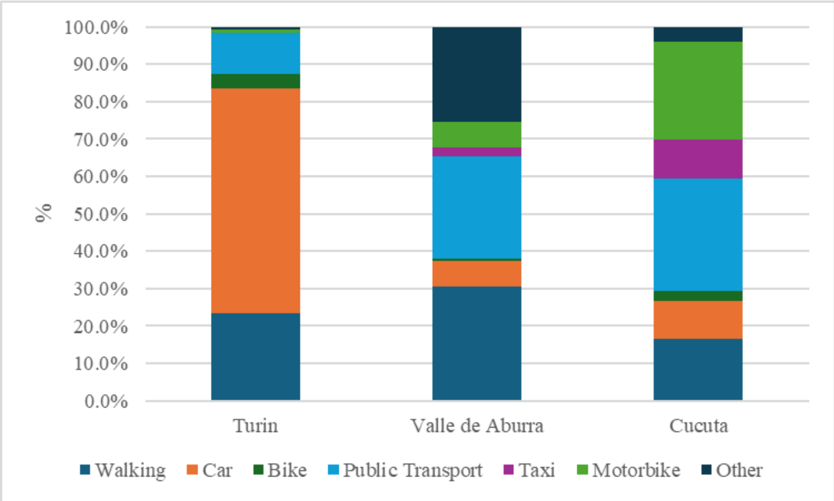


The Bar Graph 40 above shows that the Metropolitan Area of Valle de Aburrá leads in sustainable mobility, following by Cúcuta and Turin, could be the reflection of the results where the government of this metropolitan area has increased the use of public transportation in its inhabitants by controlling and renewing the bus fleet, the use of a better infrastructure and campaign where the community is encouraged to make their trips in a more active way, such as the use of bicycles and improving the infrastructure for pedestrians and cyclists (58).

In this case of metropolitan area of Turin, there is a great dependence on private car, which is also linked to the high economic possibility that its population has to access this type of transportation, where in Colombian metropolitan areas, this type of possibility is much more reduced, so most of its inhabitants have no other options but to make their trips by public transport or is to get other more affordable modes such as motorbikes.

- **Share of modes in total metropolitan area per inhabitant trips**

Graph 41
R2 "Share of modes in total city/FUA inhabitant trips"



The distribution of transport mode across the three metropolitan areas shows a notable contrast (Graph 41). Turin exhibits a high dependency on private cars, as 59% of the total trips depending on this mode. In contrast, Valle de Aburrá and Cúcuta show significantly low car use, with 6.9% and 10.2% respectively. Regarding walking and public transport, Valle de Aburrá leads with 30.4% of trips made in foot and 27.5% by public transport. Meanwhile, in Cúcuta 16.4% of the total trips are made by walking, while 29.8% are on public transport.

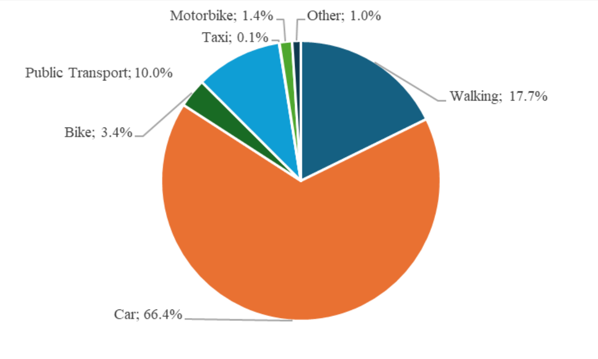
Another important trend in Valle de Aburrá is the prevalence of alternative transport modes called "others", which account 25% of the trips. This category includes special transportation companies, school bus, private vehicles with payment outside of platform and private vehicles with payment (platform as Uber). Additionally, motorbike has an important role in mobility with 26.3% in Valle de Aburrá. However, the data suggests considerably low use of bicycles, but Turin is slightly ahead at 4.1%, suggesting that the bicycle has yet to be integrated in the transportation mode of these metropolitan areas.

- **Share of modes in the metropolitan areas per inhabitant trips to and from a workplace**

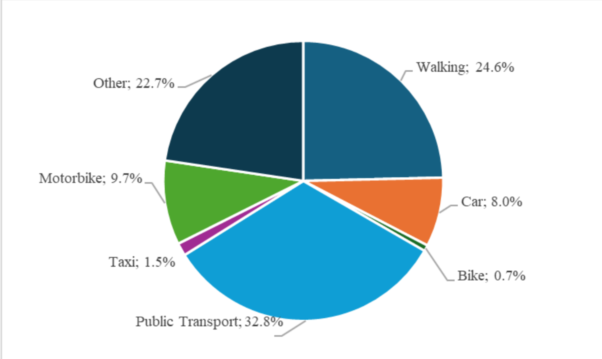
In the Graph 42, Graph 43 and Graph 44 presents the Work-related mobility patterns "indicator R3" where is could be reinforced the dominant transport modes seen in the general trip data (Graph 41). In Turin, car use is dominant at 66.4%, indicating a strong reliance on private vehicles, linked to residential patterns. Walking at 17.7% and public transport at 10% play secondary roles.

On the other hand, Valle de Aburrá shows a balanced modal distribution, where public transport is the main commuting mode with 32.8%, followed by walking trips with 24.6%, and the "other" modes have a significant high number of trips with 22.7% like Uber or work transport. This reflects that in the metropolitan Area, especially in Medellín where is concentrated the work attractor poles has a comprehensive public transport modes like metro system, gondola lift system, alongside informal transport options increasing accessibility to its community. Cúcuta stands out for high reliance on motorbikes with 33.3% for commuting, this mode surpasses the share of public transport with 27.3% and car use with 12.9%, suggesting a modal pattern shaped by economic constraints.

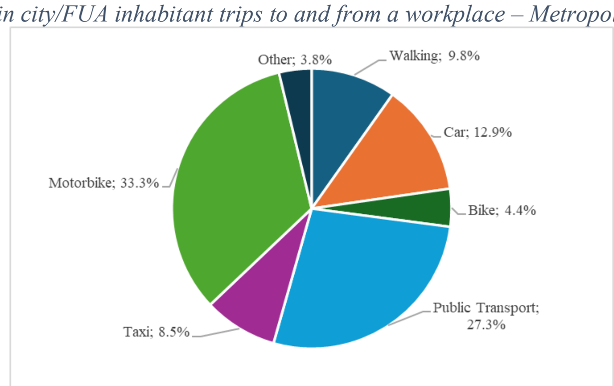
Graph 42
R3 "Share of modes in city/FUA inhabitant trips to and from a workplace – Metropolitan Area of Turin".



Graph 43
R3 Share of modes in city/FUA inhabitant trips to and from a workplace – Metropolitan Area of Valle de Aburrá



Graph 44
R3 Share of modes in city/FUA inhabitant trips to and from a workplace – Metropolitan Area of Cúcuta.

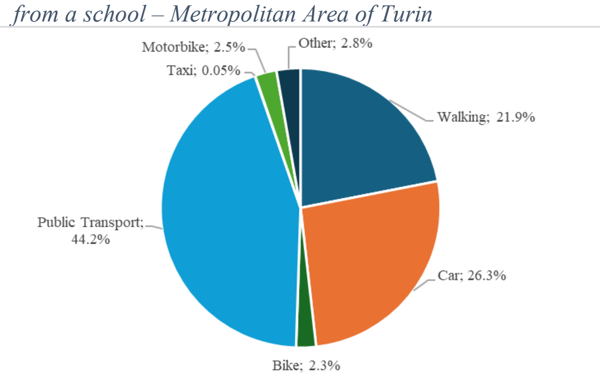


- **Modal Share of modes in the metropolitan areas per inhabitant trips to and from school**

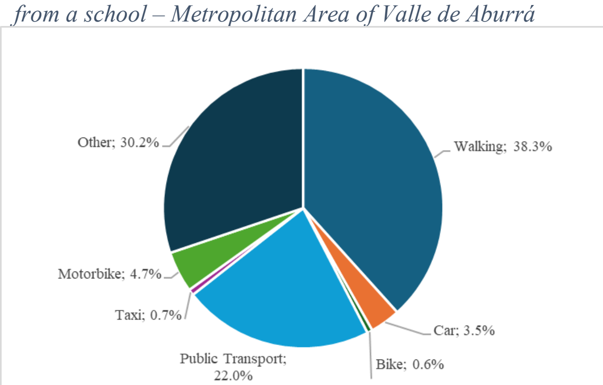
Trips to and from school "indicator R4" present a unique mobility pattern (Graph 45, Graph 46 and Graph 47). Turin demonstrates a strong reliance on public transport with 44.2%, suggesting a reliable accessible transport network and youth programs to allow the studies to allow easy public transport system, and middle ling travel distance between residential zones and educational institutions. Car use remains with an important percentage of 26.3%, while walking accounts for 21.9%, and cycling is low with 2.3%, likely due to low programs that encourage the use of the bicycle.

In Valle de Aburrá, the dominant mode is walking 38.3%, followed by public transport with 22% and considerable "other" mode like Uber or Private School Transport with 30.2%. The low car usage of 3.5% suggests that educational institutions are well distributed in the metropolitan area and very accessible to its inhabitants. In Cúcuta the walking focused the main transport mode in this activity with 36.7%, though motorbike use is strikingly high at 21.9%, and public transport is also relevant with 23.9%, indicating that transit accessibility plays a crucial role.

Graph 45
R4 "Share of modes in city/FUA inhabitant trips to and from a school – Metropolitan Area of Turin

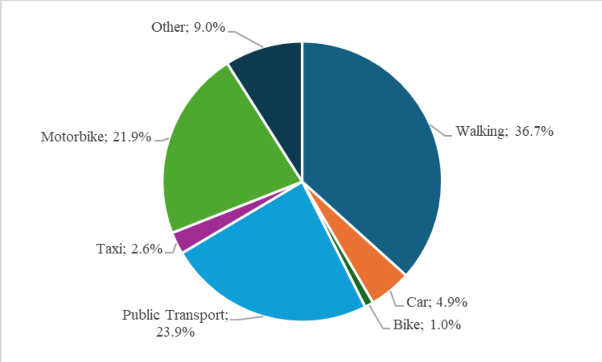


Graph 46
R4 "Share of modes in city/FUA inhabitant trips to and from a school – Metropolitan Area of Valle de Aburrá



Graph 47

R4 "Share of modes in city/FUA inhabitant trips to and from a school – Metropolitan Area of Cúcuta



- **Modal share of modes in the metropolitan areas per inhabitant trips to and from a shop**

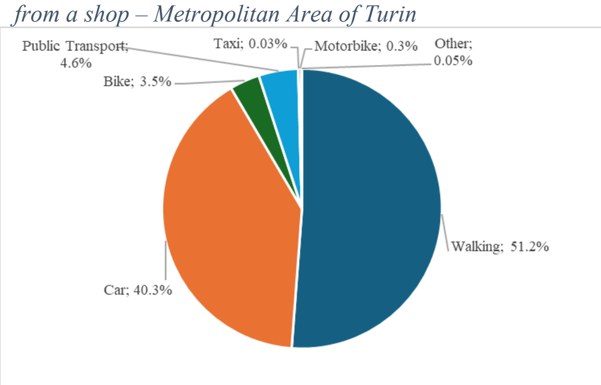
Shopping-related mobility "indicator R5" provides insight into the local trips patterns and neighborhood accessibility (Graph 48, Graph 49 and Graph 50). Turin demonstrates an extremely high level of walking trips with 51.2%, car use also high at 40.3%, pointing to mixed-use development where shops are within walking distances for some residents, while others prefer to go on vehicles.

Valle de Aburrá shows a similar trend, with walking trips at 34.1% and public transport at 15.7%, suggesting a connection between commercial poles areas and the transportation network. Additionally, reports a relatively high share of trips with "Other means" like uber or different informal options.

In Cúcuta, public transport with 34.5% and taxi use with 17.8% dominate shopping trips, followed by motorbikes with 14.3% demonstrated the dependency that the residents in this metropolitan area have with this transport mode. Walking trips are low at 18.7%, show a longer distance to commercial areas to the residential zones.

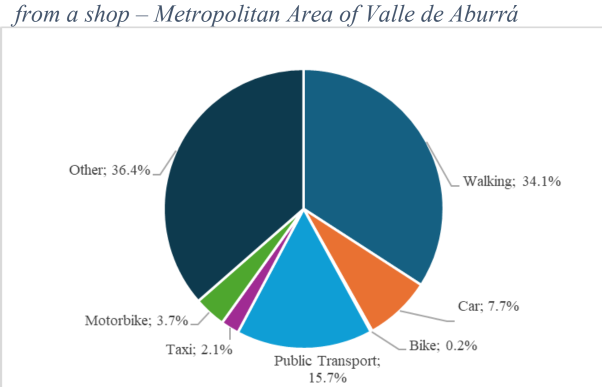
Graph 48

R5 "Share of modes in city/FUA inhabitant trips to and from a shop – Metropolitan Area of Turin



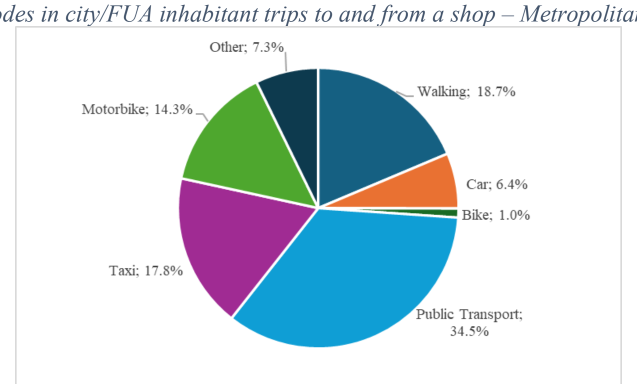
Graph 49

R5 "Share of modes in city/FUA inhabitant trips to and from a shop – Metropolitan Area of Valle de Aburrá



Graph 50

R5 "Share of modes in city/FUA inhabitant trips to and from a shop – Metropolitan Area of Cúcuta



5.3 NOISE POLLUTION

The selected indicators of the fiche called “Noise Pollution” (35) were:

1) **R1/R2 – PERCENTAGE OF POPULATION OF THE CITY/FUA EXPOSED TO DAY-EVENING-NIGHT (L_{DEN}) NOISE >=55 dB DUE TO ROAD TRANSPORT/RAIL TRANSPORT RESPECTIVELY**

Calculation	$NE_m^{Lden\geq 55} = \sum_i P_{im}^{Lden} / P$ **Where:** • P_{im}^{Lden} **Population of the metropolitan area exposed to day-evening-night (L_{den}) noise band higher or equal 55 decibels due to road/rail transport.** • P **Total population of the metropolitan Area.**
Unit	% of inhabitants
Note	These indicators measure percentage of population that are exposed to day-evening-night (L_{den}) noise level equal or higher than 55 decibels due to road/ rail transport.

2) **R4/R5 – PERCENTAGE OF POPULATION OF THE CITY/FUA EXPOSED TO DAY-EVENING-NIGHT (L_{DEN}) NOISE >=60 dB DUE TO ROAD TRANSPORT/RAIL TRANSPORT RESPECTIVELY**

Calculation	$NE_m^{Lden\geq 60} = \sum_i P_{im}^{Lden} / P$ **Where:** • P_{im}^{Lden} **Population of the metropolitan area exposed to day-evening-night (L_{den}) noise band higher or equal 60 decibels due to road/rail transport.** • P **Total population of the metropolitan Area.**
Unit	% of inhabitants
Note	These indicators measure percentage of population that are exposed to day-evening-night (L_{den}) noise level equal or higher than 60 decibels due to road/ rail transport.

3) **R7/R8 – PERCENTAGE OF POPULATION OF THE CITY/FUA EXPOSED TO NIGHTTIME (LDEN) NOISE >=50 DB DUE TO ROAD TRANSPORT/RAIL TRANSPORT RESPECTIVELY**

Calculation	$NE_m^{Lnight\geq 50} = \sum_i P_{im}^{Lnight} / P$ **Where:** • P_{im}^{Lnight} **Population of the metropolitan area exposed to nighttime (Lnight) noise band higher or equal 60 decibels due to road/rail transport.** • P **Total population of the metropolitan Area.**
Unit	% of inhabitants
Note	These indicators measure percentage of population that are exposed to nighttime (L_{den}) noise level equal or higher than 50 decibels due to road/ rail transport

5.3.1 *Comparative Analysis*

The results obtained from the Noise pollution can be compared in Table 38:

Table 38
Results of Indicators R1, R2, R4, R5, R7 and R8 – Noise Pollution

		METROPOLITAN AREA		
INDICATOR		TURIN	VALLE DE ABURRÁ	CÚCUTA
R1	Percentage of the population of the city/FUA exposed to day-evening-night (Lden) noise >=55 dB due to road transport (% of inhabitants)	20%	18%	-
R2	Percentage of the population of the city/FUA exposed to day-evening-night (Lden) noise >=55 dB due to rail transport (% of inhabitants)	2%	-	-
R4	Percentage of the population of the city/FUA exposed to day-evening-night (Lden) noise >=60 dB due to road transport (% of inhabitants)	69%	71%	-
R5	Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=60 dB due to rail transport (% of inhabitants)	2%	-	-
R7	Percentage of population of the city/FUA exposed to nighttime (Lnight) noise >=50 dB due to road transport (% of inhabitants)	79%	88%	-
R8	Percentage of population of the city/FUA exposed to nighttime (Lnight) noise >=50 dB due to rail transport (% of inhabitants)	3%	-	-

The Urban Noise level affects public health and quality of life of the inhabitants of the metropolitan areas. Cúcuta currently has no continuing monitoring in the noise field; therefore, it cannot be compared to the other two in this indicator.

Road noise exposures greater or equal than 55 dB (Lden) "day-evening-night", this indicator indicates the portion of the population exposed to potentially high noise level from road traffic, in this case Turin and Valle de Aburrá show similar levels of exposure, affecting approximately one-fifth of their population. When analyzed data greater than or equal to 60 dB in the same hour range, in both cities, more than two-thirds of the population is exposed to highly road traffic noise level, these elevated of exposure may reflect the intense traffic volumes and urban density.

In the case of night records, the population exposed to road noise levels greater than 50 dB, notably, Valle de Aburrá recodes the highest share, with 88% of its population, this is considerably higher than Turin with 79%, which is still a substantial value. The elevated night-time exposure levels in both cities could be attributed to 24-hour vehicle activity, or the road infrastructure passing through densely populated areas.

Turin is the only among the three metropolitan areas with reported exposure to rail transport noise, affecting a small percentage of population in the three range of measures, may have significant localized effects, particularly for residents near active rail lines and stations.

5.4 AIR POLLUTION

The selected indicators of the fiche called “Air Pollution” (36) were:

1) **O1 – O2 – O3- ANNUAL MEAN NO2/PM10/PM2.5 POLLUTION CONCENTRATION AT THE TRAFFIC-ORIENTED SAMPLING POINT THAT REPORTED THE HIGHEST VALUE IN THE URBAN AREA (CITY/FUA) [µG/m³]**

Calculation	$\boldsymbol{Annual\ mean}$
Unit	µg/m^3
Note	This indicator measures the annual mean of NO2/PM10/PM2.5 pollution concentration.

2) **R1 – NUMBER OF DAYS PER YEAR WHERE THE DAILY PM10 CONCENTRATION EXCEEDED THE WHO RECOMMENDED LEVEL OF 45 µg/m3 AT ANY TRAFFIC-ORIENTED SAMPLING POINT IN THE CITY/FUA**

Calculation	$\boldsymbol{Number\ of\ days}$
Unit	# of days.
Note	This indicator measures the number of days per year where the daily PM_{10} concentration exceeded recommended level of 45 µg/m^3.

3) **R2 – NUMBER OF TRAFFIC-ORIENTED SAMPLING POINTS WHERE THE ANNUAL MEAN CONCENTRATION OF PM2.5 EXCEEDED THE WHO RECOMMENDED LEVEL OF 35 µg/m3 IN THE CITY/FUA**

Calculation	$\boldsymbol{Number\ of\ stations}$
Unit	# of stations.
Note	This indicator measures the number of stations where annual mean concentration of $PM_{2.5}$ exceeded recommended level of 35 µg/m$^{3.}$

4) **R3 – NUMBER OF HOURS PER YEAR WHERE THE HOURLY NO2 CONCENTRATION EXCEEDED THE WHO RECOMMENDED LEVEL OF 200 µg/m3 AT ANY TRAFFIC-ORIENTED SAMPLING POINT IN THE CITY/FUA**

Calculation	$\boldsymbol{Hours}$
Unit	# of hours.
Note	This indicator measures the number of hours per year where NO_2 concentration exceeded recommended level of 200 µg/m^3.

5) **R4 – R22 – R25 – AVERAGE POLLUTANT EMISSION PER VEHICLE-KM RELATED TO NO_2 eq. OF PUBLIC TRANSPORT BUS/PRIVATE MOTORCYCLE/PRIVATE CAR RESPECTIVELY VEHICLE STOCK**

Calculation	$$APE^{mp} = \left(\sum_{fe} PF_{fe}^{mp} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}} \right)$$ **Where:** • PF_{fe}^{mp} **Technology-specific emission factor of pollutant “NO_2” per vehicle-km by engine fuel f and emission standard in g/km.** • V_{fe}^{m} **Number of vehicles subdivided by the engine fuel and emission standard.**
Unit	g/km
Note	The indicator measures the average pollutant emission factor per public transport bus vehicles/private motorcycle/private car related to the NO_2 eq. R4 Public transport bus/R22 Private Motorcycle/R25 Private Car

6) R5 – R6/R23 – R24/R26 – R27 – AVERAGE POLLUTANT EMISSION PER VEHICLE-KM RELATED TO $PM_{2.5}/PM_{10}$ OF PUBLIC TRANSPORT BUS/PRIVATE MOTORCYCLE/PRIVATE CAR RESPECTIVELY VEHICLE STOCK

Calculation	$$APE^{mp} = \left(\sum_{fe} PF_{fe}^{mp} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}} \right)$$ **Where:** • PF_{fe}^{mp} **Technology-specific emission factor of pollutant "$PM_{2.5}/PM_{10}$" per vehicle-km by engine fuel f and emission standard in g/km.** • V_{fe}^{m} **Number of vehicles subdivided by the engine fuel and emission standard.**
Unit	g/km
Note	The indicator measures the average pollutant emission factor per public transport bus vehicles/private motorcycle/private car related to $PM_{2.5}$ and PM_{10}. R5 – R6 Public transport bus/R23-24 Private Motorcycle/R26-R27 Private Car

5.4.1 Comparative Analysis

It is known, mobility activities are the source of the greatest contribution to air pollution in the metropolitan areas, especially for particulate matter with particles diameter of 10µg/2.5µg ($PM_{10/2.5}$) and Nitrogen Dioxide (NO_2), and other variety of air pollutants that poses significant public risks. The result of the indicator is presenting in the Table 39:

Table 39
Results of indicators O1, O2 and O3. Annual mean of NO2, PM10 and PM2.5 pollution concentration

		METROPOLITAN AREA		
INDICATOR		TURIN	VALLE DE ABURRÁ	CÚCUTA
O1	Annual mean NO_2 pollution concentration at the traffic-oriented sampling point that reported the highest value in the urban area (µg/m^3)	45.8	45.10	8.00
O2	Annual mean PM_{10} pollution concentration at the traffic-oriented sampling point that reported the highest value in the urban area (µg/m^3)	20.4	53.60	39.40
O3	Annual mean PM2.5 pollution concentration at the traffic-oriented sampling point that reported the highest value in the urban area (µg/m^3)	13.9	27.00	17.40

Among the three metropolitan areas, Valle de Aburrá reports the highest annual mean concentration for PM_{10} (53.60 µg/m^3) and PM2.5 (27.00 µg/m^3), indicating significant air pollution levels from mobility activities. Turin exhibits the highest NO2 concentration (45.8 µg/m^3) possibly associated with high levels of traffic. Meanwhile, Cúcuta records the lowest NO2 concentration level (8 µg/m^3).

In the Table 40 is reported the results of the indicators R1, R2 and R3:

Table 40
Results of indicators R1, R2 and R3

		METROPOLITAN AREA		
INDICATOR		**TURIN**	**VALLE DE ABURRÁ**	**CÚCUTA**
R1	Number of days per year where the daily PM_{10} concentration exceeded the WHO recommended level of 45 µg/m_3 at any traffic-oriented sampling point in the city/FUA	71 days	99 days	77 days
R2	Number of traffic-oriented sampling points where the annual mean concentration of PM2.5 exceeded the WHO recommended level of 35 µg/m3 in the city/FUA	0 stations	0 stations	0 stations
R3	Number of hours per year where the hourly NO2 concentration exceeded the who recommended level of 200 µg/m3 at any traffic-oriented sampling point in the city/FUA	11 hours	0 hours	0 hours

Valle de Aburrá leads in the number of days with PM_{10} levels exceeding the 45 µg/m^3 limit in 99 days, followed by Cúcuta with 77 days and -Turin with 71 days. No stations were found in the three metropolitan areas to have exceeded the annual mean concentration recommended level of 35 µg/m3 by the WHO. Finally, Turin is the only area reporting exceedances of the hourly NO2 standard (recommended level of 200 µg/m3), hours that might be correlated with the peak hours.

The results of the average pollutant emission per vehicle related to different types of vehicles are presented in Table 41 and Table 42:

Table 41
Results of Indicators R4, R22 and R25.Average pollutant emission per vehicle.km related to NO_2 eq

		METROPOLITAN AREA		
INDICATOR		**TURIN**	**VALLE DE ABURRÁ**	**CÚCUTA**
R4	Average pollutant emission per vehicle.km related to NO_2 eq. of public transport bus vehicle stock (g/km)	7.677	15.597	10.029
R22	Average pollutant emission per vehicle.km related to NO_2 eq. of private motorcycle vehicle stock (g/km)	0.043	0.113	0.040
R25	Average pollutant emission per vehicle.km related to NO_2 eq. of private car vehicle stock (g/km) - GAS	0.371	2.218	0.630
	Average pollutant emission per vehicle.km related to NO_2 eq. of private car vehicle stock (g/km) – (DIESEL)	0.589	0.593	0.587

Table 42 Results of Indicators R5-R6/R23-R24/R26-R27 Average pollutant emission per vehicle.km related to $PM_{2.5}$ and PM_{10}

		METROPOLITAN AREA		
INDICATOR		**TURIN**	**VALLE DE ABURRÁ**	**CÚCUTA**
R5 – R6	Average pollutant emissions per vehicle-km related to $PM_{2.5}$ and PM_{10} of public transport bus vehicle stock (g/km)	0.143	0.698	0.361
R23 – R24	Average pollutant emissions per vehicle-km related to $PM_{2.5}$ and PM_{10} of public transport motorcycle vehicle stock (g/km)	0.086	0.200	0.112
R26 – R27	Average pollutant emissions per vehicle-km related to $PM_{2.5}$ and PM_{10} of private car vehicle stock (g/km) -GAS	0.001	0.002	0.002
	Average pollutant emissions per vehicle-km related to $PM_{2.5}$ and PM_{10} of private car vehicle stock (g/km) -DIESEL	0.024	0.244	0.022

Nitrogen Dioxide (NO_2):

Turin and Valle de Aburrá report the highest annual NO_2 concentration (Table 39), which are aligned with the significant NO_2 equivalent emission factors from public transport buses and private vehicles (Table 41). Valle de Aburrá, with the highest NO_2 equivalent emission factor per bus (15.597 g/km); also records high NO_2pollution levels (45.10 µg/m^3), suggesting a combination of older vehicle fleets and potentially weaker emissions control technologies.

Although motorcycle contribute less to NO_2 emissions than buses and cars, their impact remains notable. In Valle de Aburrá, motorcycle emit 0.113 g/km of NO_2, almost three times more than in Turin with 0.043 g/km and Cúcuta with 0.040 g/km. This highlights their role as a significant pollution source, particularly in the metropolitan area serve as one of the transport modes used daily.

PM_{10} and $PM_{2.5}$ Particulate Matter:

Valle de Aburrá reports the highest concentration of PM_{10}(53.50 µg/m^3) and $PM_{2.5}$(27µg/m^3) reported in Table 39, especially from public buses and diesel cars. Additionally, it records the highest number of days with PM_{10} levels exceeding the WHO recommended limits (99 days Table 40). This correlates with the highest particulate matter emissions per vehicle from public transport buses (0.698 g/km for $PM_{2.5}$ and PM_{10}). Meanwhile, Cúcuta and Turin, which report lower PM pollution concentrations, also have lower emissions from their vehicle stocks.

The emission factors of $PM_{2.5}$ and $PM_1$for motorcycle show a similar pattern, is almost twice as high in Valle de Aburrá with 0.200 g/km compared to Cúcuta with 0.112 g/km and more than three times as high as in Turin with 0.086 g/km. This indicates that, motorcycles can be a major source of pollution considering that Valle de Aburrá, which has three times as many motorcycles as other metropolitan areas.

The data demonstrates that vehicle type and fuel composition significantly affect urban air quality. Metropolitan Areas with higher emission factors, particularly from buses and diesel/gas cars, tend to experience worse air quality indicators, especially in NO2 and PM10/PM2.5 levels.

5.5 CONGESTION

The selected indicators of the fiche called "Congestion" (37) were:

1) **R5 – R6 – INCREASE IN AVERAGE TIME TO TRAVEL 3 km BY PUBLIC TRANSPORT/CAR ON REPRESENTATIVE ROUTES IN THE CITY/FUA DURING PEAK HOUR COMPARED TO OFF-PEAK.**

Calculation	$$In_{av(mode\ i)} = t_{peak_{av(mode\ i)}} - t_{offpeak_{av(mode\ i)}}$$ **Where:** • $In_{av(mode\ i)}$ **Increase in average time** $t_{peak_{av(mode\ i)}}$ **Average travel time to travel 3 km on representative routes in the peak hour (e.g. morning rush hours).** • $t_{offpeak_{av(mode\ i)}}$ **Average travel time to travel 3km on representative routes in the off-peak hour (e.g. hours with less traffic like mid-morning, late evening)**
Unit	Min
Note	The indicator measures how much extra time people spend travelling during peak hour compared to off-peak hour in a section of 3km. R2 Public transport/R3 Private Car)

2) **R11 – R12 – INCREASE IN AVERAGE TIME NEEDED TO TRAVEL 3 km BY PUBLIC TRANSPORT/CAR ON REPRESENTATIVE ROUTES IN THE CITY/FUA DURING PEAK HOUR COMPARED TO OFF-PEAK**

Calculation	$$In_{av(mode\ i)} = \left(t_{peak_{av(mode\ i)}} / t_{offpeak_{av(mode\ i)}} - 1 \right) * 100\%$$ **Where:** • $In_{av(mode\ i)}$ **Increase in average time** • $t_{peak_{av(mode\ i)}}$ **Average travel time to 3km on the representative routes in the peak hour (e.g. morning rush hours)** • $t_{offpeak_{av(mode\ i)}}$ **Average travel time** to travel 3km on the representative routes **in the off-peak hour (e.g. hours with less traffic like mid-morning, late evening)**
Unit	% percentage
Note	This indicator measures the percentage increase in average time during peak hour compared to off-peak hours in the Metropolitan Area in a section of 3km. R8 Public transport/R9 Private Car

Additional considerations related to the selection of the representative routes for each metropolitan area that are mentioned in the definition of these indicators are reported in ANNEX A – Notes of the computation of the variables included in the UMI indicators in each metropolitan area.

5.5.1 Comparative Analysis

The Table 43 is presented results of the analysis of congestion level across the Metropolitan Areas of Turin, Valle de Aburrá and Cúcuta:

Table 43
Results of indicator R5, R6, R11 and R12 Increase in average time to travel 3 km by compared peak hour compared to off-peak hour

		Metropolitan Area		
Indicator		**Turin**	**Valle de Aburrá**	**Cúcuta**
R5	Increase in average time to travel 3km by public transport on representative routes in the city/FUA during peak hour compared to off-peak.	3 min	3 min	3 min
R6	Increase in average time to travel 3km by private car on representative routes in the city/FUA during peak hour compared to off-peak	2 min	4 min	2 min
R11	Increase in average time to travel 3km by public transport on representative routes in the city/FUA during peak hour compared to off-peak	9%	8%	10%
R12	Increase in average time to travel 3km by private car on representative routes in the city/FUA during peak hour compared to off-peak	9%	14%	8%

The congestion indicator reflects variations in average travel time between peak and off-peak hours for approximately 3 km distance representative routes between the Metropolitan Areas. Each of them presents different congestion patterns, reflecting different levels of transportation infrastructure, urban density and traffic management.

Public transport experiences the same congestion delays across the metropolitan areas. However, in Valle de Aburrá, the travel time increased from 34 minutes in off-peak hours to 37 minutes in peak hours representing an 8% of increase This could be a result of the topographic and fragmentation of the road networks as was described in Chapter 3.1.2 the metropolitan area is characterized by a variable slope due to is a valley territory.

Turin travel time changed from 29 to 32 minutes representing an increase of 9% and in Cúcuta the travel time varied from 34 to 31 minutes representing an increase of 10%. Turin is likely to benefit from a more developed transport infrastructure such as subway or dedicated bus lanes, which may mitigate congestion, in comparison of Cúcuta that do not have a formal public transportation system.

The congestion results for private cars Cúcuta shows a jump from 24 minutes off-peak to 26 minutes during peak hours, corresponding to an 8% increase. Car congestion in Turin presented a peak hour travel times increasing from 19 to 21 minutes, it means an increase of 9%. finally in the Valle de Aburrá passed from 27 to 31 minute that represented a 14%.

5.6 GREENHOUSE GAS EMISSION

The selected indicators of the fiche called "Greenhouse gas emission" (38) were:

1) **R1 – ANNUAL WELL-TO-WELL GHC EMISSIONS FROM ROAD TRANSPORT IN THE CITY/FUA PER INHABITANT**

Calculation	$G = C/P$ **Where:** • **C Annual Greenhouse Gas emission from the road transportation per inhabitant.** • **P Total Population**
Unit	tco2eq/Inh. per year

Note	This indicator measures the Annual CO2 equivalent emission produced by the road transportation in the Metropolitan Area.

2) R2 – R8 – R9 AVERAGE WELL-TO-WHEEL GHC EMISSION PER VEHICLE-KM OF PUBLIC TRANSPORT BUS/PRIVATE MOTORCYCLE/PRIVATE CAR VEHICLE STOCK

Calculation	$$APE^{mp} = \left(\sum_{k}\left(\sum_{fe} EF^{m}_{kfe} * \frac{V^{m}_{fe}}{\sum_{fe} V^{m}_{fe}} * (T_k + W_k)\right)\right) * 1000$$ **Where:** • EF^{m}_{kfe} **Energy specific consumption factor per vehicle-km by energy carrier by engine fuel and Emission standard.** • V^{m}_{fe} **Number of vehicles subdivided by the engine fuel and emission standard.** • T_k **Vehicle operation GHG emission factor.** • W_k **Vehicle energy GHG emission factor.**
Unit	g CO2eq/km
Note	This indicator measures the average CO_2 equivalent emission per each kind of vehicle in the Metropolitan Area. R2 Transport public buses/R8 Private Motorcycle/R9 Private Car

5.6.1 Comparative Analysis

Table 44 shows the results of the annual Greenhouse Gas Emission from road transport:

Table 44
Result indicator R1, Annual well-to-wheel GHC emissions from road transport in the metropolitan area per inhabitant per year

		METROPOLITAN AREA		
INDICATOR		**TURIN**	**VALLE DE ABURRÁ**	**CÚCUTA**
R1	Annual well-to-wheel GHC emissions from road transport in the city/FUA per inhabitant [t CO_2e/inh. per year]	1.50	0.70	0.53

Turin emission per inhabitant registered 1.50 (tCO_2e/inhabitant per year), which is higher than Valle de Aburrá with 0.70 (t CO_2e/inhabitant per year) and Cúcuta with 0.53 (tCO_2e/inhabitant per year), suggesting a greater individual environmental impact in the European metropolitan area, remembering that in Turin has the largest car fleet of the three-metropolitan area.

The analysis of the average Greenhouse Gas Emission from road transport across Metropolitan Areas of Turin, Valle de Aburrá and Cúcuta is reported in Table 44. In terms of average well-to-wheel per vehicle-kilometer, Valle de Aburrá shows the highest emission for public transport buses with 4.26 (t CO2e/km), followed by Cúcuta with 3.68 (t CO2e/km) and Turin with 3.55 (t CO2e/km). This may indicate that in the majority of Colombian cities have a potentially older public transport fleet, as described in the Sustainable Urban Mobility Plan of Valle de Aburrá were recalling the obsolescence of the service buses and low acquisition of electric vehicles due to their high acquisition costs (57 p. 29).

The motorcycle fleet, common in Colombian cities, also contributes significantly to emission. Valle de Aburrá again shows the highest emission per vehicle-kilometer 0.45 (t CO2e/km), followed by Cúcuta with 0.37 (t CO2e/km), and Turin with 0.31 (t CO2e/km). In terms of private cars, emissions vary by fuel type. For gasoline-powered vehicles, Valle de Aburrá stands out with the highest emissions with

1.05 (t CO2e/km), Cúcuta stands out with the second highest with 0.84 (t CO2e/km), and finally Turin again performs the best with 0.82 (t CO2e/km). Finally, diesel-powered cars also follow a similar trend, Valle del Cauca with 0.73 (t CO2e/km), Turin and Cucuta with 0.63 (t CO2e/km).

Table 45
Results of indicators R2, R8 and R9 - Average well-to-wheel GHC emission per vehicle-km of public transport bus/motorcycle/private car vehicle stock

Indicator		Turin	Valle de Aburrá	Cúcuta
R2	Average well-to-wheel GHC emission per vehicle-km of public transport bus stock [t CO2e/km]	3.55	4.26	3.68
R8	Average well-to-wheel GHC emission per vehicle-km of private motorcycle stock [t CO2e/km]	0.31	0.45	0.37
R9	Average well-to-wheel GHC emission per vehicle-km of private car powered by GASOLINE stock [t CO2e/km]	0.82	1.05	0.84
R9	Average well-to-wheel GHC emission per vehicle-km of private car powered by DIESEL stock [t CO2e/km]	0.63	0.73	0.63

Additionally compared Table 44 and Table 46 **Error! Reference source not found.**it can be seen that, although Turin has higher emissions per capita, it has a lower Greenhouse Gas emission intensity per vehicle kilometer, probably due to stricter emission regulations and technological advances. Valle de Aburrá, on the other hand, consistently has the highest emission per vehicle kilometer of all vehicle types, indicating the need for fleet modernization and clear fuel policies. Cúcuta has lower emissions but still faces challenges in terms of vehicle efficiency, especially in motorcycles. This comparative analysis highlights the importance of implementing strategies to reduce road transport emissions in metropolitan areas

5.7 ACCESS TO MOBILITY SERVICES

The selected indicators of the fiche called "Access to Mobility Services" (39) were:

1) **R1 – PUBLIC TRANSPORT STOPS WITH FEWER THAN 4/WITH 4 OR MORE SCHEDULED DEPARTURES PER HOUR PER 1,000 INHABITANTS**

Calculation	$$SPT_f^{station} = \frac{\sum_{i,m} PST_f^{stops}}{P} * 1000$$ **Where:** • PST_f^{stops} **Number of public transports stops (referring buses, trolleybuses, coaches, trams, light rails, waterbuses) with frequency f per 1,000 inhabitants** • P **Total Population**
Unit	# stops/1,000 inh
Note	This indicator measures the relationship between the number of public transport station and the population size of the Metropolitan Area.

2) **R3 – PUBLIC TRANSPORT STOPS WITH FEWER THAN 4/WITH 4 OR MORE SCHEDULED DEPARTURES PER HOUR PER km2**

Calculation	$$SPT_f^{station} = \frac{\sum_{i,m} PST_f^{station}}{A} * 1000$$

	Where: • $PST_f^{station}$ **Number of public transports stops (referring buses, trolleybuses, coaches, trams, light rails, waterbuses) with frequency f per 1,000 inhabitants** • A **Total area**
Unit	#stops/km^2
Note	This indicator measures the relationship between the number of public transport station and the area of the Metropolitan Area.

5.7.1 Comparative Analysis

Table 46 shows the results of access to mobility indicators:

Table 46
Access to mobility indicators R1 and R2

		METROPOLITAN AREA		
INDICATOR		**TURIN**	**VALLE DE ABURRÁ**	**CÚCUTA**
R1	Public transport stops with fewer than 4/with 4 or more scheduled departures per hour per 1,000 inhabitants [# stops/1,000 inh]	3.09	0.84	0.065
R3	Public transport stops with fewer than 4/with 4 or more scheduled departures per hour per km^2 [# stops/km^2]	1.02	2.76	0.029
Note: Public transport stops include only: urban and suburban buses and trams.				

In terms of access to mobility, significant discrepancies are observed between the metropolitan area of Turin, Valle de Aburrá and Cúcuta. Turin records 3.09 public transport stops per 1,000 inhabitants, outperforming Valle de Aburrá with 0.84 and Cúcuta with only 0.065 stops per 1,000 inhabitants. This indicates a more widespread and accessible transport system network for their population. However, when analyzing stops per square kilometers, Valle de Aburrá leads with 2.76 stops/km^2, followed by Turin with 1.02 stops/km^2 influenced by its larger geographic area (6,829.98 km2 compared to Valle de Aburrá 1,166.91 km2). Cúcuta remains the least in both measures, with 0.029 stops/km^2. These results suggest that Turin offers a more robust and uniform distributed public transport infrastructure relative its population, while the Valle de Aburrá is more spatially concentrated, possibly the public transport services are concentrated in urban areas.

In Valle de Aburrá, the lower density of stops per inhabitants can be attributed to its larger population in the metropolitan area, also less dense distribution of station, and parts of the public transport system are operated by different traditional companies that complete the system but the lack of dedicated station infrastructure affected the stations inventory in the metropolitan area. One positive point is, the system offers high-frequency services, with intervals of less than 6 minutes during peak hour on most routes (76).

In contrast, Cúcuta presents a more informal transport model, there is no official inventory of transport stations, since the existing routes operate in a flexible manner, stopping at the request of passengers. This lack of an integrated and regulated system, which is currently being structured, limits the possibility of offering an organized service. Despite the low values in the indicator, it is important to note that public transport is still one of the most modes of transport use in daily commuting. Furthermore, Cúcuta highlights a limitation of the UMI “Accessibility to Mobility Service” indicator, which does not consider the informal transport systems, as calculations are practically negligible.

5.8 ASSESSING THE URBAN MOBILITY INDICATORS WITHIN THE THREE CASE STUDIES

5.8.1 Alignment between SUMP and UMI indicators

Table 47 represents a comparison between the Urban Mobility Indicators UMI provided by the European Commission and those included in the Sustainable Urban Mobility Plan (SUMPs) of the considered metropolitan areas. The evaluation is based on the level of alignment with the UMI framework:

☑ indicates that the indicator used in the metropolitan area is fully aligned with the UMI framework.

⚠ indicates that the indicator is partial alignment.

🛇 indicates that the indicator is either not aligned or is absent from the plan.

Table 47

Comparison of UMI Indicators with planted indicators in each metropolitan area

	UMI INDICATORS	UNITS	TURIN	VALLE DE ABURRÁ	CÚCUTA
CRASHES AND INJURIES	**R1** – Number of persons fatally injured in road crashes while walking or cycling in the city/FUA	[#persons]	☑	☑	☑
	R2 – Number of persons injured in road crashes while walking or cycling in the city/FUA	[#persons]	☑	☑	☑
	R3 – Number of persons fatally injured in road crashes while walking or cycling in the city/FUA per million walking cycling trips per year	[# persons per million trips]	☑	☑	☑
	R4 – Number of persons injured in road crashes while walking or cycling in the city/FUA per million walking cycling trips per year	[# persons per million trips]	☑	☑	☑
	R5 – Number of persons fatally injured in road crashes in the city/FUA per year per 100000 inhabitants per year	[# persons per 100 thousand inhabitants]	☑	☑	☑
	R9 – Number of persons injured in road crashes in the city/FUA per 100 000 inhabitants per year	[# persons per 100 thousand inhabitants]	☑	☑	☑
MODAL SHARE	**R1** – Share of city/FUA inhabitant trips done by walking, cycling or public transport	[% total trips]	☑	☑	☑
	R2 – Share of modes in total city/FU inhabitant trips	[% total trips]	☑	☑	☑
	R3 – Share of modes in city/FUA inhabitant trips to and from a workplace	[% total trips]	☑	☑	☑
	R4 – Share of modes in city/FUA inhabitant trips to and from a school	[% total trips]	☑	☑	☑
	R5 – Share of modes in city/FUA inhabitant trips to and from a shop	[% total trips]	☑	☑	☑
NOISE POLLUTION	**R1** – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=55 dB due to road transport	[% of inhabitants]	⚠	⚠	🛇
	R2 – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=55 dB due to rail transport	[% of inhabitants]	⚠	🛇	🛇
	R4 – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=60 dB due to road transport	[% of inhabitants]	⚠	⚠	🛇

	UMI INDICATORS	UNITS	TURIN	VALLE DE ABURRÁ	CÚCUTA
	R5 – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=60 dB due to rail transport	[% of inhabitants]	⚠	🚫	🚫
	R7 – Percentage of population of the city/FUA exposed to nighttime (Lden) noise >=50 dB due to road transport	[% of inhabitants]	⚠	⚠	🚫
	R8 – Percentage of population of the city/FUA exposed to nighttime (Lden) noise >=50 dB due to rail transport	[% of inhabitants]	⚠	🚫	🚫
AIR POLLUTION	**R1** – Number of days per year where the daily PM10 concentration exceeded the WHO recommended level of 45 µg/m3 at any traffic-oriented sampling point in the city/FUA	[Number of days]	✅	⚠	⚠
	R2 – Number of traffic-oriented sampling points where the annual mean concentration of PM2.5 exceeded the WHO recommended level of 35 µg/m3 in the city/FUA	[Number of stations]	✅	⚠	⚠
	R3 – Number of hours per year where the hourly NO2 concentration exceeded the WHO recommended level of 200 µg/m3 at any traffic-oriented sampling point in the city/FUA	[Number of hours]	✅	🚫	🚫
	R4 – Average pollutant emission per vehicle-km related to NO2 eq. of public transport bus vehicle stock	[g/km]	⚠	⚠	⚠
	R5/R6 – Average pollutant emission per vehicle-km related to PM2.5/PM10 of public transport bus vehicle stock	[g/km]	⚠	⚠	⚠
	R22 – Average pollutant emission per vehicle-km related to NO2 eq. of private motorcycle vehicle stock	[g/km]	⚠	⚠	⚠
	R23/R24 – Average pollutant emission per vehicle-km related to PM2.5/PM10 of private motorcycle vehicle stock	[g/km]	⚠	⚠	⚠
	R25 – Average pollutant emission per vehicle-km related to NO2 eq. private car vehicle stock (GAS)	[g/km]	⚠	⚠	⚠
	R25 – Average pollutant emission per vehicle-km related to NO2 eq. private car vehicle stock (DIESEL)	[g/km]	⚠	⚠	⚠
	R26/R27 – Average pollutant emission per vehicle-km related to PM2.5/PM10 of private car vehicle stock (GAS)	[g/km]	⚠	⚠	⚠
	R26/R27 – Average pollutant emission per vehicle-km related to PM2.5/PM10 of private car vehicle stock (DIESEL)	[g/km]	⚠	⚠	⚠
CONGESTION	**R5** – Increase in average time to travel 3 km by public transport on representative routes in the city/FUA during peak hour compared to off-peak	[minute]	⚠	⚠	⚠
	R6 – Increase in average time to travel 3 km by car on representative routes in the city/FUA during peak hour compared to off-peak	[minute]	⚠	⚠	⚠
	R11 – Increase in average time needed to travel 3 km by public transport on representative routes in the city/FUA during peak hour compared to off-peak	[percentage]	⚠	⚠	⚠
	R12 – Increase in average time needed to travel 3 km by car on representative routes in the city/FUA during peak hour compared to off-peak	[percentage]	⚠	⚠	⚠
GHC EMISSIONS	**R1** – Annual well-to-well GHC emissions from road transport in the city/FUA per inhabitant	[t CO2e/inh. per year]	✅	✅	✅
	R2 – Average well-to-wheel GHC emission per vehicle-km of public transport bus vehicle stock	[t CO2e/km]	⚠	⚠	⚠
	R8 – Average well-to-wheel GHC emission per vehicle-km of private motorcycle vehicle stock	[t CO2e/km]	⚠	⚠	⚠

	UMI INDICATORS	UNITS	TURIN	VALLE DE ABURRÁ	CÚCUTA
	R9 – Average well-to-wheel GHC emission per vehicle-km of private car vehicle stock (GASOLINE)	[t CO2e/km]	⚠	⚠	⚠
	R9 – Average well-to-wheel GHC emission per vehicle-km of private car vehicle stock (DIESEL)	[t CO2e/km]	⚠	⚠	⚠
ACCESS TO MOBILITY	**R1** – Public transport stops with fewer than 4/with 4 or more scheduled departures per hour per 1,000 inhabitants	[# station/1,000 inh]	☑	☑	🚫
	R3 – Public transport stops with fewer than 4/with 4 or more scheduled departures per hour per km2	[# station/km2]	☑	☑	🚫

Below is a description of how the indicators proposed by each metropolitan area align with the indicators proposed by the UMI framework:

Metropolitan Area of Turin:
The Sustainable Urban Mobility Plan outlines strategies consisting of different actions, which, although featuring different indicators than those proposed in the UMI fiches, show a high alignment with the UMI framework, this reflects clear integration into the European Union's urban mobility policy.

- **Crashes and Injuries:** These indicators have baseline value included in the plan. Furthermore, the action plan includes indicators aim at reducing the risk of accidents and exposure to risk, special for vulnerable users, and promote a culture of sustainable mobility.
- **Modal Split:** These indicators also have baseline value in the plan. Strategies such as integration of transport systems, development of collective mobility, and the enhancement of pedestrian and cycling infrastructure aim to create equitable integration of all transport systems, focused on reducing car use and increasing active mobility.
- **Pollutants and Greenhouse gas emissions:** Although not all indicators are detailed in the format as the UMI framework, sufficient data is provided to allow for their calculation. A positive point is that these indicators are continuously monitored by a public authority. Through renewal of the fleet park introduce vehicles with low polluting vehicles and high energy efficiency, according to the Legislative Decree 2014/94 EU. These actions are modeled within the plan scenario and evaluated according in line with European Union standards. The measure of the reduction of noise and air pollutants and emissions are evaluated in the plan scenario based on regulatory frameworks.
- **Congestion**: Data from household survey made it possible to calculate the indicators but were not comprehensive enough to assess the real situation in the throughout corridor. Actions such as integration of transport systems and the development of collective mobility, aim to increase the commercial speed of public transport and regulate individual mobility. The estimated reduction in congestion is evaluated through plan scenario model.
- **Accessibility:** Baseline values for accessibility indicators are included. The plan details public transport system coverage and incorporate strategies to improve the accessibility of public transport for all users, especially those with reduced mobility. Efforts also focus on enhancing service quality.

Metropolitan Area of Valle de Aburrá:
The Sustainable Urban Mobility Plan emphasizes strong regional integration. Several programs with specifics milestones have been formulated to establish an efficient mobility system centred on public transport system and active modes.

- **Crash and Injuries:** These indicators have baseline values included in the plan and are continuously monitored by public authorities. They are central to the program called "Respect Life", which aims to reduce road fatalities and make road safety a key pillar of mobility policy.

- **Modal Split:** Baseline values for these indicators are included in the plan. Some programs propose increasing the share of trips made by active modes and enhancing public transport as a high-quality travel option for all residents.
- **Pollutants and Greenhouse gas emissions:** While not all indicators are detailed in the same format, sufficient data is available for calculations, and the indicators are continuously monitored by a public authority. However, key gaps exist, for example, a complete vehicle stock inventory is lacking, and the evaluation of noise pollution is insufficient. Several projects address the renovation of freight transportation systems and the efficient use of transport infrastructure to reduce environmental pollution. Nevertheless, although most of the project aims to reduce emissions, no concrete measures or indicators have been defined to evaluate during the time the efficiency of the programs.
- **Congestion:** Data from household survey made it possible to calculate the indicators but were not comprehensive enough to assess the real situation in the throughout corridor. Programs promoting equitable infrastructure focuses for all users to make efficient use of the road network. Goals include reducing road congestion by increasing the average occupancy rate of private vehicles and improving the traffic flow on the road network.
- **Accessibility:** These indicators are included as baseline values or can be derived from available public data. The Option for all program seeks to improve the physical accessibility and spatial coverage of the public transport system, ensuring availability for the entire metropolitan population.

Metropolitan Area of Cúcuta:
The Sustainable Urban Mobility Plan presents some strategies lines to support sustainable development across the metropolitan area.

- **Crash and Injuries:** These indicators are included with baseline values and are continuously monitored by public authorities. Road safety management forms part of the strategic line, with a particular emphasis on non-motorized and public transportation. The Vision Zero program is one of the most important initiatives, establishing actions to reduce accidents and promote safe behaviour.
- **Modal Split:** These indicators are either directly included or can be derived from available data reported in the SUMP. One of their programs recognizes mobility as a citizen's right and gives priority non-motorized and public transport. It envisions a mobility system where pedestrians and cyclists are prioritized, alongside the development of an integrated transportation system.
- **Pollutants and Greenhouse gas emissions:** These indicators are either included as baseline values or can be derived from public data. However, a notable limitation is the absence of data on noise pollution. Projects, like Intelligent Transportation, aim to create an efficient and low-emission transport system. Despite this, no specific indicators have been defined to quantify emissions reduction.
- **Congestion:** Data from household survey made it possible to calculate the indicators but were not comprehensive enough to assess the real situation in the throughout corridor. The Safe Mobility Management program seek to reduce congestion resulting from undefined road spaces, unauthorized parking, lack of proper cycling infrastructure, and the absence of preferential lanes for public transport.
- **Accessibility:** indicates that the indicator is either not aligned or is absent from the plan., given the metropolitan currently lacks an integrated transportation system, plans are in place to provide a sustainable, accessible and affordable collective transport services.

This analysis demonstrates that the Urban Mobility Indicators framework offers a valuable reference for standardized urban mobility monitoring. The level of alignment across the three metropolitan areas varies depending on regional context and data availability. The Sustainable Urban Mobility Plan of Turin is closely aligned with the UMI framework and benefits from a well-structured data environment, showing strong integration with European Union mobility policy.

In contrast, while Valle de Aburrá and Cúcuta show partial alignment with the UMI framework, especially in safety and modal split indicators, there is pressing need for improving in environmental monitoring and emission data collection. These metropolitan areas show a strong commitment to developing accessible, inclusive and sustainable transport systems, with an emphasis on reducing on private motorized mobility.

To ensure comparability while respecting local context, metropolitan areas should consider adopting a core set of standardized indicators, such as those defined by the UMI framework, complemented by locally metrics that address specific challenges and policy objectives.

5.8.2 Easiness of computing UMI with the available data and information gaps

The computation of Urban Mobility Indicators (UMI) within the considered metropolitan area of Turin, Valle de Aburrá and Cúcuta, shows different levels of feasibility, influenced by data availability, institutional capacity and existing monitoring practices.

In Turin, the calculation of UMI indicator was a relatively simple process due to the presence of a structured data system, historical monitoring, and compliance with European regulations. The existing IMQ2013 survey, data published in the SUMP document with its respective annexes, data sets from public authorities, and air quality and noise monitoring networks provide comprehensive data to assess UMI indicators.

Valle de Aburrá and Cúcuta metropolitan areas present some shortcomings in terms of data collection. Although several indicators, especially those related to modal share and crashes and injuries, were calculated by reliable data collected through monitoring that was carried out by public authorities, the data differed from some of the UMI guidelines, requiring adaptation, as for example noise quality measurement data.

Below is a summary of these key points of available data and information gaps in each indicator are presented:

Crashes and Injuries: The data required for computing indicators related to fatalities injured in road crashes were available across all three metropolitan areas. However, none of the areas explicitly classifies seriously injured according to WHO description, consequently, the "seriously injured" indicator was calculate using the total number of injured persons.

Modal Split: The computation of modal share indicators was feasible for all case studies, thanks to the availability of household travel surveys. These surveys provided reliable data on the number and purpose of trips, disaggregated by mode, enabling the calculation of indicators related to total trips related to workplace, school and shops.

Noise Pollution: A major limitation in the metropolitan areas in Colombia was the lack of continuous noise pollution monitoring by environmental authorities. In Valle de Aburrá, the most recent available noise map dates were in 2015, without updates identified. In Cúcuta measurements were not found. Despite this gap, the SUMPs of both Valle de Aburrá and Cúcuta highlighted the importance of monitoring transport related noise and recognize it as a pending institutional task. In contrast, in Turin the noise level is continuously monitored by the European Environment Agency.

Air Pollution and GHC Emissions: Computing air pollutions and greenhouse gas emissions indicators encountered some challenges, particularly in Valle de Aburrá, where there was no complete classification of vehicle technologies by emissions standards of fuel types. In contrast, Turin and Cúcuta include such classifications in their SUMPs, although the classification in Cúcuta was not fully clear or standardized. Additionally, in Cúcuta, the environmental authority data related to pollutants and emissions remains poorly consolidated, which limits the computation of the related indicators.

Congestion: The congestion indicators were calculated using origin-destination (O/D) matrices that identified trips meeting the 3 km length the indicator requirement.

Accessibility to Mobility Services: In Turin and Valle de Aburrá, data on public transport stations and service frequency made it possible to compute accessibility indicators. However, in Cúcuta, no official data existed on bus stops infrastructure, given the lack of integrated transport system. As such, the indicator fails to account for informal public transport services. Nevertheless, Cúcuta SUMP indicated that the development of a structured system is underway.

Additionally, it is essential to consider the level of data reliability, and the assumptions made for the computation of the UMI indicators:

1. **High reliable indicators:**
   a. **Modal split:** Data obtained from detailed mobility surveys in the three metropolitan areas.
   b. **Serious fatality rates in traffic crashes**: Data taken directly from the SUMPs documents and official transport statistics in the three metropolitan areas.
2. **Moderately reliable indicator due to assumptions:**
   a. **Seriously injured people:** In the three metropolitan areas, were assumed equivalence between general injuries and serious injuries based on the official reports.
   b. **Air pollution:** Calculations were based on reported environmental data in the SUMPs and local authorities, but vehicle classification was incomplete in Valle de Aburrá and Cúcuta, which led assumptions of standard emission factor.
   c. **Congestion:** Travel time estimations relied on origin-destination surveys, lacking validations against real – time measurements.
3. **Less Reliable Indicators due to missing data:**
   a. **Noise pollution:** In the metropolitan area of Valle de Aburrá and Cúcuta does not have continuous noise monitoring.
   b. **Accessibility:** Cúcuta does not have formal inventory of transport stops, impacting calculation accuracy.
4. **Key assumptions:**
   a. The special assumptions are listed in the tables presented in the ANNEX A – Notes of the computation of the variables included in the UMI indicators in each metropolitan area.

Finally, some of the challenges faced by calculating the indicators were as follows:

a. **Indicator standardization:** The absence of uniform methodologies across cities complicates direct comparisons. Differences in definition, data collection techniques, and reporting standards can create inconsistencies.
b. **Limited continuous data:** The Colombian metropolitan areas have gaps in historical datasets or fragmented data collections, which do not allow a good monitoring process of these indicators.
c. **Environmental and Congestion Metrics:** Noise, air pollution, greenhouse gas emissions, and congestion require specialized and real-time monitoring, which are underdeveloped special in the Colombian metropolitan areas.

5.8.3 *Recommendations to embed UMI in the SUMP monitoring process of the considered case studies*

In order to integrate the Urban Mobility Indicators (UMI) into the SUMPs monitoring process of the metropolitan areas of Turin, Valle de Aburrá and Cúcuta, the following recommendations can be proposed based on the recommendations planted in the European Guidelines for Developing and Implemented a SUMPs (11 pp. 67-70, 95-102, 121-124, 153-158):

1. **Embed UMI performance evaluations systems:** Integrate UMI into the sustainability evaluation frameworks of the SUMPs by aligning local indicators with the UMI methodology by adopting a common definition terminology, units of measurement, and calculation methods, in order to track the progress of each strategy planned in the SUMP.

2. **Strengthen data collection:** The development of standardized and systematic data collection methods will ensure the feasibility of calculating UMI such as improved air quality and noise pollution monitoring infrastructure, especially in Colombia, where continuous data is often lacking. Other possible data collection could include GPS-based traffic congestion data to provide a more accurate travel time assessment.

3. **Enhancing public accessibility to mobility data:** Develop open platforms or dashboards for sharing with researchers, policymakers, stakeholders and citizens the UMI metrics, allowing comparison of data between different metropolitan areas.

4. **Improve informality in accessibility metrics:** Expand UMI methodology to recognize and incorporate the informal transport system in the evaluations. Additionally, it is recommended that a definition about what is a representative route is provided by the framework, so that the indicator does not have different interpretations.

5. **Integration of monitoring:** Authorities should train all professionals involved in the monitoring progress of the SUMP, about UMI methodologies and data collection techniques, additionally define a baseline assessment and create a monitoring plan with the frequency of measurements (usually 1 and 2 years) and assign clear responsibilities across each government entity for data collection, reporting and analysis for each indicator.

6. **Institutional collaboration:** Promote partnerships with universities, research institutions, and the private sector to support data collection, analysis, and monitoring. This collaboration can improve the technical quality of these measurements.

Table 48 presents specifications and operational considerations for the three case studies, which can be used for the computation of the indicators during the SUMP monitoring process that complement the recommendations described above.

Table 48
Specification and operational consideration for the three case studies

CRASHES AND INJURIES	
R1 – Number of persons fatally injured in road crashes while walking or cycling in the city/FUA **R3 –** Number of persons fatally injured in road crashes while walking or cycling in the city/FUA per million walking cycling trips per year **R5 –** Number of persons fatally injured in road crashes in the city/FUA per year per 100000 inhabitants per year	
Turin	The available data was enough to compute the indictor.
Valle de Aburrá	

Cúcuta	
R2 – Number of persons injured in road crashes while walking or cycling in the city/FUA **R4 –** Number of persons injured in road crashes while walking or cycling in the city/FUA per million walking cycling trips per year **R9 –** Number of persons injured in road crashes in the city/FUA per 100 000 inhabitants per year	
Turin	It is important to note that road crash data are reported by ISTAT. If it is necessary to compute the indicator as is expressed in the fiche in terms of the severity of the injuries, it is recommendable include a segregation of the level of injury in the data collection and reporting.
Valle de Aburrá	In the case of Colombian metropolitan areas, DITRA is the primary entity responsible for producing road crashes reports. If it is necessary to compute the indicator as is expressed in the fiche in terms of highest severity injuries, these should include a classification of the severity of each injury and should be cross-referenced with hospital reports to verify that the final reports are reliable.
Cúcuta	
MODAL SHARE	
R1 – Share of city/FUA inhabitant trips done by walking, cycling or public transport **R2** – Share of modes in total city/FU inhabitant trips **R3** – Share of modes in city/FUA inhabitant trips to and from a workplace **R4** – Share of modes in city/FUA inhabitant trips to and from a school **R5** – Share of modes in city/FUA inhabitant trips to and from a shop	
Turin	The household travel data was enough to compute the indicator. As recommended in the SUMP guidelines (2019) and illustrated by the good practice example of Malmö city (11 p. 77). It is advisable to update travel survey every five year and conduct traffic counts twice a year to effectively monitor and verify the travel trends
Valle de Aburrá	
Cúcuta	
NOISE POLLUTION	
R1 – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=55 dB due to road transport **R4** – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=60 dB due to road transport **R7** – Percentage of population of the city/FUA exposed to nighttime (Lden) noise >=50 dB due to road transport	
Turin	The report data presented by European Environmental Agency was enough to compute the indicator, however, this data only included the city of Turin, if possible, the report could be expanded to include the whole metropolitan area. Additionally, as is expressed in the Article 7 of Directive 2002/49/EC relating to the assessment and management of environmental noise, strategic noise maps must be updated every five years (77 p. 4).
Valle de Aburrá	The metropolitan area can implement the EU Directive 2002/49/EC described for Turin, as the strategic noise map for Valle de Aburrá dates to 2017. Additionally, is recommended to implement a noise continuous monitoring network across the metropolitan area.
Cúcuta	Conduct initial strategic noise maps for agglomerations with more than 250,000 inhabitants and for all major roads which have more than six million of vehicle passages a year, in accordance with Article 7 of EU Directive 2002/49/EC. Additionally, is recommended to implement a noise continuous monitoring network across the metropolitan area.
R2 – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=55 dB due to rail transport **R5** – Percentage of population of the city/FUA exposed to day-evening-night (Lden) noise >=60 dB due to rail transport **R8** – Percentage of population of the city/FUA exposed to nighttime (Lden) noise >=50 dB due to rail transport	

Turin	The reported data presented by European Environmental Agency was enough to compute the indicator.
Valle de Aburrá	The metropolitan area does not have rail network. The metro system can initiate continuous data collection at its stations based on operational schedules.
Cúcuta	In the metropolitan area does not have rail or metro network.
AIR POLLUTION	
R1 – Number of days per year where the daily PM10 concentration exceeded the WHO recommended level of 45 µg/m3 at any traffic-oriented sampling point in the city/FUA **R2** – Number of traffic-oriented sampling points where the annual mean concentration of PM2.5 exceeded the WHO recommended level of 35 µg/m3 in the city/FUA **R3** – Number of hours per year where the hourly NO2 concentration exceeded the WHO recommended level of 200 µg/m3 at any traffic-oriented sampling point in the city/FUA	
Turin	The report data presented by ARPA PIEMONTE and SUMP reports were enough to compute the indicator. Maintain monitoring network, ensuring at least the following minimum number of sampling points if concentration exceeded the limit values: six for NO_2, four for PM_{10} and $PM_{2.5}$, according to the population and the recommendation presented in the Annex III of EU Directive 2024/2881 (78 p. Annex III).
Valle de Aburrá	The report data presented by Metropolitan Area of Valle de Aburrá was enough to compute the indicator. Maintain monitoring network, ensuring at least the following minimum number of sampling points if concentration exceeded the limit values: eight for NO_2, five for PM_{10} and six for $PM_{2.5}$, according to the population and recommendation presented in the Annex III of EU Directive 2008/50/EC (78 p. Annex III). , as Resolution 2254 de 2017 (79) from Colombian Ministry of Environment does not specify the minimum number of sampling points for these measurement.
Cúcuta	The report data presented by CORPONOR was enough to compute the indicator. Maintain monitoring network, ensuring at least the following minimum number of sampling points if concentration exceeded the limit values: three for NO_2, two for PM_{10} and $PM_{2.5}$, according to the population and recommendation presented in the Annex III of EU Directive 2008/50/EC (78 p. Annex III), as Resolution 2254 de 2017 (79) from the Colombian Ministry of Environment does not specify the minimum number of sampling points for these measurement.
R4 – Average pollutant emission per vehicle-km related to NO2 eq. of public transport bus vehicle stock **R5/R6** – Average pollutant emission per vehicle-km related to PM2.5/PM10 of public transport bus vehicle stock **R22** – Average pollutant emission per vehicle-km related to NO2 eq. of private motorcycle vehicle stock **R23/R24** – Average pollutant emission per vehicle-km related to PM2.5/PM10 of private motorcycle vehicle stock **R25** – Average pollutant emission per vehicle-km related to NO2 eq. private car vehicle stock (GAS) **R25** – Average pollutant emission per vehicle-km related to NO2 eq. private car vehicle stock (DIESEL) **R26/R27** – Average pollutant emission per vehicle-km related to PM2.5/PM10 of private car vehicle stock (GAS) **R26/R27** – Average pollutant emission per vehicle-km related to PM2.5/PM10 of private car vehicle stock (DIESEL)	

<table>
<tr><td>Turin</td><td>Specific emission factor data missing specific for the metropolitan area; however, the indicator were easily computed with the factors provided in the EMEP/EEA guidelines.</td></tr>
<tr><td>Valle de Aburrá</td><td rowspan="2">Specific emission factor data missing specific for the metropolitan area; however, the indicator were easily computed with the factors presented in the EMEP/EEA guidelines. Additionally, it is recommended to maintain updated fleet composition data, including vehicle age, fuel type, technology, in the national transport data system.</td></tr>
<tr><td>Cúcuta</td></tr>
<tr><td colspan="2">CONGESTION</td></tr>
<tr><td colspan="2">R5 – Increase in average time to travel 3 km by public transport on representative routes in the city/FUA during peak hour compared to off-peak
R11 – Increase in average time needed to travel 3 km by public transport on representative routes in the city/FUA during peak hour compared to off-peak</td></tr>
<tr><td>Turin</td><td rowspan="3">The data from household survey was useful to compute the indicator.
However, if the operators of the public transport periodically collect data of the trip duration in the whole transport network and the representative routes, would be useful to validate travel times with real time measurements.</td></tr>
<tr><td>Valle de Aburrá</td></tr>
<tr><td>Cúcuta</td></tr>
<tr><td colspan="2">R6 – Increase in average time to travel 3 km by car on representative routes in the city/FUA during peak hour compared to off-peak
R12 – Increase in average time needed to travel 3 km by car on representative routes in the city/FUA during peak hour compared to off-peak</td></tr>
<tr><td>Turin</td><td rowspan="3">The data from household survey was useful to compute the indicator.
However, continuous and periodic data collection of trip durations across the complete transport network and the representative routes should be done. This information could be obtained from vehicles equipped with tracking devices or from share mobility vehicles, providing valuable real time metrics. For example, using OBD devices to collect trip distance and durations would help validate the data (80).</td></tr>
<tr><td>Valle de Aburrá</td></tr>
<tr><td>Cúcuta</td></tr>
<tr><td colspan="2">GHC EMISSIONS</td></tr>
<tr><td colspan="2">R1 – Annual well-to-well GHC emissions from road transport in the city/FUA per inhabitant</td></tr>
<tr><td>Turin</td><td>The report data presented by ARPA PIEMONTE and SUMP reports were enough to compute the indicator.
Ensuring that all data is annually updated of the Annual CO_2-equivalent emissions from road transport.</td></tr>
<tr><td>Valle de Aburrá</td><td>The report data presented by Metropolitan Area of Valle de Aburrá was enough to compute the indicator.
Ensuring that all data is annually updated of the Annual CO_2-equivalent emissions from road transport.</td></tr>
<tr><td>Cúcuta</td><td>The report data presented by CORPONOR was enough to compute the indicator.
Ensuring that all data on annual CO_2-equivalent emissions from road transport are updated every year.</td></tr>
<tr><td colspan="2">R2 – Average well-to-wheel GHC emission per vehicle-km of public transport bus vehicle stock
R8 – Average well-to-wheel GHC emission per vehicle-km of private motorcycle vehicle stock
R9 – Average well-to-wheel GHC emission per vehicle-km of private car vehicle stock (GASOLINE)
R9 – Average well-to-wheel GHC emission per vehicle-km of private car vehicle stock (DIESEL)</td></tr>
<tr><td>Turin</td><td rowspan="3">Specific emission factor data missing specific for the metropolitan area; however, the indicator were easily computed with the factors provided in the EMEP/EEA guidelines.
Ensuring that fleet registration data, and the fuel consumption with the national fuel sales data are annually updated</td></tr>
<tr><td>Valle de Aburrá</td></tr>
<tr><td>Cúcuta</td></tr>
<tr><td colspan="2">ACCESS TO MOBILITY</td></tr>
</table>

R1 – Public transport stops with fewer than 4/with 4 or more scheduled departures per hour per 1,000 inhabitants **R3** – Public transport stops with fewer than 4/with 4 or more scheduled departures per hour per km2	
Turin	Data presented in the GTT and Moovit app were enough to compute the indicator. The possible recommendation is to update data on these websites for periodic calculations. Additionally, a unique list of the total stops should be published as the calculations were made based on the stops that appears on each route.
Valle de Aburrá	Data presented in the SITVA and Moovit app were enough to compute the indicator. The possible recommendation is to update data on these websites for periodic calculations. Additionally, a unique list of the total stops should be published as the calculations were made based on the stops that appears on each route.
Cúcuta	The indicator could not be computed because the metropolitan area transport system is informal, and there is not an inventory of the transport stops. However, with the implementation of the new integrated transport system currently under development, it will be possible to obtain the necessary data for its calculation.

VI. CONCLUSION

This chapter provides the thesis conclusions in relation to the use of the EU Urban Mobility Indicators (UMIs) as an instrument for evaluating and monitoring the implementation of Sustainable Urban Mobility Plans (SUMPs) in different urban contexts, focusing on a comparative case study of the Metropolitan Areas of Turin (Italy), Valle de Aburrá and Cúcuta (Colombia), based on theoretical foundations, household survey data, and SUMPs documentation, determining the feasibility and adaptability of UMIs to support the SUMP monitoring process.

Sustainability Urban Mobility Plans (SUMPs)
The European Union has developed SUMPs embedded in a paradigm shift from traditional transport planning towards sustainable urban mobility planning prioritizing accessibility, environmental quality and public health. All three cases studies presented different SUMP structures, local dynamics, and levels of institutional consolidation, with shared common goals like reducing private motorized vehicles dependency, improving safety and strengthening the interaction between active and public transport modes.

The univariate and bivariate analysis of household survey data provided a fundamental understanding of mobility behavior in the Metropolitan Areas, showing how demographic, geographic and infrastructure factors affect urban mobility patterns. These analyses exposed variations attributes such as age, gender, vehicle ownership, the influence of local geography on modal choice, and the connection between trip purpose and transport preference.

From this assessment, Turin demonstrated higher car ownership and shorter trip durations, mainly influenced by its economic development degree, aging population and consolidated transport infrastructure. Valle de Aburrá exhibited strong commitment to public and active transport modes, supported by a relatively young and working age population. Cúcuta, on the other hand, reflected lower car ownership and high use of motorcycle, with informal mobility system that playing an important role in daily travel. These statistical insights proved essential data for calculating UMIs and highlighted the contextual realities to which each SUMP must respond. Additionally, the analysis reinforced the importance of evidence-based planning, helping to identify mobility strategies to meet the specific needs, behaviors and limitations faced by each metropolitan area.

Applicability of EU Urban Mobility Indicators (UMIs)
Regarding the EU UMIs, they provide a comprehensive and standardized framework for assessing sustainability, accessibility, safety and environmental outcomes planned in the SUMPS. Their structure allows metropolitan areas to monitor progress, identify policy gaps, potentially mobility future issues, and make strengthening data adjustments. Particularly in Turin, these indicators are almost already embedded into the existing monitoring system and benefit from rich data and institutional capacity. In Colombia, while metropolitan areas like Valle de Aburrá and Cúcuta have adopted the SUMP model guided by national regulations, the UMI framework could not yet be fully implemented.

The evaluation of the UMI indicators revealed that modal share and crash and injuries indicators were the most universally applicable, while challenges in noise and emission monitoring underscore the need for expanded sensor networks, especially in the Colombian metropolitan areas. The embedding of UMIs into Colombian SUMP framework would be possible through the alignment of national instruments or by strengthening institutionalization in order to obtain high data quality. Moreover, the UMIs should be flexibles and context sensitivity should be improved, for example in aspects like informal transport systems, common in Latin America, to be sure not exclude measurement and planning strategies regarding this aspect.

Best Practices and learning opportunities:

The thesis identified some best practices to strengthen SUMPs through UMI based monitoring:

1. **Structured cyclical planning models:** Turin's SUMP exemplifies a structured cyclical planning model, enabling continuous improvement, this long-term approach ensures periodic plan updates, based on monitoring results, contrary in Valle de Aburrá and Cúcuta, where planning cycles is linear and less adaptive to changes.
2. **Advanced transport modelling for planning scenario:** Turin applied sophisticated transport models to build multiple futures scenarios, including policy choices, strategies and actions to improve mobility and test whether they are effective. In contrast, while Valle de Aburrá and Cúcuta show planned results across different time horizons, which are necessary milestones to fully meet the stated objectives all based on transport models that had limited simulations. This represents a major learning opportunity to develop capacity in advanced modelling to inform and evaluate strategic priorities.
3. **Multimodal integration:** Turin prioritized modal integration by joining public transport, cycling and walking networks, and shared mobility system to reduce car dependency. Valle de Aburrá showed progress through the integration of public transport system with active mobility polices, while Cúcuta remains in early stages of multimodal transport system design. Learning opportunities focus on formalizing multimodal connectivity where sustainable mobility options play the crucial role in daily trips.
4. **Low-emission fleet:** Regarding Turin, included the procurement of electric buses through public-private partnerships as this approach helps to the process of decarbonization while involving moderate inversion costs. Valle de Aburrá and Cúcuta should explore similar models such as the Turin one to strengthen their goals of reducing urban transport emissions and improve air quality.
5. **Embedding UMIs within SUMP cycle:** Using UMIs within the SUMP cycle allows for improvements against emerging mobility challenges.
6. **Indicator-informed decision making:** Indicators such as modal share, congestion and accessibility are used to guide urban mobility decisions, a practice that metropolitan areas can strengthen to reduce car dependency and emissions.
7. **Institutional collaboration:** Effective UMI implementation requires agency collaboration, in order avoid the limitation of data availability, quality, or urban characteristics. Improving institutional coordination remains critical for development in Colombian metropolitan areas.

Finally, this comparative analysis has shown that despite varying levels of institutional capacity, data availability, and different urban challenges, the UMI framework provides the basis for evaluating mobility performance and guiding policy recommendations, emphasizing that it is essential to align data and monitoring tools with inclusive and sustainable mobility strategies are essential. UMIs not only help metropolitan areas assess their current mobility conditions but also support the monitoring of the strategies and next phases of planning. With continued investment in data quality, monitor capacity and institutional collaboration, metropolitan areas regardless of their size or geography, can steer their mobility system towards a safer, more equitable and environmentally friendly future.

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ANNEX A – Notes of the computation of the variables included in the UMI indicators in each metropolitan area

METROPOLITAN AREA OF TURIN

Table 49
Data for Crash and Injuries calculation in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Number of inhabitants*	I_1=2,249,998 *inhabitants*	Population reported in the document "Metropolitan area summary report" (81 p. 6).	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf
Number of trips per year	I_3 *Number of walking trips* I_4 *Number of cycling trips.* I_7 *Number of motorcycle trips.* I_8 *Number of cars trips.*	I_3=*376,047,578 trips/year* I_4=*65,456,793 trips/year* I_7=*17,062,828 trips/year* I_8=*956,198,516 trips/year*	To calculate this variable, the total number of trips recorded in the O/D matrix published in the IMQ2013 Report (70 p. 90) and the trips observed in the survey were considered in order to obtain an expansion factor that allow for estimating the total number of trips made during a year. The following operation was performed:. $Expansion\ factor = \frac{Total\ trips\ IMQ2013}{Trips\ reported\ in\ the\ survey\ dataset}$ $Expansion\ factor = \frac{4{,}376{,}155}{108{,}029} = 40{,}51$	2013	https://www.mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/IMQ2013_opendata.zip
Fatally injured	O_3 *Number of persons fatally injured in road crashes per year in the city*	O_3 *Pedestrian/cyclist=36 inhabitants* O_3 *All vehicles =107 inhabitants*	The number of persons fatally injured in road crashes in the Metropolitan Area of Turin was taken from the "Report of Pedestrians or cyclists killed in 2014.Table 3.14.vii - Annual trends in the number of accidents and people injured" - Sustainable Urban Mobility Plan (72 p. 157).	2014	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/allegati/p_approvato/ALLEGATO_H_-_Sicurezza_stradale_v12.pdf
Seriously injured	O_4*Number of persons seriously injured in road crashes per year in the city*	O_4 *Pedestrian/cyclist=1,434 inhabitants* O_4 *All vehicles =9,008 inhabitants*	The number of persons seriously injured in road crashes in the Metropolitan Area of Turin was taken from the "*feriti*" from the "Report of Pedestrians or cyclists killed in 2014.Table 3.14.vii - Annual trends in the number of accidents and people injured"- Sustainable Urban Mobility Plan (72 p. 157)	2014	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/allegati/p_approvato/ALLEGATO_H_-_Sicurezza_stradale_v12.pdf

Table 50
Data for Modal Share calculation in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Total urban population*	I_1=2,249,998 *inhabitants*	Population reported in the document "Metropolitan area summary report" (81 p. 6).	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf
Number of trips per year by mode and by reason	O_1 *Walking, cycling, public transport and all modes Number of walking trips per year.* O_2 *Number of trips by city/FUA inhabitants to and from workplace, broken down by mode* O_3 *Number of trips by city/FUA inhabitants to and from school per year, broken down by mode* O_4 *Number of trips by city/FUA inhabitants to and from shop per year, broken down by mode*	**O_1** *Walking*=376,047,578 *trips/year* *Car*=956,198,516 *trips/year* *Bicycle*=65,456,793 *trips/year* *Public Transport*=171,323,213 *trips/year* *Taxi*=961,078 *trips/year* *Motorbike*=17,062,828 *trips/year* *Other*=10,246,568 *trips/year* *All vehicles*=1,597,296,575 *trips/year* **O_2 *Trips to and from workplace*** *Walking*=52,297,420 *trips/year* *Car*=195,734,590 *trips/year* *Bicycle*=9,891,709 *trips/year* *Public Transport*=29,527,268 *trips/year* *Taxi*=162,644 *trips/year* *Motorbike*=4,273,100 *trips/year* *Other*=2,957,163 *trips/year* *All vehicles*=294,843,894 *trips/year* **O_3 *Trips to and from school*** *Walking*=13,558,590 *trips/year* *Car*=16,249,608 *trips/year* *Bicycle*=1,419,438 *trips/year* *Public Transport*=27,309,396 *trips/year* *Taxi*=29,572 *trips/year* *Motorbike*=1,537,725 *trips/year* *Other*=1,715,154 *trips/year* *All vehicles*=61,819,483 *trips/year* **O_4 *Trips to and from shop*** *Walking*=169,548,916 *trips/year*	To calculate this variable, the total number of trips recorded in the O/D matrix published in the IMQ2013 Report (70 p. 90) and the trips observed in the survey were considered in order to obtain an expansion factor that allow for estimating the total number of trips made during a year. The following operation was performed: $Expansion\ factor = \frac{Total\ Trips\ IMQ2013}{Trips\ reported\ in\ the\ survey\ dataset}$ $Expansion\ factor = \frac{4{,}376{,}155}{108{,}029} = 40{,}51$	2013	https://www.mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/IMQ2013_opendata.zip

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		Car=133,663,748 trips/year *Bicycle=11,503,362 trips/year* *Public Transport=15,125,887 trips/year* *Taxi=103,501 trips/year* *Motorbike=1,153,293 trips/year* *Other=162,644 trips/year* *All vehicles=331,261,351 trips/year*			

Table 51
Data for Noise Pollution in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	***P*** *Total population of the metropolitan Area*	I_1*=1,430,286 inhabitants*	The total population was taken from the file EEA_T_NOISE_EXPOSURE-2017, European Environment Agency dataset. (82)	2016	https://sdi.eea.europa.eu/data/c341fea8-8bb5-4dbf-9a1b-bac8ac80d780
Population of the city/FUA exposed to different (Lden) noise levels	P_{im}^{Lden} *Population of the metropolitan area exposed to (Lden) noise*	P_{Lden} ***– Road/Rail >=55 dB*** *Road=279,500 inhabitants* *Rail=22,700 inhabitants* P_{Lden} ***– Road/Rail >=60 dB*** *Road=983,300 inhabitants* *Rail=32,700 inhabitants* P_{Lnight} ***– Road/Rail >=50 dB*** *Road=1,135,900 inhabitants* *Rail=46,300 inhabitants*	The number of inhabitants exposed to different noise levels due to road and train transport was reported in the dataset from European Environment Agency (EEA) concerning environmental noise exposure focused on the urban sector of Turin, Italy. (82)	2016	https://sdi.eea.europa.eu/data/c341fea8-8bb5-4dbf-9a1b-bac8ac80d780

Table 52
Data for Air Pollution in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Annual mean per year where of PM10, PM2.5 and NO2 concentration	O_1 *Annual mean NO2* O_2 *Annual mean PM10* O_3*- Annual PM2.5 pollution concentration*	O_1*=45.8 μg/m3* O_2*= 20.4 μg/m3* O_3*=13.9 μg/m3*	Data taken from the table 3.7.iii- Mean and maximum statistics of estimated ground-level concentrations from the UTAQ model for the State of the current scenario, of the Sustainable Urban Mobility Plan (41 p. 146).	2019	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/RapportoFIN.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Vehicle stock composition	V_{fe}^{m} *Number of vehicles subdivided by the engine fuel and emission standard*	V_{fe}^{m}**public buses** Euro 0=91 Buses Euro 1=33 Buses Euro 2=514 Buses Euro 3=470 Buses Euro 4=297 Buses Euro 5=501 Buses Euro 6=267 Buses V_{fe}^{m}**motorcycle** Euro 0=72,601 Motorcycle Euro 1=32,234 Motorcycle Euro 2=30,549 Motorcycle Euro 3=71,224 Motorcycle Euro 4=18,986 Motorcycle V_{fe}^{m}**private car gas** Euro 0=87,597 Vehicles Euro 1=20,050 Vehicles Euro 2=78,471 Vehicles Euro 3=93,914 Vehicles Euro 4=187,715 Vehicles Euro 5=88,983 Vehicles Euro 6=172,673 Vehicles n.i=599 Vehicles V_{fe}^{m}**private cars diesel** Euro 0=12,717 Vehicles Euro 1=3,639 Vehicles Euro 2=17,677 Vehicles Euro 3= 66,046 Vehicles Euro 4=140,907 Vehicles Euro 5=136,455 Vehicles Euro 6=164,411 Vehicles n.i=3 Vehicle	Data obtained from the annex G of the Sustainable Urban Mobility Plan: - Public transport vehicle stock composition: table. 3.2.ix: Buses by use and class of approval (83 p. 41) - Private motorcycle vehicle stock: table. 3.2.iv: Motorcycles by displacement and homologation class (83 p. 37) - Private car vehicle stock: table. 3.2.i : Cars by power supply and class of approval (83 p. 35).	2019	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/allegati/p_approvato/ALLEGATO_G_-_Traffico_automobilistico_e_sosta_v12.pdf
Recommended levels of PM2.5,	R_1 *Number of days per year where the daily PM10 concentration exceeded the recommended level of 45 µg/m3.*	R_1=71 days R_2= - days R_3= 11 hours	Data taken from the ARPA Piedmont environment indicators of different monitoring station in the Metropolitan Area of Turin	2019	https://aria.ambiente.piemonte.it/qualita-aria/dati

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
PM10 and NO2	*R_2 Number of traffic-oriented sampling points where the annual mean concentration of PM2.5 exceeded the WHO recommended level of 35 µg/m3.* *R_3 Number of hours per year where the hourly NO2 concentration exceeded recommended level of 200 µg/m3.*				
Average pollutant emission per vehicle.km related to NO_2 Average pollutant emission per vehicle.km related to $PM_{2.5}$-PM_{10}	PF_{fe}^{mp} Technology-specific emission factor of pollutant "NO2" per vehicle-km by engine fuel f and emission standard in g/km PF_{fe}^{mp} Technology-specific emission factor of pollutant "PM2.5" and "PM10" per vehicle-km by engine fuel f and emission standard in g/km	***PF_{fe}^{mp} NO2/PM10-2.5*** ***Public buses*** *Euro 0=15.90 g/km / 0.69 g/km* *Euro 1=9.78 g/km / 0.37 g/km* *Euro 2=10.59 g/km / 0.18 g/km* *Euro 3=9.18 g/km / 0.19 g/km* *Euro 4=5.75 g/km / 0.05 g/km* *Euro 5=6.17 g/km / 0.08 g/km* *Euro 6=1.34 g/km / 0.01 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5*** ***motorcycles*** *Euro 0=0.03 g/km / 0.20 g/km* *Euro 1=0.04 g/km / 0.08 g/km* *Euro 2=0.05 g/km / 0.04 g/km* *Euro 3=0.05 g/km / 0.01 g/km* *Euro 4=0.06 g/km / 0.01 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5*** ***Private car (GAS)*** *Euro 0=2.41 g/km / 0.0024 g/km* *Euro 1=0.45 g/km / 0.0024 g/km* *Euro 2=0.25 g/km / 0.0024 g/km* *Euro 3=0.11 g/km / 0.0010 g/km* *Euro 4=0.06 g/km / 0.0010 g/km* *Euro 5= 0.05 g/km / 0.0010 g/km* *Euro 6=0.03 g/km / 0.0005 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5*** ***Private car (DIESEL)***	The fiche indicates that one of the methods for calculating the result indicator is through an equation based on the Tier 2 method, which can be applied at the European scale as it uses average European emission factors. $$APE^{mp} = \left(\sum_{fe} PF_{fe}^{mp} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}} \right)$$ The formula estimates air pollutant emission per vehicle-kilometre using emission factors specific to vehicle category and technology, in accordance with EMEP/EEA guidelines (Tire 2). So, the emission factors, which are standard values representing the emissions of various types of vehicles, such as passenger cars, buses, motorcycles, and others, were selected from the following tables and introduced into the equation described above, along with the number of each vehicle type: **NO_2 equivalents (NO_2 eq.):** - **Table 3-23:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii - Urban Diesel Buses Standard 15-18 t. *(Buses were assumed as Standard 15-18 t)* (84 p. 42) - **Table 3-25:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv - Motorcycles 2-stroke >50 cm³ *(Motorcycle were assumed as 2-stroke>50³ cm)* (84 p. 44) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - Petrol Medium *(Gas Passenger cars were assumed as Petrol Medium)* (84 p. 27) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - Diesel Medium *(Diesel Passenger cars were assumed as Medium)* (84 p. 28) **PM2.5/ PM10:**	2023	https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		Euro 0= 0.57 g/km / 0.24 g/km *Euro 1=0.70 g/km / 0.09 g/km* *Euro 2=0.73 g/km / 0.06 g/km* *Euro 3=0.79 g/km / 0.05 g/km* *Euro 4=0.60 g/km / 0.04 g/km* *Euro 5=0.56 g/km / 0.0002 g/km* *Euro 6=0.51 g/km / 0.0001 g/km*	**- Table 3-24:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii - Urban Diesel Buses Standard 15-18 t. *(Buses were assumed as Standard 15-18 t)* (84 p. 43) - **Table 3-27:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv - Motorcycles 2-stroke >50 cm³. *(Motorcycle were assumed as 2-stroke>50³ cm)* (84 p. 46) - **Table 3-18**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - Petrol Medium *(Gas Passenger cars were assumed as Petrol Medium)* (84 p. 29) - **Table 3-18**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - Diesel Medium. *(Diesel Passenger car were assumed as Medium)* (84 p. 30) Additionally: In the case of Euro 0, the conventional data was selected. This assumption was made.		

Table 53
Data for Congestion in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Total urban population*	I_1=2,249,998 *inhabitants*	Population reported in the document "Metropolitan area summary report" (81 p. 6).	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf
Total road network	I_2 *Total road **network***	I_2= *5,982 km*	The total road network is described in the table 2.1.i – Extent of the CMTO road network - Totals, urban and suburban area (83 p. 8).	2022	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/allegati/p_approvato/ALLEGATO_G_-_Traffico_automobilistico_e_sosta_v12.pdf
Satisfaction with the mobility network	O_2 *Satisfaction with public transport the network* O_3 *Satisfaction with the car network.*	O_2 *Public transport=6.82* O_3 *Car network=7.43*	The percentage of satisfaction with the transport network was obtained from the perception-based mobility survey available on the graph *Average initial judgment - metropolitan area residents, of the Metropolitan Area Summary Report* (81 p. 21)	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Average measured time to travel 3 km	$t_{peak_{av(mode\ i)}}$ *Average travel time in the peak hour (e.g. morning rush hours)* $t_{offpeak_{av(mode\ i)}}$ *Average travel time in the off-peak hour (e.g. hours with less traffic like mid-morning, late evening)*	***Public transport*** $t_{peak\ hour}$=*32 min* $t_{off-peak\ hour}$=*29 min* ***Car*** $t_{peak\ hour}$=*21 min* $t_{off-peak\ hour}$=*19 min*	The average travel time during peak and off-peak hour was calculated in the following way: 1. The Origin/Destination matrix was built using the reported trips in the household survey, to identify the zones with the highest number of trips. 2. For the previous identified zones coordinates were assigned to all origin and destination pears, to calculate the distances in km. 3. A range of distances between 3 and 4 km were filtered, and the travel times in peak and off-peak for public transport and private cars hours were computed. 4. The peak hour (period where the majority of trips are made where working and school activities begins and finishes) and off-peak hours (period with relatively low number of trips in the mid-morning or mid-afternoon) were selected based on Graph 8 and Graph 9, which present the departure and arrival frequencies of trips in the metropolitan area: - Public Transport: Peak hour trips between 7:00 am and 8:00 am and 4:00 pm and 6:00 pm, Off-Peak hour trips between 11:00 am and 2:00 pm. - Car: Peak hour trips between 7:00 am and 8:00 am and 4:00 pm and 6:00 pm, Off-Peak hour trips between 11:00 am and 2:00 pm.	2013	https://www.mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/IMQ2013_opendata.zip

Table 54
Data for Greenhouse Gas Emissions in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	***P*** *Total population of the metropolitan Area*	***P***=2,249,998 *inhabitants*	Population reported in the document “Metropolitan area summary report” (81 p. 6).	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf
Annual CO2 equivalent emission	***C*** *Annual CO_2-equivalent emissions from road transport in the city/FUA*	***C****=3,365,694 tCO2/year*	The reported Annual CO2 equivalent for the transportation sector was taken from the table. 3.7.i – Energy consumption and air emissions by street rank – Current Scenario. Of the document Sustainable Urban Mobility Plan (41 p. 145).	2019	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/RapportoFIN.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Vehicle stock compositio n	V_{fe}^{m} Number of vehicles subdivided by the engine fuel and emission standard	V_{fe}^{m}**public buses** Euro 0=91 Buses Euro 1=33 Buses Euro 2=514 Buses Euro 3=470 Buses Euro 4=297 Buses Euro 5=501 Buses Euro 6=267 Buses V_{fe}^{m}**motorcycle** Euro 0=72,601 Motorcycle Euro 1=32,234 Motorcycle Euro 2=30,549 Motorcycle Euro 3=71,224 Motorcycle Euro 4=18,986 Motorcycle V_{fe}^{m}**private car gas** Euro 0=87,597 Vehicles Euro 1=20,050 Vehicles Euro 2=78,471 Vehicles Euro 3=93,914 Vehicles Euro 4=187,715 Vehicles Euro 5=88,983 Vehicles Euro 6=172,673 Vehicles n.i=599 Vehicles V_{fe}^{m}**private cars diesel** Euro 0=12,717 Vehicles Euro 1=3,639 Vehicles Euro 2=17,677 Vehicles Euro 3= 66,046 Vehicles Euro 4=140,907 Vehicles Euro 5=136,455 Vehicles Euro 6=164,411 Vehicles n.i=3 Vehicles	Data obtained from the annex G of the Sustainable Urban Mobility Plan: - Public transport vehicle stock composition: table. 3.2.ix: Buses by use and class of approval (83 p. 41) - Private motorcycle vehicle stock: table. 3.2.iv: Motorcycles by displacement and homologation class (83 p. 37) - Private car vehicle stock: table. 3.2.i : Cars by power supply and class of approval (83 p. 35).	2019	http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/allegati/p_approvato/ALLEGATO_G_-_Traffico_automobilistico_e_sosta_v12.pdf
Average pollutant emission per vehicle.km	APE^{mp}	APE^{mp}**Public buses** Euro 0=1,150.30 g/km Euro 1=974.50 g/km Euro 2=941.81 g/km Euro 3=987.67 g/km	The fiche indicates that one of the methods for calculating the result indicator is through an equation based on the Tier 2 method, which can be applied at the European scale as it uses average European emission factors.	2023	https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
related to CO2		*Euro 4*=*923.56* *g/km* *Euro 5*=*886.88* *g/km* *Euro 6*=*967.45* *g/km* ***APE^{mp} motorcycles*** *Euro 0*=*99.83* *g/km* *Euro 1*=*92.37* *g/km* *Euro 2*=*92.37* *g/km* *Euro 3*=*56.51* *g/km* *Euro 4*=*55.76* *g/km* ***APE^{mp} Private car (GAS)*** *Euro 0*=*236.84* *g/km* *Euro 1*=*205.03* *g/km* *Euro 2*=*199.75* *g/km* *Euro 3*=*208.62* *g/km* *Euro 4*=*214.94* *g/km* *Euro 5*=*214.93* *g/km* *Euro 6*=*214.91* *g/km* ***APE^{mp} Private car (DIESEL)*** *Euro 0*=*194.47* *g/km* *Euro 1*=*171.49* *g/km* *Euro 2*=*178.12* *g/km* *Euro 3*=*168.74* *g/km* *Euro 4*=*168.74* *g/km* *Euro 5*=*168.73* *g/km* *Euro 6*=*168.69* *g/km*	$APE^{mp} = \left(\sum_k \left(\sum_{fe} EF^m_{kfe} * \frac{V^m_{fe}}{\sum_{fe} V^m_{fe}} * (T_k + W_k)\right)\right) * 1000$ The equation estimates GHC emission per vehicle-km using emission factors specific to vehicle operation (tank to wheel), vehicle energy provision (well to tank), and vehicle classification according to its category and technology, in accordance with EMEP/EEA guidelines (Tier 2). The variables included in the equation are: • EF^m_{kfe} Energy specific consumption factor per vehicle-km by energy carrier by engine fuel and Emission standard. (taken from the EMEP/EEA guidelines (Tier 2) • V^m_{fe} Number of vehicles subdivided by the engine fuel and emission standard. • T_k Vehicle operation GHG emission factor. According to the fiche, for the Tire 2 methodology is assumed a tank to wheel CO2 emission (Tk: Diesel: 3.17, Gasoline: 3.19) (38 p. 35) • W_k Vehicle energy GHG emission factor. According to the fiche, for the Tire 2 methodology is assumed a well to tank CO2 emission (Tk: Diesel: 0.57, Gasoline: 0.64) (38 p. 36) So, the emission factors, which are standard values representing the emissions of various types of vehicles, such as passenger cars, buses, motorcycles, and others, were selected from the following tables and introduced into the equation described above, along with the number of each vehicle type: **CO_2 Energy specific consumption factor:** - **Table 3-23:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii - Urban Diesel Buses Standard 15-18 t. *(Buses were assumed to be Standard 15-18 t)* (84 p. 42) - **Table 3-25:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv - Motorcycles 2-stroke >50 cm³. *(Motorcycle were assumed to be 2-stroke>50³ cm)* (84 p. 44) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - Petrol Medium. *(Gas Passenger cars were assumed to be Petrol Medium)* (84 p. 27)		chapters/1-energy/1-a-combustion/1-a-3-b-i/view

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
			- **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - Diesel Medium. *(Diesel Passenger cars were assumed to be Diesel Medium)* (84 p. 28) Additionally: In the case of Euro 0, the conventional data was selected. This assumption was made**.**		

Table 55
Data for Accessibility in the Metropolitan Area of Turin

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	P *Total Population*	***P***=2,249,998 *inhabitants*	Population reported in the document "Metropolitan area summary report" (81 p. 6).	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf
Total area of city/FUA	A *Total area*	***A***= *6,830 km2*	The area of the metropolitan area of Turin was reported in the Metropolitan Area Summary Report of the Survey (81 p. 6).	2013	https://mtm.torino.it/wp-content/uploads/dati-statistiche/indagine-imq-2013/pdf/IMQ2013_RapportoSintesi.pdf
Number of public transport stations	SPT_f^{stops} *Number of public transports stops with frequency f per 1,000 inhabitants*	$\boldsymbol{SPT_f^{stops}}$ *GTT Urban Bus= 3,344 stops* *GTT Suburban Bus= 3,370 stops* *GTT Tram= 299 stops*	The fiche suggests the following equation in order to compute the indicator: $SPT_f^{station} = \frac{\sum_{i,m} PST_f^{station,m}}{A} * 1000$ Where $PST_f^{station,m}$ is the kind of public transport stops whit than 4/with 4 or more scheduled departures per hour. **Tram:** The number of tram stations was obtained from the GTT "Turin Transport Group" **Bus:** The number of the bus stations was obtained from the report on the Moovit app website.	2022	https://www.gtt.to.it/cms/percorari/urbano https://moovitapp.com/index/en/public_transit-lines-Torino-222-2226

METROPOLITAN AREA OF VALLE DE ABURRÁ

Table 56

Data for Crash and Injuries calculation in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Number of inhabitants*	I_1=3,821,797 *inhabitants*	Population reported in the document Theoretical and Methodological Framework of the Mobility Survey 2017. (43 p. 18).	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7
Number of trips per year	I_3 *Number of walking trips* I_4 *Number of cycling trips.* I_7 *Number of motorcycle trips.* I_8 *Number of cars trips.*	I_3 =680,970,265 *trips/year* I_4=13,366,290 *trips/year* I_7=154,992,711 *trips/year* I_8=154,548,648 *trips/year*	To calculate this variable, the total number of trips recorded in the survey summary (61 p. 9) and the trips observed in the survey were considered to obtain an expansion factor that allow for estimating the total number of trips made during a year. The following operation was performed. $Expansion\ factor = \frac{Total\ trips}{Trips\ reported\ in\ the\ survey\ dataset}$ $Expansion\ factor = \frac{6{,}132{,}000}{151{,}207} = 40{,}55$	2017	https://datosabiertos.metropol.gov.co/dataset/b21cf253-484f-4199-856e-c52675a47cbf
Fatally injured	O_3 *Number of persons fatally injured in road crashes per year in the city*	O_3 *Pedestrian/cyclist*=143 *inhabitants* O_3 *All vehicles* =457 *inhabitants*	The number of persons fatally injured in road crashes in the Metropolitan Area of Valle de Aburrá was taken from the data reported by the National Agency for Road Safety (85 pp. 2-7). As the data presented in the Sustainable Urban Mobility Plan was poorly detailed, it only mentioned the total number of motorized users and pedestrian fatally injured, and the document stated that the information was sourced from the National Agency. While this information was included in the Sustainable Urban Mobility Plan, it was necessary to verify the primary source.	2017	https://www.ansv.gov.co/es/observatorio/publicaciones/boletin-estadistico-fallecidos-lesionados-y-hechos-de-transito-antioquia
Seriously injured	O_4*Number of persons seriously injured in road crashes per year in the city*	O_4 *Pedestrian/cyclist*=957 *inhabitants* O_4 *All vehicles* =3,405 *inhabitants*	The number of persons seriously injured in road crashes in the Metropolitan Area of Valle de Aburrá was taken from the data reported by the National Agency for Road Safety (85 pp. 8-13) As the data presented in the Sustainable Urban Mobility Plan was poorly detailed, it only mentioned the total number of motorized users and pedestrian fatally injured, and the document stated that the information was sourced from the National Agency. While this information was included in the Sustainable Urban Mobility Plan, it was necessary to verify the primary source	2017	

Table 57
Data for Modal Share calculation in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Total urban population*	I_1=3,821,797 *inhabitants*	Population reported in the document Theoretical and Methodological Framework of the Mobility Survey 2017. (43 p. 18).	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7
Number of trips per year by mode and by reason	O_1 *Walking, cycling, public transport and all modes Number of walking trips per year.* O_2 *Number of trips by city/FUA inhabitants to and from workplace, broken down by mode* O_3 *Number of trips by city/FUA inhabitants to and from school per year, broken down by mode* O_4 *Number of trips by city/FUA inhabitants to and from shop per year, broken down by mode*	**O_1** *Walking*=680,970,265 *trips/year* *Car*=154,548,648 *trips/year* *Bicycle*=13,366,290 *trips/year* *Public Transport*=615,056,547 *trips/year* *Taxi*=49,172,551 *trips/year* *Motorbike*=154,992,711 *trips/year* *Other*=570,072,988 *trips/year* *All vehicles*=2,238,180,000 *trips/year* **O_2 *Trips to and from workplace*** *Walking*=138,266,346 *trips/year* *Car*=44,924,351 *trips/year* *Bicycle*=3,922,555 *trips/year* *Public Transport*=184,108,426 *trips/year* *Taxi*=8,318,776 *trips/year* *Motorbike*=54,693,732 *trips/year* *Other*=127,179,579 *trips/year* *All vehicles*=561,413,764 *trips/year* **O_3 *Trips to and from school*** *Walking*=86,621,845 *trips/year* *Car*=7,919,119 *trips/year* *Bicycle*=1,376,595 *trips/year* *Public Transport*=49,675,822 *trips/year* *Taxi*=1,569,022 *trips/year* *Motorbike*=10,701,913 *trips/year* *Other*=68,193,240 *trips/year* *All vehicles*=226,057,557 *trips/year*	To calculate this variable, the total number of trips recorded in the survey summary (61 p. 9) and the trips observed in the survey were considered to obtain an expansion factor that allow for estimating the total number of trips made during a year. The following operation was performed. $Expansion\ factor = \frac{Total\ trips}{Trips\ reported\ in\ the\ survey\ dataset}$ $Expansion\ factor = \frac{6{,}132{,}000}{151{,}207} = 40{,}55$	2017	https://datosabiertos.metropol.gov.co/dataset/b21cf253-484f-4199-856e-c52675a47cbf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		O_4 *Trips to and from shop* $_{Walking}$=19,420,345 *trips/year* $_{Car}$=4,381,419 *trips/year* $_{Bicycle}$=118,417 *trips/year* $_{Public\ Transport}$=8,955,266 *trips/year* $_{Taxi}$=1,198,969 *trips/year* $_{Motorbike}$=2,087,095 *trips/year* $_{Other}$=20,722,929 *trips/year* $_{All\ vehicles}$=56,884,441 *trips/year*			

Table 58
Data for Noise Pollution in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	P *Total population of the metropolitan Area*	P=3,821,797 *inhabitants*	Population reported in the document Theoretical and Methodological Framework of the Mobility Survey 2017. (43 p. 18).	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7
Population of the city/FUA exposed to different (Lden) noise levels	P_{im}^{Lden} *Population of the metropolitan area exposed to (Lden) noise*	$P_{Lden-Road/Rail>=55\ dB}$ =668,814 *inhabitants* $P_{Lden-Road/Rail>=60\ dB}$ =2,713,476 *inhabitants* $P_{Lnight-Road/Rail>=50\ dB}$ =3,378,469 *inhabitants*	The Sustainable Urban Mobility Plan did not report information related to noise pollution. However, the document *"Update of the Noise Maps of the municipalities of Bello, Itagüi and Medellín."* presents a graph showing the percentage of the affected population exposed to different noise levels. These percentages were from 2015, but to obtain results for the survey year, they were multiplied by the population in 2017 (86 p. 70).	2017	https://www.metropol.gov.co/ambiental/Ruido/Informe-Medellín-mapa-de-ruido.pdf

Table 59
Data for Air Pollution in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Annual mean per year where of PM10, PM2.5 and	O_1 *Annual mean NO2* O_2 *Annual mean PM10* O_3*- Annual PM2.5 pollution concentration*	O_1=45.1 *μg/m3* O_2= 53.6 *μg/m3* O_3=27 *μg/m3*	The Sustainable Urban Mobility Plan reported air pollution in terms of emissions from mobile sources as a percentage. For this reason, these values were directly consulted in the *Annual Air Quality Report of the Metropolitan Area of Valle de Aburrá*, where the monthly air quality report. (87 pp. 30-46)	2018	https://www.metropol.gov.co/ambiental/calidad-del-aire/informes_red_calidaddeaire/Informe%20Anual%20Aire%202018.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
NO2 concentration					
Vehicle stock composition	V_{fe}^{m} Number of vehicles subdivided by the engine fuel and emission standard	V_{fe}^{m} **public buses** Conventional Light=284 Buses Conventional Medium=4,965 Buses Conventional Heavy=26 Buses V_{fe}^{m} **motorcycle** Motorcycles 2-stroke >50 cm³ Conventional=19,765 Motorcycle Motorcycles 4-stroke <250 cm³ Conventional=205,147 Motorcycle Motorcycles 4-stroke 250 - 750 cm³ Conventional=597,716 Motorcycle Motorcycles 4-stroke >750 cm³ Conventional=23,702 Motorcycle V_{fe}^{m} **private car gas** PRE ERE-Conventional – Light= 236,192 Vehicles PRE ERE-Conventional – Medium=293,234 Vehicles PRE ERE-Conventional – Heavy=30,687 Vehicles V_{fe}^{m} **private cars diesel** Conventional Light=862 Vehicles Conventional Medium=17,549 Vehicles Conventional Heavy=1,550 Vehicles	In the household survey, respondents were asked about the type of vehicle they owned; however, the information was incomplete. For this reason, the number of vehicles was taken from the Update inventory of atmospheric emissions in the Valle de Aburrá, 2018 document, which presents the number of vehicles distributed by stock, vehicle categories and fuel type (88 p. 28). Additionally: The classification of vehicles presented in the document was categorized as light, medium and heavy. For that reason, the following assumptions were made: • The light classification was considered equivalent to the small class, medium was equivalent to the medium class, and heavy corresponded to the large class, according to the E*MEP/EEA air pollutant emission inventory guidebook 2023*. • Diesel Bus: All vehicles were considered conventional across the three classifications. • Motorcycles: In the metropolitan area, two types were identified: 2-stroke and 4-stroke, and all motorcycle were considered conventional across the three classifications. • Private Car: Diesel cars were classified as conventional, whereas petrol cars were considered PRE-ERE vehicles.	2018	https://www.metropol.gov.co/ambiental/calidad-del-aire/Documents/Inventario-de-emisiones/Inventario-de-Emisiones-2018.pdf
Recommended levels of PM2.5, PM10 and NO2	R_1 Number of days per year where the daily PM10 concentration exceeded the recommended level of 45 µg/m3. R_2 Number of traffic-oriented sampling points where the annual mean concentration of PM2.5 exceeded the WHO recommended level of 35 µg/m3.	R_1=99 days R_2= - days R_3= - hours	The indicators were directly consulted in the *Annual Air Quality Report of the Metropolitan Area of Valle de Aburrá*, where the monthly air quality report. (87 pp. 30-46)	2018	https://www.metropol.gov.co/ambiental/calidad-del-aire/informes_red_calidaddeaire/Informe%20Anual%20Aire%202018.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
	R_3 Number of hours per year where the hourly NO2 concentration exceeded recommended level of 200 µg/m3.				
Average pollutant emission per vehicle.km related to NO_2 Average pollutant emission per vehicle.km related to $PM_{2.5}$-PM_{10}	PF_{fe}^{mp} Technology-specific emission factor of pollutant "NO2" per vehicle-km by engine fuel f and emission standard in g/km PF_{fe}^{mp} Technology-specific emission factor of pollutant "PM2.5" and "PM10" per vehicle-km by engine fuel f and emission standard in g/km	***PF_{fe}^{mp} NO2/PM10-2.5 Public buses*** *Conventional Light=9.93 g/km /0.78 g/km* *Conventional Medium=15.90 g/km / 0.69g/km* *Conventional Heavy=20.11 g/km / 0.86 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5 motorcycles*** *Motorcycles 2-stroke >50 cm³ Conventional=0.029 g/km / 0.20 g/km* *Motorcycles 4-stroke <250 cm³ Conventional=0.351 g/km / 0.20 g/km* *Motorcycles 4-stroke 250 - 750 cm³ Conventional=0.032 g/km / 0.20 g/km* *Motorcycles 4-stroke >750 cm³ Conventional=0.172 g/km / 0.20 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5 Private car (GAS)*** *PRE ERE-Conventional – Light=1.795 g/km /0.00235 g/km* *PRE ERE-Conventional – Medium=2.402 g/km / 0.00235 g/km* *PRE ERE-Conventional – Heavy=3.708 g/km / 0.00235 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5 Private car (DIESEL)*** *Conventional Light=0.567 g/km / 0.244 g/km* *Conventional Medium=0.567 g/km / 0.244 g/km*	The fiche indicates that one of the methods for calculating the result indicator is through an equation based on the Tier 2 method, which can be applied at the European scale as it uses average European emission factors, in the case of Colombia that is not an EU member, but it has been aligning its environmental and mobility planning with international best practices, and using the Tier 2 methodology can improve the accuracy of calculations in terms of pollution. $$APE^{mp} = \left(\sum_{fe} PF_{fe}^{mp} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}}\right)$$ The formula estimates air pollutant emission per vehicle-kilometre using emission factors specific to vehicle category and technology, in accordance with EMEP/EEA guidelines (Tire 2). So, the emission factors, which are standard values representing the emissions of various types of vehicles, such as passenger cars, buses, motorcycles, and others, were selected from the following tables and introduced into the equation described above, along with the number of each vehicle type: **NO_2 equivalents (NO_2 eq.):** - **Table 3-23:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii. (84 p. 42) - **Table 3-25:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv (84 p. 44) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 27) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 28) **PM2.5/ PM10:** - **Table 3-24:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b. (84 p. 43) - **Table 3-27:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv (84 p. 46) - **Table 3-18**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 29)	2023	https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		Conventional Heavy=0.905 *g/km* / 0.244 *g/km*	- **Table 3-18**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 30)		

Table 60
Data for Congestion in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Total urban population*	I_1=3,821,797 *inhabitants*	Population reported in the document Theoretical and Methodological Framework of the Mobility Survey 2017. (43 p. 18).	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7
Total road network	I_2 *Total road* ***network***	I_2=5,459 *km*	According to the diagnostic document of the Territorial Planning Plan in 2017, the road infrastructure totalled 5,458.8 km. (89 p. 169).	2017	https://www.metropol.gov.co/planeacion/Paginas/plan-estrategico-metropolitano-de-ordenamiento-territorial.aspx
Satisfaction with the mobility network	O_2 *Satisfaction with public transport the network* O_3 *Satisfaction with the car network.*	O_2 *Public transport*=5.44 O_3 *Car network*=5.80	The percentage of satisfaction with the car network was obtained based on the perception-based mobility survey reported in the *Quality-of-Life Report of Medellín, 2017* (90 p. 6). However, it was not included in the Sustainable Urban Mobility Plan.	2017	https://www.Medellíncomovamos.org/sites/default/files/2020-01/documentos/Informe%20de%20indicadores%20objetivos%20sobre%20c%C3%B3mo%20vamos%20en%20movilidad%20y%20espacio%20p%C3%BAblico%2C%202017.pdf
Average measured time to travel 3 km	$t_{peak_{av(mode\ i)}}$ *Average travel time in the peak hour (e.g. morning rush hours)* $t_{offpeak_{av(mode\ i)}}$ *Average travel time in the off-peak hour (e.g. hours with less traffic like mid-morning, late evening)*	***Public transport*** $t_{peak\ hour}$=37 *min* $t_{off-peak\ hour}$=34 *min* ***Car*** $t_{peak\ hour}$=31 *min* $t_{off-peak\ hour}$=27 *min*	The average travel time during peak and off-peak hour was calculated in the following way: 1. The Origin/Destination matrix was built using the reported trips in the household survey, to identify the zones with the highest number of trips, that in this case these zones were aggregated in Medellin. 2. With the help of the dashboards of household survey (62) published in the Mobility Observatory was filtered car and public transport mode, considering at the same time the range of distance between 3 and 4 km.	2017	https://datosabiertos.metropol.gov.co/dataset/b21cf253-484f-4199-856e-c52675a47cbf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
			3. With the zones with the highest number of trips captured in the last steps, was proceeded to compute travel time in the main survey dataset. 4. The peak hour (period where the majority of trips are made where working and school activities begins and finishes) and off-peak hours (period with relatively low number of trips in the mid-morning or mid-afternoon) were selected based on Graph 15 and Graph 16, which present the departure and arrival frequencies of trips in the metropolitan area: - Public Transport: Peak hour trips between 6:30 am and 7:30 am and 5:00 pm and 6:00 pm, Off-Peak hour trips between 1:00 pm and 4:30 pm. - Car: Peak hour trips between 6:30 am and 7:30 am and 5:00 pm and 6:00 pm, Off-Peak hour trips between 1:00 pm and 4:30 pm.		

Table 61
Data for Greenhouse Gas Emissions in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	P *Total population of the metropolitan Area*	P=*3,821,797* *inhabitants*	Population reported in the document Theoretical and Methodological Framework of the Mobility Survey 2017. (43 p. 18).	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7
Annual CO2 equivalent emission	C *Annual CO_2-equivalent emissions from road transport in the city/FUA*	C=*2,673,761* *tCO2/year*	The Sustainable Urban Mobility Plan reported GHC Emissions in terms of emissions from mobile sources as a percentage. The reported Annual CO2 equivalent for the transportation sector in 2018 was taken from the Emission of GHC Inventory of the Metropolitan Area (91 p. 21).	2017	https://www.metropol.gov.co/ambiental/calidad-del-aire/Documents/Inventario-de-emisiones/Inventario%20GEI%202016-2021_VF_4Sectores.pdf
Vehicle stock composition	V^{m}_{fe} *Number of vehicles subdivided by the engine fuel and emission standard*	V^{m}_{fe}**public buses** *Conventional Light*=*284* *Buses* *Conventional Medium*=*4,965* *Buses* *Conventional Heavy*=*26* *Buses* V^{m}_{fe}**motorcycle**	In the household survey, respondents were asked about the type of vehicle they owned; however, the information was incomplete. For this reason, the number of vehicles was taken from the Update inventory of atmospheric emissions in the Valle de Aburrá, 2018 document, which presents the number of vehicles distributed by stock, vehicle categories and fuel type (88 p. 28).	2018	https://www.metropol.gov.co/ambiental/calidad-del-aire/Documents/Inventario-de-emisiones/Inventario-de-Emisiones-2018.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		Motorcycles 2-stroke >50 cm³ Conventional=19,765 *Motorcycle* *Motorcycles 4-stroke <250 cm³ Conventional*=205,147 *Motorcycle* *Motorcycles 4-stroke 250 - 750 cm³ Conventional*=597,716 *Motorcycle* *Motorcycles 4-stroke >750 cm³ Conventional*=23,702 *Motorcycle* V_{fe}^{m}***private car gas*** *PRE ERE-Conventional – Light*= 236,192 *Vehicles* *PRE ERE-Conventional – Medium*=293,234 *Vehicles* *PRE ERE-Conventional – Heavy*=30,687 *Vehicles* V_{fe}^{m}***private cars diesel*** *Conventional Light*=862 *Vehicles* *Conventional Medium*=17,549 *Vehicles* *Conventional Heavy*=1,550 *Vehicles*	Additionally: The classification of vehicles presented in the document was categorized as light, medium and heavy. For that reason, the following assumptions were made: • The light classification was considered equivalent to the small class, medium was equivalent to the medium class, and heavy corresponded to the large class, according to the EMEP/*EEA air pollutant emission inventory guidebook 2023*. • Diesel Bus: All vehicles were considered conventional across the three classifications. • Motorcycles: In the metropolitan area, two types were identified: 2-stroke and 4-stroke, and all motorcycle were considered conventional across the three classifications. • Private Car: Diesel cars were classified as conventional, whereas petrol cars were considered PRE-ERE vehicles.		
Average pollutant emission per vehicle.km related to CO2	APE^{mp}	PF_{fe}^{mp}***NO2/PM10-2.5 Public buses*** *Conventional Light*=915.40 *g/km* *Conventional Medium*=1,150.30 *g/km* *Conventional Heavy*=1,425.54 *g/km* PF_{fe}^{mp}***NO2/PM10-2.5 motorcycles*** *Motorcycles 2-stroke >50 cm³ Conventional*= 99.83 *g/km* *Motorcycles 4-stroke <250 cm³ Conventional*= 98.79 *g/km* *Motorcycles 4-stroke 250 - 750 cm³ Conventional*= 122.66 *g/km* *Motorcycles 4-stroke >750 cm³ Conventional*= 141.67 *g/km* PF_{fe}^{mp}***NO2/PM10-2.5 Private car (GAS)***	The fiche indicates that one of the methods for calculating the result indicator is through an equation based on the Tier 2 method, which can be applied at the European scale as it uses average European emission factors, , in the case of Colombia that is not an EU member, but it has been aligning its environmental and mobility planning with international best practices, and using the Tier 2 methodology can improve the accuracy of calculations in terms of pollution. $$APE^{mp} = \left(\sum_{k}\left(\sum\nolimits_{fe} EF_{kfe}^{m} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}} * (T_k + W_k)\right)\right) * 1000$$ The equation estimates GHC emission per vehicle-km using emission factors specific to vehicle operation (tank to wheel), vehicle energy provision (well to tank), and vehicle classification according to its category and technology, in accordance with EMEP/EEA guidelines (Tier 2). The variables included in the equation are:	2023	https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		PRE ERE-Conventional – Light=*243.26 g/km* *PRE ERE-Conventional – Medium*=*290.84 g/km* *PRE ERE-Conventional – Heavy*=*350.66 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5 Private car (DIESEL)*** *Conventional Light*=*194.47 g/km* *Conventional Medium*=*194.47 g/km* *Conventional Heavy*=*194.47 g/km*	• EF_{kfe}^{m} Energy specific consumption factor per vehicle-km by energy carrier by engine fuel and Emission standard. (taken from the EMEP/EEA guidelines (Tier 2) • V_{fe}^{m} Number of vehicles subdivided by the engine fuel and emission standard. • T_k Vehicle operation GHG emission factor. According to the fiche, for the Tier 2 methodology is assumed a tank to wheel CO2 emission (Tk: Diesel: 3.17, Gasoline: 3.19) (38 p. 35) • W_k Vehicle energy GHG emission factor. According to the fiche, for the Tier 2 methodology is assumed a well to tank CO2 emission (Tk: Diesel: 0.57, Gasoline: 0.64) (38 p. 36) So, the emission factors, which are standard values representing the emissions of various types of vehicles, such as passenger cars, buses, motorcycles, and others, were selected from the following tables and introduced into the equation described above, along with the number of each vehicle type: **CO_2 Energy specific consumption factor:** - **Table 3-23:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii (84 p. 42) - **Table 3-25:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv - (84 p. 44) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - (84 p. 27) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 28)**.**		

Table 62
Data for Accessibility in the Metropolitan Area of Valle de Aburrá

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	P *Total Population*	***P***=*3,821,797 inhabitants*	Population reported in the document Theoretical and Methodological Framework of the Mobility Survey 2017. (43 p. 18).	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total area of city/FUA	*A* *Total area*	***A***=*1,167* *km2*	The area of the metropolitan area of Cúcuta was reported in the *Origin and Destination Mobility Survey, 2017. Theoretical and Methodological Framework*. (43 p. 18)	2017	Encuesta de Movilidad Origen y Destino 2017. Marco teórico y metodológico. Medellín: s.n., 2019. 978-958-8513-99-7
Number of public transport stations	SPT_f^{stops} *Number of public transports stops with frequency f per 1,000 inhabitants*	$\boldsymbol{SPT_f^{stops}}$ *Tram=9* *stops* *Metroplus=22* *stops* *BTR= 20* *stops* *Feeder Bus=50* *stops* *Integrated Buses=3133* *stops*	The fiche suggests the following equation in order to compute the indicator: $$SPT_f^{station} = \frac{\sum_{i,m} PST_f^{station,m}}{A} * 1000$$ Where $PST_f^{station,m}$ is the kind of public transport station whit than 4/with 4 or more scheduled departures per hour. **Subway, Tram, Gondola Lift**: The number of stations of the Subway, Gondola Lift System, and Tram was obtained from the reported data from SITVA *"Valle de Aburrá Integrated transport system"*, since this information is not detailed in the Sustainable Urban Mobility Plan (59) **Bus:** Number of the station of Metroplus and integrated bus system, was obtained from the mooviatapp.	2022	https://www.metropol.gov.co/la-movilidad/transporte-p%C3%BAblico/sitva https://moovitapp.com/index/es-419/transporte_p%C3%BAblico-Medellín-1642

METROPOLITAN AREA OF CÚCUTA

Table 63
Data for Crash and Injuries calculation in the Metropolitan Area of Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Number of inhabitants*	I_1=*908,276 inhabitants*	Population reported in the Stage II: Integral mobility diagnosis - VOLUME II. (64 p. 355)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Number of trips per year	I_3 *Number of walking trips* I_4 *Number of cycling trips.* I_7 *Number of motorcycle trips.* I_8 *Number of cars trips.*	I_3 =*64,204,072 trips/year* I_4=*11,087,527 trips/year* I_7=*102,799,408 trips/year* I_8=*40,072,395 trips/year*	To calculate this variable, the total number of trips reported in the executive overview of the Sustainable Urban Mobility Plan (57 p. 14) and the trips observed in the survey were considered to obtain an expansion factor that allow for estimating the total number of trips made during a year. The following operation was performed. $Expansion\ factor = \frac{Total\ trips}{Trips\ reported\ in\ the\ survey\ dataset}$ $Expansion\ factor = \frac{1{,}071{,}754}{20{,}393} = 52.55$	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Fatally injured	O_3 *Number of persons fatally injured in road crashes per year in the city*	O_3 *Pedestrian/cyclist=59 inhabitants* O_3 *All vehicles =130 inhabitants*	The number of persons fatally injured in crashes in the Metropolitan Area of Cúcuta was taken from the reported data of the National Agency for Road Safety (92 p. 10). As the data reported in the Sustainable Urban Mobility Plan was not well detailed, and the document mentioned that the information was sourced from the National Agency. The information was reported in the Sustainable Urban Mobility Plan, but it was necessary to verify the primary source.	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/Resumen-ejecutivo-PMSS_compressed.pdf https://www.ansv.gov.co/sites/default/files/2023-03/Boletin_Norte%20de%20Santander_diciembre_2022.pdf
Seriously injured	O_4*Number of persons seriously injured in road crashes per year in the city*	O_4 *Pedestrian/cyclist=160 inhabitants* O_4 *All vehicles =572 inhabitants*	The number of persons seriously injured in crashes in the Metropolitan Area of Cúcuta was taken from the reported data of the National Agency for Road Safety (92 p. 17). As the data reported in the Sustainable Urban Mobility Plan was not well detailed, and the document mentioned that the information was sourced from the National Agency. The Information was reported in the Sustainable Urban Mobility Plan, but it was necessary to verify the primary source.	2022	

Table 64
Data for Modal Share calculation in the Metropolitan Area of Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 *Total urban population*	I_1=908,276 *inhabitants*	Population reported in the Stage II: Integral mobility diagnosis - VOLUME II. (64 p. 355)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Number of trips per year by mode and by reason	O_1 *Walking, cycling, public transport and all modes Number of walking trips per year.* O_2 *Number of trips by city/FUA inhabitants to and from workplace, broken down by mode* O_3 *Number of trips by city/FUA inhabitants to and from school per year, broken down by mode* O_4 *Number of trips by city/FUA inhabitants to and from shop per year, broken down by mode*	O_1 *Walking*=64,204,072 *trips/year* *Car*=40,072,395 *trips/year* *Bicycle*=11,087,527 *trips/year* *Public Transport*= 116,591,678 *trips/year* *Taxi*=41,127,436 *trips/year* *Motorbike*=102,799,408 *trips/year* *Other*=15,307,693 *trips/year* *All vehicles*=391,190,210 *trips/year* O_2 ***Trips to and from workplace*** *Walking*=11,049,162 *trips/year* *Car*=14,482,843 *trips/year* *Bicycle*=4,910,739 *trips/year* *Public Transport*=30,711,299 *trips/year* *Taxi*=9,591,286 *trips/year* *Motorbike*=37,406,017 *trips/year* *Other*=4,239,349 *trips/year* *All vehicles*=112,390,695 *trips/year* O_3 ***Trips to and from school*** *Walking*=11,797,282 *trips/year* *Car*=1,572,971 *trips/year* *Bicycle*=326,104 *trips/year* *Public Transport*=7,692,212 *trips/year* *Taxi*=824,851 *trips/year* *Motorbike*=7,059,187 *trips/year* *Other*=2,896,569 *trips/year* *All vehicles*=32,169,175 *trips/year* O_4 ***Trips to and from shop***	To calculate this variable, the total number of trips reported in the executive overview of the Sustainable Urban Mobility Plan (57 p. 14) and the trips observed in the survey were considered to obtain an expansion factor that allow for estimating the total number of trips made during a year. The following operation was performed. $Expansion\ factor = \frac{Total\ trips}{Trips\ reported\ in\ the\ survey\ dataset}$ $Expansion\ factor = \frac{1{,}071{,}754}{20{,}393} = 52.55$	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/Resumen-ejecutivo-PMSS_compressed.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		$Walking$=2,071,718 trips/year Car=709,755 trips/year $Bicycle$=115,095 trips/year $Public\ Transport$=3,836,515 trips/year $Taxi$=1,975,805 trips/year $Motorbike$=1,592,154 trips/year $Other$=805,668 trips/year $All\ vehicles$=11,106,710 trips/year			

Table 65
Data for Noise Pollution in the Metropolitan Area of Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	P Total population of the metropolitan Area	P=908,276 inhabitants	Population reported in the Stage II: Integral mobility diagnosis - VOLUME II. (64 p. 355)	2022	https://sdi.eea.europa.eu/data/c341fea8-8bb5-4dbf-9a1b-bac8ac80d780
Population of the city/FUA exposed to different (Lden) noise levels	P_{im}^{Lden} Population of the metropolitan area exposed to (Lden) noise	P_{Lden} – Road/Rail >=55 dB Road= - inhabitants P_{Lden} – Road/Rail >=60 dB Road= - inhabitants P_{Lnight} – Road/Rail >=50 dB Road= - inhabitants	In the Sustainable Urban Mobility Plan did not report information related to noise pollution. Additional, when requesting information from the Major of Cúcuta, they stated that “The metropolitan Area of Cúcuta does not have noise measuring stations”.		

Table 66
Data for Air Pollution in the Metropolitan Area of Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Annual mean per year where of PM10, PM2.5 and NO2 concentration	O_1 Annual mean NO2 O_2 Annual mean PM10 O_3- Annual PM2.5 pollution concentration	O_1=8 μg/m3 O_2= 39.4 μg/m3 O_3=17.4 μg/m3	In the Sustainable Urban Mobility Plan reported air pollution in terms of emissions from mobile sources in (t/year). For that reason, these values were consulted directly with the Government Entity in charge of environment administration in the Metropolitan Area of Cúcuta, where the monthly air quality report for 2023 was reviewed, as the reports for 2022 were not completed (93).	2023	https://corponor.gov.co/web/index.php/boletin-ambiental/calidad-del-aire/

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Vehicle stock composition	V^m_{fe} *Number of vehicles subdivided by the engine fuel and emission standard*	V^m_{fe}**public buses** *Conventional*=199 *Buses* *Euro 1*=1,528 *Buses* *Euro 2*=115 *Buses* *Euro 4*=159 *Buses* *Euro 5*=43 *Buses* *Gas*= 839 *Buses* V^m_{fe}**motorcycle** *Conventional*=54,822 *Motorcycle* *Euro 1*=8,925 *Motorcycle* *Euro 2*=63,747 *Motorcycle* V^m_{fe}**private car gas** *PRE ECE*= 9,240 *Vehicles* *Open Loop*=6,160 *Vehicles* *Euro 1*=31,496 *Vehicles* *Euro 2*=9,240 *Vehicles* *Euro 4*=12,322 *Vehicles* *Euro 5*=6,930 *Vehicles* V^m_{fe}**private cars diesel** *Conventional*= - *Vehicles* *Euro 1*=39 *Vehicles* *Euro 2*=39 *Vehicles* *Euro 4*=770 *Vehicles* *Euro 5*=770 *Vehicles*	The number of register vehicles and their classifications were obtained from the "Emission Inventory of Pollutants in the Metropolitan Area of Cúcuta, in 2022". The Sustainable Urban Mobility Plan reported the total number of vehicles, but it did not include a classification (94). The following assumptions were made: - Buses were assumed to be Standard 15-18 t, since their classification was not clear). - Motorcycle was assumed to be 2-stroke>50³ cm - Gas Passenger cars were assumed to be Petrol Medium Diesel Passenger cars were assumed to be Medium	2022	https://corponor.gov.co/calidad_del_aire/2022/FEBRERO/Cúcuta-region/Inventario_emisiones_contaminantes_Cúcuta_Region.pdf
Recommended levels of PM2.5, PM10 and NO2	R_1 *Number of days per year where the daily PM10 concentration exceeded the recommended level of 45 µg/m3.* R_2 *Number of traffic-oriented sampling points where the annual mean concentration of PM2.5 exceeded the WHO recommended level of 35 µg/m3.* R_3 *Number of hours per year where the hourly NO2 concentration exceeded*	R_1=77 *days* R_2= - *days* R_3= - *hours*	The Sustainable Urban Mobility Plan reported air pollution in terms of emissions from mobile sources as a percentage. For that reason, these values were consulted directly with the Government Entity in charge of environment administration in the Metropolitan Area of Cúcuta, where the monthly air quality report.	2023	https://corponor.gov.co/web/index.php/boletin-ambiental/calidad-del-aire/

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
	recommended level of 200 µg/m3.				
Average pollutant emission per vehicle.km related to NO_2 Average pollutant emission per vehicle.km related to $PM_{2.5}$-PM_{10}	$\boldsymbol{PF_{fe}^{mp}}$ Technology-specific emission factor of pollutant "NO2" per vehicle-km by engine fuel f and emission standard in g/km $\boldsymbol{PF_{fe}^{mp}}$ Technology-specific emission factor of pollutant "PM2.5" and "PM10" per vehicle-km by engine fuel f and emission standard in g/km	***PF_{fe}^{mp} NO2/PM10-2.5*** ***Public buses*** *Conventional=15.898 g/km /0.693 g/km* *Euro 1=9.777 g/km /0.372 g/km* *Euro 2=10.592 g/km /0.182 g/km* *Euro 4=5.748 g/km /0.046 g/km* *Euro 5=6.170 g/km /0.079 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5*** ***motorcycles*** *Conventional=0.029 g/km /0.200 g/km* *Euro 1=0.043 g/km /0.080 g/km* *Euro 2=0.050 g/km /0.040 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5*** ***Private car (GAS)*** *PRE ECE=2.402 g/km / 0.0024 g/km* *Oper loop=1.235 g/km / 0.0024 g/km* *Euro 1=0.454 g/km / 0.0024 g/km* *Euro 2=0.247 g/km / 0.0024 g/km* *Euro 4=0.064 g/km / 0.0010 g/km* *Euro 5=0.047 g/km / 0.0010 g/km* ***PF_{fe}^{mp} NO2/PM10-2.5*** ***Private car (DIESEL)*** *Conventional=0.567 g/km / 0.2440 g/km* *Euro 1=0.697 g/km / 0.0895 g/km* *Euro 2=0.729 g/km / 0.0594 g/km* *Euro 4=0.599 g/km / 0.0383 g/km* *Euro 5=0.562 g/km / 0.0002 g/km*	The fiche indicates that one of the methods for calculating the result indicator is through an equation based on the Tier 2 method, which can be applied at the European scale as it uses average European emission factors, in the case of Colombia that is not an EU member, but it has been aligning its environmental and mobility planning with international best practices, and using the Tier 2 methodology can improve the accuracy of calculations in terms of pollution. $APE^{mp} = \left(\sum_{fe} PF_{fe}^{mp} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}}\right)$ The formula estimates air pollutant emission per vehicle-kilometre using emission factors specific to vehicle category and technology, in accordance with EMEP/EEA guidelines (Tire 2). So, the emission factors, which are standard values representing the emissions of various types of vehicles, such as passenger cars, buses, motorcycles, and others, were selected from the following tables and introduced into the equation described above, along with the number of each vehicle type: **NO_2 equivalents (NO_2 eq.):** - **Table 3-23:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii. (84 p. 42) - **Table 3-25:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv (84 p. 44) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 27) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 28) **PM2.5/ PM10:** - **Table 3-24:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b. (84 p. 43) - **Table 3-27:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv (84 p. 46) - **Table 3-18**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 29) - **Table 3-18**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 30)	2023	https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view

Table 67
Data for Congestion in the Metropolitan Area Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	I_1 Total urban population	I_1=908,276 inhabitants	Population reported in the Stage II: Integral mobility diagnosis - VOLUME II. (64 p. 355)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Total road network	I_2 Total road **network**	I_2=1,272 km	The total road network is described in the diagnostic document Vol. 2 of the Sustainable Urban Mobility Plan (64 p. 107)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Satisfaction with the mobility network	O_2 Satisfaction with public transport the network O_3 Satisfaction with the car network.	$O_{2\ Public\ transport}$=38% $O_{3\ Car\ network}$=32%	The percentage of satisfaction with the transportation network was obtained based on the perception mobility survey reported in the diagnostic document Vol. 2 of the Sustainable Urban Mobility Plan (64 p. 391)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Average measured time to travel 3 km	$t_{peak_{av(mode\ i)}}$ Average travel time in the peak hour (e.g. morning rush hours) $t_{offpeak_{av(mode\ i)}}$ Average travel time in the off-peak hour (e.g. hours with less traffic like mid-morning, late evening)	***Public transport*** $t_{peak\ hour}$=34 min $t_{off-peak\ hour}$=31 min ***Car*** $t_{peak\ hour}$=26 min $t_{off-peak\ hour}$=24 min	The average travel time during peak and off-peak hour was calculated in the following way: 1. The Origin/Destination matrix was built using the reported trips in the household survey, to identify the zones with the highest number of trips, in this case these zones were aggregated in Cúcuta. 2. For the previous identified zones coordinates were assigned to all origin and destination pears, to calculate the distances in km. 3. A range of distances between 3 and 4 km were filtered, and the travel times in peak and off-peak for public transport and private cars hours were computed. 4. The peak hour (period where the majority of trips are made where working and school activities begins) and off-peak hours (period with relatively low number of trips in the mid-morning or mid-afternoon) were selected based on Graph 23 and Graph 24, which present the departure and arrival frequencies of trips in the metropolitan area:	2017	Survey 2022

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
			- Public Transport: Peak hour trips between 6:00 am and 7:00 am and 5:00 pm and 6:00 pm, Off-Peak hour trips between 9:00 am and 11:00 am. - Car: Peak hour trips 6:00 am and 7:00 am and 5:00 pm and 6:00 pm, Off-Peak hour trips between 1:00 pm and 4:00 pm.		

Table 68
Data for Greenhouse Gas Emissions in the Metropolitan Area of Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	P *Total population of the metropolitan Area*	P=908,276 *inhabitants*	Population reported in the Stage II: Integral mobility diagnosis - VOLUME II. (64 p. 355)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Annual CO2 equivalent emission	C *Annual CO_2-equivalent emissions from road transport in the city/FUA*	C=484,684 *tCO2/year*	The reported Annual CO2 equivalent for the transportation sector in 2022 was taken from the diagnostic document Vol. 2 of the Sustainable Urban Mobility Plan (64 p. 438)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Vehicle stock composition	V_{fe}^{m} *Number of vehicles subdivided by the engine fuel and emission standard*	V_{fe}^{m}**public buses** *Conventional*=199 *Buses* *Euro 1*=1,528 *Buses* *Euro 2*=115 *Buses* *Euro 4*=159 *Buses* *Euro 5*=43 *Buses* *Gas*= 839 *Buses* V_{fe}^{m}**motorcycle** *Conventional*=54,822 *Motorcycle* *Euro 1*=8,925 *Motorcycle* *Euro 2*=63,747 *Motorcycle* V_{fe}^{m}**private car gas** *PRE ECE*= 9,240 *Vehicles* *Open Loop*=6,160 *Vehicles* *Euro 1*=31,496 *Vehicles*	The number of register vehicles and their classifications were obtained from the "Emission Inventory of Pollutants in the Metropolitan Area of Cúcuta, in 2022". The Sustainable Urban Mobility Plan reported the total number of vehicles, but it did not include a classification (94). The following assumptions were made: - Buses were assumed to be Standard 15-18 t, since their classification was not clear). - Motorcycle was assumed to be 2-stroke>50³ cm - Gas Passenger cars were assumed to be Petrol Medium Diesel Passenger cars were assumed to be Medium	2022	https://corponor.gov.co/calidad_del_aire/2022/FEBRERO/Cúcuta-region/Inventario_emisiones_contaminantes_Cúcuta_Region.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
		Euro 2=9,240 Vehicles Euro 4=12,322 Vehicles Euro 5=6,930 Vehicles **V_{fe}^{m}private cars diesel** Conventional= - Vehicles Euro 1=39 Vehicles Euro 2=39 Vehicles Euro 4=770 Vehicles Euro 5=770 Vehicles			
Average pollutant emission per vehicle.km related to CO2	APE^{mp}	**APE^{mp} Public buses** Conventional=1,150.30 g/km Euro 1=974.50 g/km Euro 2=941.81 g/km Euro 4=923.56 g/km Euro 5=886.88 g/km **APE^{mp}motorcycles** Conventional=99.83 g/km Euro 1=92.37 g/km Euro 2=92.37 g/km **APE^{mp} Private car (GAS)** PRE ECE=290.84 g/km Open Loop=239.51 g/km Euro 1=205.03 g/km Euro 2=199.75 g/km Euro 4=214.94 g/km Euro 5=214.93 g/km **APE^{mp} Private car (DIESEL)** Conventional=194.47 g/km Euro 1=171.49 g/km Euro 2=178.12 g/km Euro 4=168.74 g/km Euro 5= 168.73 g/km	The fiche indicates that one of the methods for calculating the result indicator is through an equation based on the Tier 2 method, which can be applied at the European scale as it uses average European emission factors, , in the case of Colombia that is not an EU member, but it has been aligning its environmental and mobility planning with international best practices, and using the Tier 2 methodology can improve the accuracy of calculations in terms of pollution. $$APE^{mp} = \left(\sum_{k}\left(\sum_{fe} EF_{kfe}^{m} * \frac{V_{fe}^{m}}{\sum_{fe} V_{fe}^{m}} * (T_k + W_k)\right)\right) * 1000$$ The equation estimates GHC emission per vehicle-km using emission factors specific to vehicle operation (tank to wheel), vehicle energy provision (well to tank), and vehicle classification according to its category and technology, in accordance with EMEP/EEA guidelines (Tier 2). The variables included in the equation are: • EF_{kfe}^{m} Energy specific consumption factor per vehicle-km by energy carrier by engine fuel and Emission standard. (taken from the EMEP/EEA guidelines (Tier 2) • V_{fe}^{m} Number of vehicles subdivided by the engine fuel and emission standard. • T_k Vehicle operation GHG emission factor. According to the fiche, for the Tier 2 methodology is assumed a tank to wheel CO2 emission (Tk: Diesel: 3.17, Gasoline: 3.19) (38 p. 35) • W_kVehicle energy GHG emission factor. According to the fiche, for the Tier 2 methodology is assumed a well to tank CO2 emission (Tk: Diesel: 0.57, Gasoline: 0.64) (38 p. 36)	2023	https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
			So, the emission factors, which are standard values representing the emissions of various types of vehicles, such as passenger cars, buses, motorcycles, and others, were selected from the following tables and introduced into the equation described above, along with the number of each vehicle type: **CO_2 Energy specific consumption factor:** - **Table 3-23:** Tier 2 exhaust emission factors for buses, NFR 1.A.3.b.iii (84 p. 42) - **Table 3-25:** Tier 2 exhaust emission factors for L-category vehicles, NFR 1.A.3.b.iv - (84 p. 44) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i - (84 p. 27) - **Table 3-17**: Tier 2 exhaust emission factors for passenger cars, NFR 1.A.3.b.i (84 p. 28)**.**		

Table 69
Data for Accessibility in the Metropolitan Area of Cúcuta

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
Total population	*P Total Population*	***P***=*908,276 inhabitants*	Population reported in the Stage II: Integral mobility diagnosis - VOLUME II. (64 p. 355)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf
Total area of city/FUA	*A Total area*	***A***=*2,028 km2*	The area of the metropolitan area of Cúcuta was reported in the executive overview of the Sustainable Urban Mobility Plan (57 p. 8)	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/Resumen-ejecutivo-PMSS_compressed.pdf
Number of public transport stations	SPT_f^{stops} *Number of public transports stops with frequency f per 1,000 inhabitants*	$\boldsymbol{SPT_f^{stops}}$ *Bus stops= 59 stops*	The fiche suggests the following equation in order to compute the indicator: $$SPT_f^{station} = \frac{\sum_{i,m} PST_f^{station,m}}{A} * 1000$$ Where $PST_f^{station,m}$ is the kind of public transport station whit than 4/with 4 or more scheduled departures per hour. Informal transport system: There is no inventory of public transport stations in the Metropolitan Area of Cúcuta; however, the diagnostic	2022	https://Cúcuta.gov.co/wp-content/uploads/2023/02/PAF024-UT-2-GEN-INF-BIM-Informe-Etapa-II-Diagnostico-PMSS-2.2_TOMO-II.pdf

Name of variable	Label	Value	Notes of the computation of the variable	Year	Source
			document Vol. 2 (64 p. 122) identifies 59 passenger dispatch points, where bus routes start and finish.		

ANNEX B – Estimation of the average population in each zone in which the three metropolitan areas are subdivided

Table 70
Estimation of the average population distributed in each zone of the Metropolitan Area of Turin

#	Zone	Population of each homogenous area	Area of each homogenous area (km2) (46)	Total Zones	Average population in each zone	Average area in each zone (km2)
1	Torino città	870,952	130.06	130	6,699.63	1.00
2	Area Metropolitana Torino Ovest	237,561	203.29	49	4,848.18	4.15
3	Area Metropolitana Torino Sud	268,978	385.72	67	4,014.60	5.76
4	Area Metropolitana Torino Nord	137,178	175.02	30	4,572.60	5.83
5	Pinerolese	130,516	1,302.23	54	2,416.96	24.12
6	Valli di Susa e Sangone	103,500	1,246.87	41	2,524.39	30.41
7	Ciriacese-Valli di Lanzo	101,148	972.89	40	2,528.70	24.32
8	Canavese occidentale	82,080	974.51	47	1,746.38	20.73
9	Eporediese	86,980	554.47	68	1,279.12	8.15
10	Chivassese	99,588	422.57	26	3,830.31	16.25
11	Chierese-Carmagnolese	131,517	462.30	43	3,058.53	10.75
	Total	2,249,998	6,829.93			13.77
	Subtotal in the Metropolitan Area (included only zone # 1 to 4)				**5,034**	**4.19**

Table 71
Estimation of the average population distributed in each zone of the Metropolitan Area of Valle de Aburrá

#	Zone	Population of each homogenous area	Area of each homogenous area (km2) (43)	Total Zones	Average population in each zone	Average area in each zone (km2)
1	Barbosa	50,832	206.00	20	2,541.60	10.30
2	Bello	464,560	149.00	31	14,985.81	4.81
3	Caldas	78,762	133.40	8	9,845.25	16.68
4	Copacabana	71,033	70.00	14	5,073.79	5.00
5	Envigado	227,599	78.78	24	9,483.29	3.28
6	Girardota	55,477	78.00	15	3,698.47	5.20
7	Itagüi	270,920	21.09	24	11,288.33	0.88
8	La Estrella	63,332	35.00	20	3,166.60	1.75
9	Medellín	2,486,723	380.64	344	7,228.85	1.11
10	Sabaneta	52,559	15.00	13	4,043.00	1.15
	Total	3,821,797	1,166.91		**7,135**	**5.02**

Table 72
Estimation of the average population distributed in each zone of the Metropolitan Area of Valle de Cúcuta

#	Zone	Population of each homogenous area	Area of each homogenous area (km2) (57)	Total Zones	Average population in each zone	Average area in each zone (km2)
1	San Jose de Cúcuta	791,986	1,131.30	118	6,711.75	9.59
2	El Zulia	29,955	490.48	5	5,991.00	98.10
3	Los Patios	99,081	127.13	23	4,307.87	5.53
4	Puerto Santander	9,439	44.14	2	4,719.50	22.07
5	San Cayetano	7,939	141.99	1	7,939.00	141.99
6	Villa del Rosario	113,384	92.48	7	16,197.71	13.21
	Total	1,051,784	2,027.52		7,644	48.4
	Subtotal in the Metropolitan Area (included only zone # 1, 3 and 6)				**9,072**	**9.44**